MANIPULATING PIG PRODUCTION VIII

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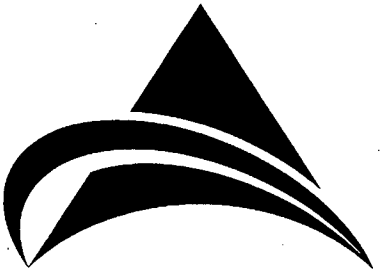

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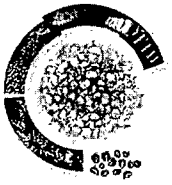

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The Proceedings, 'Manipulating Pig Production VIII', contains 86 one-page papers, five Reviews and three Symposia, a total of 276 pages. As is the policy of the Association, all one-page papers, Reviews and Symposia were reviewed by external referees (at least two per paper). The committee of APSA and the editor gratefully acknowledges the assistance generously given during 2001 by the following referees and those who may have been inadvertently omitted from the list, and also to a small band of independent biometricians who wish to remain anonymous.

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PREFACE

This book is a record of the proceedings of the Eighth Biennial Conference of the Australasian Pig Science Association (APSA). The biennial conference and its proceedings are the major forum in Australia for presenting and discussing the science of pig production. The conference has now achieved international recognition as demonstrated by the number of delegates who come from overseas to attend and participate, and the number of proceedings that are sold overseas.

International recognition for the book has been achieved because APSA has deliberately encouraged high-quality science that is relevant to the pig industry. This requires three things. First, a dedicated committee who begin designing a scientific program 18 months before the conference takes place and who put together a relevant program with invitations to the best speakers from around the world. Hence, scientists from Australia have to compete with the worlds' best. Second, high standards of refereeing and editorship are rigorously adhered to. Third, high-quality debate from participants at the conference ensures that standards are maintained. Such principals for success are well known but, in the current climate of science, they are sometimes forgotten and short cuts taken.

Accordingly, I wish to thank the organising committee, Susanne Hermesch, Sally Tritton, Mingan Choct, Darryl D'Souza, Ray King, John Pluske, Robert van Barneveld and Mike Taverner. The editor, Peter Cranwell, and the many referees have ensured the quality of this book and I thank them. To stimulate debate two discussion sessions, Genetic Improvement and Alternative Housing, were included in this program. These sessions were not recorded in this book but I wish to thank Suzanne Hermesch and Bruce Mullan who kept these discussions focused.

The original aim of APSA was to promote scientific discussion and collaboration among scientists interested in pig research. These aims were foremost in the minds of members of the organising Committee when the program was designed. However, where possible these aims have been expanded and the program has been designed to stimulate participation and contribution from the pig industry in general. This reflects the change in science in recent years where more projects have a direct industry focus.

Successful conferences require sponsorship and I am most grateful to all our sponsors, particularly our principal sponsor, Australian Pork Limited. Their generous support is evidence of the value that they think APSA has to the Australian Pig Industry.

I.H. Williams
President
APSA

A REVIEW - PRODUCTIVE RESEARCH ENVIRONMENTS IN THE RURAL INDUSTRIES – CAN WE DO BETTER?

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Abstract

The literature on management of research and development and the history of large and successful Research and Development (R & D) companies contain many pointers on the management of R & D in the rural industries that need to be taken seriously if Australia's rural industries are to remain competitive. There is strong evidence that using return-on-investment techniques or variations of them are a waste of time and money because the real returns from research are far too complex and unpredictable for these simplistic methods to account for. Instead, this paper argues, Australia should be shifting its attention to the research workforce in whose creativity rest its hopes for genuine research gains. Researchers themselves have been largely ignored so far in the administration process for R & D and there are many cogent reasons and compelling precedents for making them the focus when deciding the best way to use research funds. It is argued that the key issues in making decisions about research funding should be the quality of the science, the motivation and creativity of researchers and the relevance of the research to the industry that is funding it. A major change in philosophy and policies in many of Australia's research corporations will be needed if this is to happen.

Tony Dunkin

Tony Dunkin was one of a very small group of people who pioneered the concept of using research for the benefit of the Australian pig industry. He had the perception and vision to match his and others' scientific skills with pragmatism and practicality to make research an obvious necessity for what was then virtually a back yard industry. There is no doubt that he foresaw the enormous changes in the industry that would come about in the next forty years and the transparently pivotal role that research would play in these changes. But could he have foreseen the changes, and the pressures for more changes, in the way research, itself, has been organised in the Australian rural industries? I am sure that, had he still been with us, his wisdom, his practical outlook towards the organisation of research and his passion for the industry would have seen him making a critical contribution.

This paper is an unashamed attempt to debunk some of the irrational (and very costly) theories on how rural research should be managed in this country and suggest some attitudes that could improve the long term rewards for expenditure of the research dollar. In doing so, it frequently steps outside of the pig industry for two reasons. First, by any analysis, the pig industry has been one of the most successful and respected of the Australian rural industries in its use and management of research. Second, forces outside the pig industry have, and will no doubt continue to have, an influence on many aspects of its management and thinking about research. It is a paper that Tony would have enjoyed writing and he would have done it better and with more authority than I. What a pity that his untimely death robbed us of the opportunity to have the benefit of his wisdom and experience.

Introduction

Rural research organisations began in this country in the mid 60s with a commitment to using producers' funds to develop a research base to enhance the competitiveness of agricultural industries. The original research organisations have changed remarkably in the following forty years and newer ones bear little resemblance to the first funding bodies. In the evolution of research funding of agricultural industries,

three distinct eras can be easily distinguished. They represent a very clear change from science-based decisions to management-based decisions and many people have argued that they have done this without agricultural producers ever seriously or systematically having a dominant role in the process

In the early research committees, science was represented on the funding and policy committees in almost equal proportions with industry representatives. Management consisted usually of one individual acting as executive officer and a small support staff to handle the funds and routine matters. Inevitably, accusations were made of nepotism in the committees and favouritism by the all-powerful executive officer.

Then, in 1986, came corporatisation and by 1990, 14 Rural Research Corporations had been established. The early years were characterised by the overriding importance of general policy making by boards over critical decision making about research projects which was left to paid staff. The composition of the controlling bodies in the first few years of corporatisation was directed fairly heavily by the Federal Department of Primary Industry and all of the industries began with a very similar composition and philosophy, dictated largely by the ideological wishes of the Department. Researchers and representatives from research organisations were dumped almost instantly from the boards and committees that advised the board and the representation from industry was diluted by the introduction of people with designated expertise, not necessarily associated with either research or the relevant industries. They came largely from other sectors of the community in keeping with the overall "business" tone of the new order. Part of that ideology was to have industries take increasing responsibility for their research destinies although the constraints against this in terms of tight government control were still strong

Despite the measure of Government control, each of the research corporations began to develop its own identity and approach to the encouragement, direction and funding of research. This dichotomy across the agricultural industries accelerated in the last decade so that today there is a wide spectrum of research corporations that have achieved relative independence of action. They manage research in different ways and, if it could be measured, presumably with differing degrees of success. Compared with the earlier organisations, modern research corporations are characterised by:

i. a much larger staff with a much bigger say in the research portfolio,

ii. a much higher proportion of their budget for administration,

iii. Boards deciding only on policy and having little contact with researchers or research organisations,

iv. the apportioning of funds and monitoring of progress being the responsibility of the staff, with or without the help of committees, but according to the broad policy of the Board.

There is no comparative report card to say which among them is getting the best long term value for the research dollar nor, as far as I know, are there plans in place to find this out. When such a review is initiated, as inevitably it must be, it is essential that all of the issues, particularly those that involve the research environment and the encouragement of productive researchers, are major considerations. This paper raises issues that suggest that, in many cases, there has been a singular lack of attention to administration of the research environment and the management of both productivity and creativity.

The research environment

What is a research environment?

The answer to this question varies enormously depending on the respondent. Research scientists would probably describe a Utopian environment for research as one in which they could think about their research in relative freedom from distractions, be stimulated by good facilities with productive and collaborative colleagues, have access to a well run library and time and resources to attend conferences to allow them to indulge

in continual self education. It would also include having the time and resources to seek to understand the fundamentals of research issues as well as their applicability. It was a view that the founders of CSIRO attempted to approach in the 1940s and 1950s but which required a level of financial resources that the community was unwilling to support in subsequent years.

The non-scientific community has a much different view. Much of their reluctance to allow scientists to live in their Utopia comes from their quite different perception of what constitutes a good research environment. This, in turn, stems from their judgement of what constitutes worthwhile research which can be reduced briefly, if cynically, to three concepts. The first is that research is relatively easy—you spend money and you get a result. The more pressing the problem the more money you spend, and the more money you spend the quicker the result. The second is that scientists are unworldly and need to be closely guided by administrators trained in business and economics. The third is that all research, when entrepreneurially managed, is capable of returning very large financial returns to its financial backer, generally the Rural Research Corporation. At least two rural research corporations in the recent past have been managed for periods in which these views have had an obvious influence on research policy even to the level of dictating the type of research that was funded. One corporation openly predicted that it would be self-funding from royalties and patents within the next decade. The results have been patently disastrous for both the research and the research environment but it is not clear that the messages will be passed on given that these corporations have had massive upheavals in their structure that have eliminated both corporate loyalty and memory.

Somewhere between these two views lies the sort of environment that a rural industry must have to compete with alternative products and cope with the continuously worsening terms of trade that beset virtually all agricultural commodities.

How do you create a favourable research environment?

Each of the rural research industries in Australia has attempted to find effective policies to ensure the best return for its research dollar and since no two of them appear to have the same research philosophy, one way of answering this question might be to sort amongst them to find the most successful and follow in its footsteps. A less empirical approach is to look to the literature in business management, extract principles of management that have been successful in managing industrial research and attempt to adapt them to the needs of rural industries. Fortunately, a small amount of recent literature in the business management field has begun to address this field seriously, and offers new insights into the handling of creative endeavour in a competitive industrial environment.

Tangible versus non-tangible assets in management

The assets that are used in any business enterprise are of two sorts, tangible and intangible. The tangible ones include the buildings, machines and financial reserves and the intangible ones include the skills and experience of staff, and information, often in the form of unexpressed, tacit knowledge (Kennedy, 1998). In modern enterprises, the proportion of tangible to intangible assets is decreasing. In business speak, companies have become less and less capital intensive and more information intensive. The degree to which this is so is illustrated by Strassman (1998) who found that in nearly 3000 US companies that he studied, over 90% were information based and less than 10% were capital based. Modern management techniques are struggling to come to grips with this change and are seeking to define and categorise "intellectual capital" and to formalise, share and exploit it (Stewart, 1997, Sveiby, 1997). One criterion is based on how quickly a business learns. If its rate of learning is less than the rate of change in the external environment—if it can't keep one pace ahead—then it is a business headed for oblivion. Unfortunately there are many other criteria related to institutional knowledge and most of them so far remain unaccountable.

However almost all of the modern management experts agree that the techniques that were in place twenty or thirty years ago to manage capital intensive enterprises are totally inappropriate for managing the increasing numbers of information intensive ones. As Sveiby (1997) describes it, managers invest money in their enterprise and expect a return on their investment. This is a relatively easy exercise in accounting providing that the assets that are the subject of the investment and the returns are both tangible. However, the costs of intangibles such as training, R & D and information databases has to be ignored as an investment in the traditional balance sheet. By contrast, any benefits from these investments will appear only as better performance in the areas that can be measured such as increased output or lower costs of production and, unless the manager is acutely aware of what is happening, the real value of investment in intangibles is likely to be lost.

The growing awareness of the importance of intangible assets has triggered a new approach to management, and this is particularly pertinent to the management of R & D in the rural industries. Administering R & D is an extreme form of management of knowledge. Not only is it a matter of dealing with knowledge that is largely intangible but of dealing, in most cases, with knowledge that doesn't yet exist. Research corporations and research institutions have to learn to manage not just knowledge but creativity.

The lessons of history

Much of the confusion in managing research in the rural industries stems from the need for research to be simultaneously creative, innovative and commercial. Many highly commercial corporations have successfully married these seemingly disparate objectives and it is surprising that more use has not been made of their experience in deciding the policies for Rural Research Corporations in Australia. Companies like Dupont, IBM, Microsoft, Upjohn, Dow and many others exist only because of the quality and successes of their research departments. In the increasingly competitive world environment for rural products, it is tempting to believe that the same may soon be said for our rural industries. If this is even partially true, Australia should be learning as much as it can from the people who have made research an integral part of their commercial activities.

The most comprehensive study available is that of Houndshell and Smith (1988) who analysed the R & D of the Dupont Company over most of the 20th century. Dupont is well known as a pioneer in corporate research but it is less well known that they were also pioneers in business management, particularly in the development of techniques of calculating return on investment and using it to remarkable advantage in their business activities like streamlining their production chains and targeting take-over options. As Houndshell (1998) emphasised, they believed intimately in quantitative data, cost analysis and the benefits of return on investment calculations in decision making. They managed the manufacturing part of their business through tight accounting and financial controls. "Yet they never assumed that the firm's research could be managed by the numbers...they never thought for a moment that the firm's investment in research could be evaluated by the same means it used in evaluating whether a new plant should be built.." (Hounshell, 1998).

What led them to this emphatic attitude and how did they evaluate research? The first and most important realisation made by Pierre Dupont in 1911 was that returns on research could not be measured simply by direct effects, such as new products and techniques which, by and large, are measurable. He recognised that research had secondary and tertiary effects that were probably greater than the direct effects, and which have been described three quarters of a century later as intangibles. The secondary ones were that successful research breeds more successful research. It developed for Dupont a staff of some of the smartest scientists in the world who were likely to stay with and be loyal to the firm in the long term. The tertiary benefits were the positioning of Dupont to be able to get maximum benefit from changes in the global business and social environment. The most dramatic of these changes were the two world wars where Dupont was in a unique position to develop a host of new products and make almost

unbelievable profits from nylon, new explosives, neoprene and others commodities developed from the research they had already done. Dupont's successes are not confined to wars. There have been many other, less dramatic global changes, for example, in dress fashion, wash-and wear and car upholstery that bought similar multi-million dollar coups.

Just twice in Dupont's history, 1915 and the early 1960s it reverted to narrow financial evaluation of return on investment in its research departments but abandoned it both times. In the 1960s this narrow policy led the company to come as close as it has ever been to bankruptcy. A decision had been made on strictly financial grounds that the key to greater profits from research lay in emphasising the D rather than the R in R & D and it ran into two problems. It quickly ran out of new things to develop and it only poorly understood the products that it was developing anyway, so the success rate dropped dramatically.

Dupont enunciated a policy about investment in research, which it largely adhered to for 70 years. It is all the more remarkable because it was made in the era of the Great Depression. Decisions about what research to fund were based on just three judgements:

i. the scientific merit of the project,

ii. the accomplishments of the scientific investigator and

iii. the relevance of the proposed work to Dupont.

The only other stipulation that they put on the whole process was that the manager of the research, the person who made the decision about whether to fund a project or not, should be outstanding in both technical competence and business perspective. After all, these are the criteria that allow good judgement in all three of the categories above.

Other major research companies do not have their histories as well and completely documented as Dupont (Houndshell and Smith, 1988) but there are reports such as that by Jasinski (1998) that show that IBM's thinking followed a similar path. That company and others (Kash, 1998) place specific emphasis on another factor that is largely intangible but is relevant to rural research; the value of the long view of research. Benefits from research usually result either directly or indirectly from research initiated at least a decade earlier. This is an assumption that these companies build into their business plans as a matter of course.

The implications for managing rural research

The foregoing makes it clear that managing research is not for the faint hearted but it is also clear that it is not for the uninformed. A lack of understanding of research and science may make decision making easy but it almost certainly ensures that the decisions will be the wrong ones. Nevertheless, in the end, decisions do have to be made to allocate limited funds to the projects that are most likely to benefit the industry. And it is, without doubt, a complex process.

Historical evidence such as that above from large companies and experience from various experiments in some Australian R & D corporations show that the blind use of formulae to measure returns on investment is not at all helpful. As Hounshell (1998) says "If people tell you that they have an accurate and infallible way to measure return on investment in R & D .....take it with a grain of salt". The quicker we get away from this approach which has filled so many fruitless hours of researchers' time and encouraged them to make so many outlandish assumptions, the better.

Another complication with rural research in Australia that companies like Dupont and IBM do not have to consider is that the funding is not all "in house". The Research Corporations usually provide only some of the funds and the organisation, State Departments, CSIRO, universities or private companies usually provides the rest. In other words, there are often several research managers associated with a piece of research in a particular field. Unless they can agree on at least the broad policy for allocation of funds, the outcome in terms of the research projects that receive money can only be chaotic or, at best, uncoordinated.

Then there is the perennial problem of the balance between long and short term research. It is not a simple problem of optimisation because the certainty of benefits becomes less and less as the list of projects moves from very short term to long term. Yet, if all investment is on a strictly short term basis to maximise the certainty of a result, the industry risks "technological obsolescence" (Schumpeter, 1975). So, to invest simply in short term, incremental research is to condemn the industry to the likelihood of falling behind its competitors in the same industry overseas or in similar but more forward looking industries in Australia that generate competitive products. For long term research, the importance of the benefits, should they eventuate, is large in direct contrast to the original chances of success. Again decisions about the right mix are not amenable to cold formulae. However, the Dupont model suggests we will have a much better chance if projects are subjected to peer review and judgement based on scientific merit, track record of the chief investigator and relevance to the industry. There has been an alarming tendency over the last decade to move away from this approach rather than towards it and the lamentable paucity of significant research success in certain of the animal industries (fortunately, not the pig industry!) may well reflect this.

A question that troubles some Australian rural research corporations and is a minor issue with others is the capturing of intellectual property through patents. Some of the corporations have even announced at one time or another that they might fund all of their future research from royalties. A great deal of time has been wasted for little return in pursuit of this goal. An examination of the approach of big companies to this question also shows diversity but for clearly articulated reasons. In the telecommunications and electronics industries the strategy is not to seek patent protection because of the short life span of new discoveries which may be less than the time it takes to get a patent registered. They rely on secrecy and attempt to gain a commercial advantage for the product by getting it to the market as soon as possible and make profits before their rivals catch up. On the other hand, in the medical and pharmaceutical fields, the long lead time for development encourages firms to seek patent protection. In most rural fields the proportion of research projects from which intellectual property may be captured is extremely small. Techniques of production, feeds and husbandry practices that develop from research may be of great benefit to producers but are virtually unpatentable. There is also the strong likelihood that producers who have contributed to the research through their levy funds will have a strong resentment to having the results tied up in patents and only available to them on payment of royalties. Some rural corporations have argued that the revenue goes to further research but the small gross value of funds from this source and high expenditure to protect it seem to make this a spurious argument.

If our industries are to gain more benefit than they do now, they will need to keep a eye on the opportunities for long term breakthroughs from projects that involve sound science and are led by good researchers. These projects would be balanced by shorter term incremental programs. I doubt that many R & D corporations have the mechanisms in place to identify and handle such balanced programs.

Implications for managing researchers

In effect, the managers of rural research organisations, including the corporations have two main assets with which to work; the money they handle annually from commodity levies and the people who do the research for them. Managing the people is a component that has been paid scant attention, yet it is arguably the area from which the greatest gains in productivity from research can come. Here lies the intangible part of the assets and the part that creates new knowledge and develops ways of using it to the advantage of the industry. Pierre Dupont knew about it intuitively seventy years ago, modern business academics have defined it more formally since and most research managers in Australia, and not just those in research corporations, have ignored it. At Dupont it was an accepted fact until about 1928 that many of their best scientists made a name with the firm and then moved to a teaching post at a university because of the prestige that such a move carried with it. (How things have changed!) Charles Stein, the scientist who led the teams that produced, among other things, nylon and neoprene,

sought to create a better atmosphere in his chemical laboratories. His major strategy was to give chemists more independence in their work and this, rather than increased wages or any other incentive, induced many of them to remain with his department for the rest of their working lives. Part of this independence involved education in at least three forms. Formal courses at universities and other academies, attendance at conferences, and in-house education through being permitted to follow a desire to understand the processes and products on which they were working.

Much more recently, Reisenbichler (1995) studied the same phenomenon and came up with a plausible reason. She concluded that..."Only one characteristic of personality and orientation to life is absolutely, across the board, present in all creative people: motivation. Creative people want to create and be creative, not merely successful or effective or competent". So, part of managing creativity is to foster motivation.

One way of doing this was described by Senge (1990) as the principle of creative tension. Simply put, creative tension is a recognition of the gap between where we would like to be and where we are and a positive determination to close the gap.

Scientists who have sufficient independence to set some goals in their scientific career, as presumably Dupont's chemists did, and who are resolved mentally to meet those goals are experiencing creative tension. The empirical theory is that, because they are aware of the gaps and marginally uncomfortable about them, they have extra motivation to overcome them and are prone to inspirational leaps and mental breakthroughs. They don't leave their creative tension behind in the laboratory at 5.30 when they go home from work. They keep pressure on themselves to achieve. People who slog away without the benefit of this desire to create, either because it makes them too uncomfortable or because they are diverted by too many other tasks to make it seem worthwhile, are seldom likely to achieve as much in research as those who have it. Dupont is not the only firm that recognised that a good research environment is essential to get good research. The Upjohn Company described its goals in this direction (Smith 1959) stating that it needed an organisation that fulfilled the company's goals but it had to do this without diminishing "the effectiveness of the individual creative man".

If we accept that motivation and creative tension are desirable for more efficient research then there are three conditions that must be met:

i. Researchers have to have enough autonomy and flexibility to develop a clear vision of their own goals (Greenberg (1992).

ii. Managers have to remove blocks and barriers that interfere with the researchers perception of where they are (Adams, 1975).

iii. All sides must be committed to telling the truth (Senge,1990). This sounds simple but it alludes to the almost universal practice of encouraging the exaggeration of the worth of data, politically motivated, selective amnesia, over-optimistic predictions and gilded reports to stakeholders. If researchers delude themselves as well as others about the reality around them then there is no room for creativity.

It is certainly possible to get research done by paying a competent scientist to go through the routine of doing it. It probably won't be inspirational research, it probably won't be innovative research, but it will add knowledge to our information bank. I get the impression that an increasing amount of rural research done in this country is in this category. I also get the impression that we have to lift our game by encouraging research of a better quality. Quality of research is not a serious issue on the agenda of research corporations or, at least there have been no explicit policy statements that address it. By contrast, corporations that make their money from research or the products of research see it as their most important issue. But they have to come up with new things to stay ahead of the competition. Perhaps Australia doesn't have to bother about this—but I don't think so.

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A REVIEW - FACTORS LIMITING THE PERFORMANCE OF GROWING PIGS IN COMMERCIAL ENVIRONMENTS

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Abstract

The performance of pigs raised under commercial conditions is well below their potential when housed in an ideal environment. This so-called 'growth gap' has a significant impact on the potential profitability of a pig enterprise. Many factors within a commercial environment contribute to the depression in feed intake, growth rate and efficiency of feed use, and to the tendency for increased fatness of the final carcasses. These factors include the number of pigs per pen, floor area and air volume per pig, the quality of the air and its bacterial load, the prevalence of disease and the climate within the sheds. The temperament of the pig also appears to be important with those pigs having a passive, coping temperament eating more and growing faster than pigs with an aggressive, non-coping temperament.

There is strong evidence suggesting that the factors shown to reduce the performance of pigs raised under commercial conditions increase the stress levels of the animals. In most situations, the negative effect of several stressors acting simultaneously appear to be additive and the removal of any one stressor should have a positive effect on performance. The adverse effects of stress on an animal are mediated through the endocrine, autonomic nervous and immune systems. The mechanisms by which specific hormones and cytokines are activated and interact to reduce feed intake, muscle protein deposition and immune competence and to increase fatness are now being understood. The advances in gene technology and gene therapy have increased significantly the potential to manipulate these physiological systems.

Strategies for improving the performance of pigs raised commercially fall into three categories, removal of the stressor, reducing the pig's perception of stress and altering the pig's physiological response to stress. Evidence is provided to indicate the possible success of a range of management strategies that could be adopted to reduce the stress and increase the performance of pigs raised commercially.

Introduction

The rate of growth and efficiency of feed use by pigs raised under commercial conditions are well below their genetic potential and the values that could be achieved if the animals were housed under ideal conditions. Campbell and Taverner (1985) measured growth rates of over 1100 g/day for entire male pigs grown from 45 to 90 kg live weight (LW) during laboratory experiments, whereas the identical strain and sex of pig grew at less than 800 g/day over the same weight range in commercial piggeries. Similarly, Carr and Hanson (cited by Black and Carr, 1993) found that the rate of growth of male pigs housed in the boar test sheds of a commercial piggery grew 22% faster from 20 to 87 kg LW than pigs of identical breeding raised in grower-finisher sheds. There are many examples of this phenomenon showing that pigs housed in individual pens under ideal experimental environments, in boar test pens, in new buildings or in extensively cleaned buildings grow from 15 to 30% faster than similar animals raised under common commercial conditions (Williams, 1998; Cargill *et al.*, 2000). In addition, commercially raised animals tend to be fatter than their counterparts given the same amount of feed under more ideal conditions (Chapple, 1993; Williams, 1998). The slower growth rate, reduced efficiency of feed use and fatter carcasses of commercially raised pigs relative to

their genetic potential have been estimated, using the AUSPIG decision support software, to decrease the profitability of pig enterprises by as much as 25% (Black *et al.*, 1994).

The reduced performance of pigs raised in normal commercial environments has been termed the "growth gap". Understanding its causes and ameliorating its impact represents a significant opportunity for the pig industry. This opportunity has been recognised by the Pig Research and Development Corporation and several commercial companies with substantial funding for research in the "Growth Gap Program". Evidence from the Growth Gap Program and other published information is presented in this review on the extent to which management, environmental and animal factors contribute to the sub-optimal performance of pigs raised commercially. Possible physiological reasons for the 'growth gap' and ways for improving the performance of pigs raised commercially are discussed.

Factors contributing to the 'growth gap'

Individual compared with group penning

Contrary to current commercial practices where growing pigs are normally housed in groups of similar age and often similar sex, pigs allowed to live under natural conditions form small groups with one to four sows, their progeny of various ages and one or two adult males (Stobla and Wood-Gush, 1989). There is now strong evidence that the group penning of growing pigs has a detrimental effect on feed intake and performance. Chapple (1993) showed that simply by increasing the number of pigs in a pen from one to three or five caused a significant linear reduction in feed intake and growth rate (Table 1). Chapple (1993) observed also that backfat measured at the P2 site increased from 18.7 to 21.7 mm for pigs in single pens compared with pigs in groups of five. The increase in fatness associated with a reduction in feed intake is contrary to the conventional observation for pigs housed in single pens where a decrease in feed intake causes a reduction in fat content of the body (Campbell *et al.*, 1985).

Table 1. Effect of group size on feed intake, growth rate and back-fat thickness of castrated male pigs[1].

	Group size (pigs/pen)		
	1	3	5
Growth rate (g/d)[2]	890	870	840
Feed intake (kg/d)[2]	2.41	2.30	2.19
Feed/gain ratio	2.71	2.66	2.64
P_2 back-fat (mm)	18.7	20.1	21.7

[1]Results from Chapple (1993) for an experiment in which pigs were grown from 20 to 100 kg live weight. [2]Significant linear depression ($P<0.01$) of values with increasing group size.

Many reports of experiments conducted in research facilities show that feed intake and growth rate of pigs kept in groups are substantially less than for similar pigs housed in individual pens (Oka *et al.*, 1982; Patterson, 1985; Spicer and Ahern, 1987; de Haer and Merks, 1992; Gonyou *et al.*, 1992; Chapple, 1993; de Haer and de Vries, 1993; Hacker *et al.*, 1994; Nielsen *et al.*, 1996a; Giles and Kilgour, 1999; Gomez *et al.*, 2000). The phenomenon has been observed for entire male, castrated male and female pigs and the reported difference in growth rate between individual and group penned pigs has ranged from around 5 to 17%. Not all experiments, however, have shown a significant increase in the fatness of group penned pigs.

Reduction in the performance of pigs when placed into groups occurs even when the animals have been acquainted previously with one another (Gomez *et al.*, 2000). In a recent experiment within the Growth Gap Program (C.A. Kerr, P.J. Nicholls, L.R. Giles, K.O. Mathews, P.C. Wynn and M.R. Jones, unpublished), six pigs were grown in adjacent individual pens, formed into a group by removing the pen dividers and then returned to individual pens. The effect of group penning on performance was found to be reversible (Figure 1).

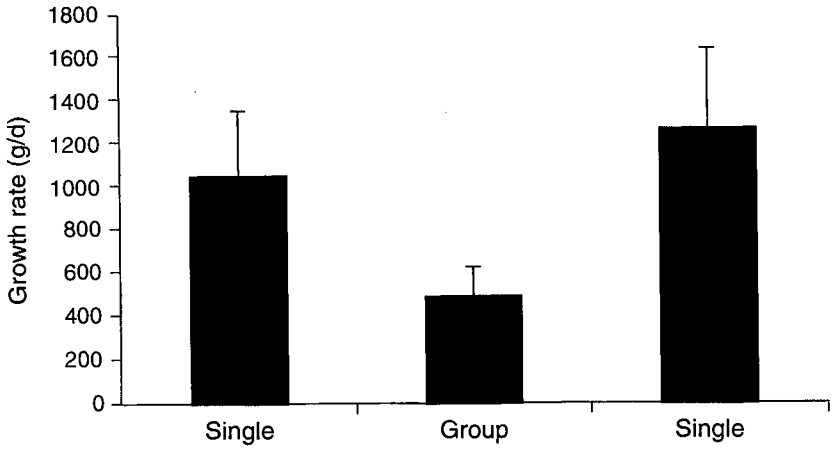

Figure 1. *Growth rate of groups of six pigs when penned individually for 1 week, in a group for 1 week and returned to individual pens for 1 week (mean± SEM). The differences in growth rate between the individually and group penning periods were significant (P≤0.05). Adapted from the experiment of C.A. Kerr, P.J. Nicholls, L.R. Giles, K.O. Mathews, P.C. Wynn and M.R. Jones (unpublished)*

Effect of group size

The experiments reported by Chapple (1993) indicate that the greatest adverse effects of group size on feed intake and performance occur when the number of pigs in a pen is increased from one to five. Table 1 shows that feed intake declined by 4.5% as the number of pigs in a pen was increased from one to three and then declined a further 5% as the number of pigs in a pen was increased from three to five. There appears to be little additional effect on performance from increasing the number of pigs in a pen beyond five, but the published results are equivocal. Chapple (1993) found that the intake of pigs was similar irrespective of group size ranging from five to 15 pigs per pen. Similarly, Nielsen and Lawrence (1993) observed no difference in feed intake for pigs housed in groups of five, 10, 15 or 20. Gonyou and Stricklin (1998) examined the effect of group size ranging from three to 15 pigs per pen and found the greatest depression in feed intake occurred between group sizes of three and six pigs, but a small depression in intake continued to 15 pigs per pen. Petherick *et al.* (1989) reported that the intake of pigs housed in groups of 36 was significantly less than that for pigs in groups of either six or 18 per pen. Although McGlone and Newby (1994) observed no difference in the performance of pigs housed in groups of 10, 20 or 40 per pen, animals in the pen with 40 pigs showed the greatest rates of injury and morbidity. Turner *et al.* (2000) found that the growth rate was greater for pigs housed in a group of 20 than for groups of 80 pigs. However, neither Schmolke and Gonyou (2000) nor Wolter *et al.* (2001) observed any differences in the performance of pigs housed in groups of 10, 20, 40 or 80 and 25, 50 and 100, respectively. Giles (2001c) also observed little difference in the growth rate of weaner pigs housed in groups of 20, 40 or 100, but there was significant variation between experimental runs and sex of pig. Increasing group size had no effect on the variation in live weight among individual pigs within the groups.

There is anecdotal evidence that pigs raised in extremely large groups of 400 or more perform exceptionally well (Brumm, 1999), but there appears to be no experimental evidence to support the conjecture. The number of aggressive encounters between pigs has been shown to increase with group size up to six pigs per pen and then decrease with further increases in group size (Moore *et al.*, 1996). Gonyou (2001) suggests that the reduction in aggressive encounters between pigs with increasing group size may be due to either the formation of subgroups which avoid each other or the pigs develop a

tolerance of other individuals in large groups. The reduction in aggressive behaviour may explain the reported improved performance of pigs raised in large groups in ecosheds.

Stocking rate

The overcrowding of pigs in a pen is known to reduce feed intake and growth rate. A review of the published experiments examining the effect of floor area per pig with groups of five pigs or more indicates that a depression in feed intake commences when the space allocation falls below 0.035 $m^2/LW^{0.67}$ (Black, 1999). However, Petherick (1982) suggested that 0.030 $m^2/LW^{0.67}$ would be adequate space for pigs housed on fully perforated floors. Gonyou and Stricklin (1998) examined the effect of group size from three to 15 pigs per pen at three stocking rates of 0.030, 0.039 and 0.048 $m^2/W^{0.67}$ and found that intake and growth rate were depressed only at the lowest area allocated per pig. Hyun *et al.* (1998) found that a space allocation of 0.25 m^2/pig (approximately 0.019 $m^2/W^{0.67}$) reduced growth rate by 16% compared with an allocation of 0.56 m^2/pig (approximately 0.043 $m^2/W^{0.67}$). Space allocations sufficient to reduce pig performance have been shown to increase abnormal behaviours and aggression in pigs (Randolph *et al.*, 1981; Turner *et al.*, 2000). Edmonds *et al.* (1988) attempted to compensate for the reduced intake of overcrowded pigs by increasing the nutrient density of the diet. However, growth rate of the pigs was not improved by the treatment and Gonyou (2001) suggested that the reduced feed intake of overcrowded pigs was due to stress-induced metabolic changes in the animals.

Air quality and cleanliness of the environment

There is now convincing evidence that the differences in feed intake and performance between pigs housed in individual pens and those in group pens is dependent on the cleanliness of the environment and the quality of the air. The classical experiment to demonstrate the effect was performed by Carr and Hanson during the late 1970's (Black and Carr, 1993), when they erected individual pens from the boar test sheds within a large pen of grower pigs in a commercial unit of a piggery. The normal mean growth rate of entire male pigs in the boar test unit was 860 g/d compared with 675 g/d for identical animals in the commercial units. However, when the boars were transferred to the pens erected within the commercial pens, growth rate of the pigs fell to 708 g/d and was not significantly different from that of 719 g/d measured over the same live weight range for pigs reared concurrently in the commercial pens. The fall in growth rate of the boars transferred from the boar test unit was associated with a fall in feed intake and not with changes in the efficiency of feed use.

A significant effect of the environment on the performance of pigs housed in either individual or group pens has been demonstrated more recently from an experiment within the Growth Gap Program. Lee *et al.* (1997) housed weaner pigs in either individual pens or in groups of 10 pigs per pen within a clean or dirty environment in a commercial piggery. The clean environment was created by the daily hosing of pens, flushing the effluent with clean water and spraying the air space with a disinfectant, whereas the room for the dirty environment was not cleaned prior to or during the experiment and the sub-floor area was flushed with recycled effluent. There were large differences in the quality of the air between the two rooms with the clean environment having significantly less ammonia, carbon dioxide and total dust than the dirty environment (Currie *et al.*, 1997). Similar to the many reports from experimental facilities quoted above there was a trend for growth rate to decrease when pigs were penned in groups in a clean environment compared with those penned individually. However, the differences were not apparent in the dirty environment and the performance of the pigs in the dirty environment, irrespective of number per pen, was similar to pigs penned in groups in the clean environment (Table 2). The results from both the experiment of Carr and Hanson and that from the Growth Gap Program suggest that the depressed performance of pigs raised in commercial environments is associated more with the characteristics of the building environment than with the number of pigs in a pen.

Table 2. Effect of group size and cleanliness of the environment on feed intake and performance of weaner pigs[1].

Environment	Clean		Dirty		SE[2]
Group size	1	10	1	10	
Ammonia (ppm)	6.0[a]		12.7[b]		0.60
CO_2 (ppm)	1773[a]		2268[b]		105.7
Total dust (mg/m^3)	1.46[a]		2.28[b]		0.231
Feed intake (g/d)	804[a]	767[ab]	703[b]	760[ab]	28.8
Growth rate (g/d)	611[a]	573[ab]	534[b]	544[b]	22.3

[1]From Currie *et al.* (1997) and Lee *et al.* (1997). [2]Average standard error for environment and environment x group size. [a,b]Means in the same row with different superscripts are significantly different (P≤ 0.05).

A strong positive relationship between the air volume per pig and the mean growth rate of pigs housed from 10 to 22 weeks of age in single-phase, commercial units has been observed by Murphy *et al.* (2000). There was also a strong negative correlation across pig production units between air volume per pig and the number of viable bacteria in the air, such that the growth rate of the pigs declined significantly as the concentration of bacteria in the air increased (Figure 2). Previous research by Cargill and Banhazi (1998) has demonstrated the importance for pig performance of cleaning sheds and reducing the concentration of viable bacteria in the air. The thorough cleaning of pens and walls between batches of 300 pigs in an all in/all out system reduced the number of air-borne viable bacteria by 53% compared to a continuous-flow management system with the same number of pigs and the same volume of air per pig. The concentration of viable bacteria was reduced by only 14% compared with the continuous-flow system when the sheds were not cleaned between batches of pigs. The reduction in bacterial count was associated with a 7.3% increase in growth rate of the pigs in cleaned all in/all out system compared with the continuous-flow system. The pigs in the all in/all out system that was not cleaned grew only 1.5% faster than the animals in the conventional system.

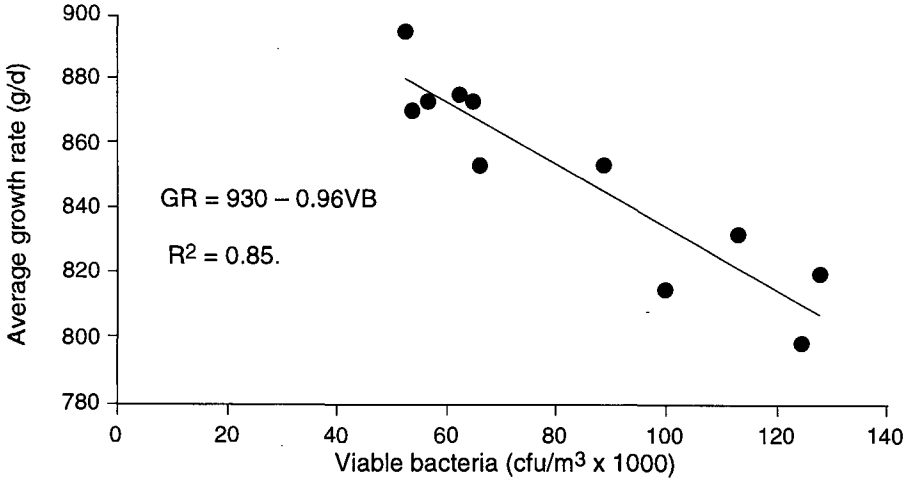

Figure 2. *Relationship between viable bacteria (VB) in the air and growth rate (GR) of pigs reared in commercial single phase fattening units in Queensland. Adapted from Murphy et al. (2000).*

Disease and microbial load

The presence of disease in commercial piggeries contributes significantly to the poor performance of pigs raised in these environments. The disease may be acute and result from an infective challenge by a pathogenic agent such as enteric disease organisms causing colibacillosis and swine dysentery or respiratory diseases including pleuropneumonia, mycoplasmosis and pasteurellosis. Animals challenged with a disease-causing dose of a pathogenic organism show overt clinical signs, with performance generally being greatly reduced and mortalities sometimes occurring. Kerr *et al.* (1999) challenged growing pigs with an endotracheal inoculation of *Actinobacillus pleuropneumoniae* that produced mild pleuropneumonia. Although none of the 10 animals inoculated with the organism died, feed intake fell from approximately 2.5 kg/d prior to the inoculation to a mean value of only 200 g/d by two days after the challenge. All pigs had recovered to clinical normality by 4 days after challenge, but the mean weight of the inoculated group of pigs was still 6.8 kg less than that for sham operated control pigs 12 days after challenge.

Similar large effects on pig performance have been observed following challenge with an enteric pathogen, with the severity of disease being affected markedly by the composition of the diet. For example, McDonald *et al.* (1997) observed a growth rate of only 57 g/d in weaner pigs consuming a normal diet after a challenge with haemolytic *Escherichia coli*, whereas challenged pigs given a diet of pregelatinised rice with an animal protein supplement grew at a rate of 141 g/d.

There is evidence that pigs need not show clinical signs of disease to have a reduction in performance. Pigs exposed to pathogenic organisms at a dose lower than that which causes overt clinical disease may develop immunity to the organisms but with a resulting depression in performance. Williams (1998) raised pigs from 6 to 112 kg LW in two environments, which caused either a low or high chronic stimulation of the immune system. Low stimulation of the immune system was achieved by vaccinating sows prior to parturition against the known piggery diseases, using a medicated early weaning regime and maintaining the pigs in an isolated environment. The high immune stimulation group was selected from a conventional continuous-flow piggery and the animals did not receive injectable antibiotics. Despite no clinical signs of disease in either group, the pigs with high stimulation of the immune system ate 5.5% less feed and grew 17% more slowly than pigs with low immune stimulation. In addition, at slaughter, back-fat thickness for the pigs with high immune system stimulation was 17% greater and eye muscle area 15% less than for pigs with low immune stimulation.

Climatic environment

Banhazi *et al.* (2000) recorded continuously for one year the ambient temperature near pig height within various production units on 12 farms in South Australia. The mean temperature within the fattening units of the farms was 9°C during the winter months and 40°C during summer. The lowest temperature recorded in the fattening sheds was 2°C and the highest almost 50°C. Frequently the daily range in temperature was around 20°C. The temperature within these sheds was assessed to be below the zone of thermal comfort of the pigs for 94% of the time during the winter months and above the comfort zone for 47% of the time during summer. Clearly, temperature control within many Australian pig sheds is poor and temperatures either above or below the zone of thermal comfort for a pig are known to have profound effects on performance and health status.

Giles and Black (1991) showed that raising the ambient temperature from 23°C to 31°C reduced the voluntary intake of finisher pigs prevented from wetting their skin from 2.8 to 0.9 kg/d. This reduction in intake was maintained for the 11 days of the experiment with significant detrimental effects on growth. However, pigs were shown to be capable of maintaining intake near normal provided they could spend at least 12 hours each day within their zone of thermal comfort. Lorschy *et al.* (1991) found that feed intake of finisher pigs fell by 33% and 39% when they were allowed to spend only 8 or 4 hours,

respectively, each day at 22°C with the remainder at 31°C. The reduction in feed intake when pigs are exposed to hot conditions appears to be related closely to deep body temperature and occurs soon after body temperature starts to rise (Black *et al.*, 1998).

Many experiments show that feed intake of pigs exposed to cold temperatures tends to increase, often after a short delay of around one day, to compensate for the increase in heat loss to the environment (Close, 1989). However, the extent of this compensation is variable and related to the capacity of the digestive tract and whether the pigs are penned individually or in groups. Small pigs in particular have difficulty increasing feed intake in the cold because of the limited capacity of their digestive tract (Close, 1989; Black *et al.*, 1998). The energy density of the diet and its capacity to be digested and move through the digestive tract clearly has an impact on the ability of pigs exposed to cold conditions to increase their intake (Black *et al.*, 1998). Pigs in groups that are exposed to cold conditions spend more time huddling than feeding compared with pigs in individual pens exposed to the same conditions. Nienaber *et al.* (1990) subjected pigs housed either individually or in groups of four to ambient temperatures 12°C below their lower critical temperature and observed a 30% increase in feed intake for the cold-exposed individual pigs compared with only an 11% increase for the cold, group-penned pigs. Presumably the pig prefers to remain warm in a group and eat only when the hunger drive is high and for shorter periods compared with the individual-penned pig. The time spent eating each meal by the cold, group-penned pigs was observed to be only about half that of either the cold, individual-penned pigs or control animals in the zone of thermal comfort. In addition, Nienaber *et al.* (1990) showed that the cold pigs had a slower eating rate than pigs in thermal comfort, with a consequent depression of 19% in growth rate for the cold group-penned compared with cold individual-penned pigs.

There is strong evidence that pigs exposed to cold conditions have greater clinical disease than pigs housed under favourable climatic conditions. Cargill and Byrt (1983) showed that the incidence of scouring increased in neonatal pigs and death rate increased from 0.1 to 1.3 per litter when conditions were changed from a constant temperature of 29°C to a daily fluctuating temperature from 21°C to 29°C. Similarly, Hessing and Tielen (1994) observed a marked increase in diarrhoea, coughing, sneezing and haemorrhagic ear lesions in pigs exposed to draughts and low temperatures compared with pigs housed under thermoneutral conditions.

Pig temperament

There is now strong evidence that some pigs adapt to group penning better than other pigs and the characteristic appears to be related to an innate difference in their capacity to cope with new situations. Hessing *et al.* (1993) showed that it was possible to distinguish between active (non-coping) and passive (coping) piglets by restraining them for one minute on their back and observing the number of escape attempts. Hessing *et al.* (1993) defined active piglets as those that attempted to escape on more than two occasions, whereas passive pigs attempted to escape on less than two occasions. Hessing *et al.* (1993) observed that the active pigs also had a higher number of squealing bouts than the passive pigs. Consequently, Giles and Furley (1999) developed a quantitative method for measuring the vocalisation score for growing pigs by restraining them for one minute with a nose snare and measuring the total noise emitted using a decibel meter held adjacent to the pig's mouth. Vocalisation score was measured on a group of 137 pigs, which showed that the score changed continuously from low to high (Figure 3). Eight pigs were selected from across the range in vocalisation scores and their average feed intake measured for 14 days when held in individual pens. There was a strong negative relationship between feed intake and vocalisation score with the quietest pig eating 10% more feed than the noisiest pig.

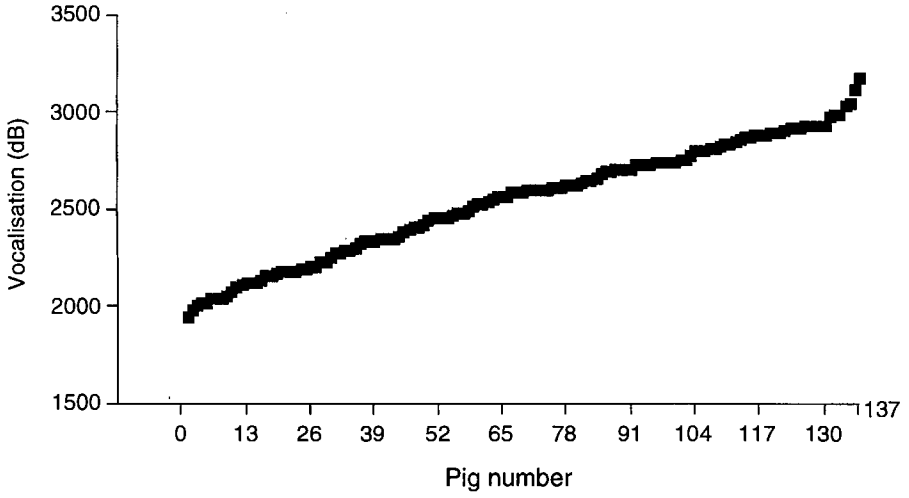

Figure 3. *Vocalisation scores for individual pigs from one group of 137 animals reared commercially (L.R. Giles unpublished).*

In a subsequent experiment, L.R. Giles (unpublished) measured the vocalisation score of 150 pigs, selected pigs with the highest and lowest vocalisation scores and examined the effect of either individual or group penning on their feed intake and growth rate (Table 3). The experiments showed that pigs with low vocalisation scores, irrespective of whether they were in group or in individual pens, consumed approximately 10% more feed than those with high vocalisation scores. The experiment showed also that the intake and performance of pigs with low vocalisation scores and penned in groups was still 8% below that of pigs with high vocalisation scores and housed in individual pens. There was a strong negative relationship between vocalisation score and feed intake for pigs in both group and individual pens. The relationship is given for pigs in individual pens in Figure 4.

Video recordings from an experiment where pigs with high and low vocalisation score were placed in a group of six, showed that pigs with high vocalisation scores were the most dominant animals in the group. The pigs with high vocalisation scores spent a significant amount of time fighting, 'guarding' the feeder either by lying in front of it or standing in it, but not eating, and spent less time eating than pigs with low vocalisation scores. The latter pigs spent little time fighting, went to the feeder only to eat and spent a greater proportion of the time lying down.

Table 3. Mean aggregate vocalisation scores (week 0), feed intake and growth rate (weeks 5-9) of male pigs grown from 57-87 kg live weight and housed in either individual (n=16, one pig/pen) or group pens (n=8, six pigs/pen), (L.R. Giles unpublished).

Group size (G)	Group		Single		SED		Significance[2]	
Vocalisation (V)[1]	Low	High	Low	High	Group	Single	G	V
Vocalisation (dB)	2199	2909	2175	2896	62	21	NS	***
Intake (g/d)	2594	2413	2964	2822	63	110	***	*
Gain (g/d)	1059	1047	1210	1139	58	58	*	NS

[1]Pig restraint with a nose snare and vocalisation (decibels) recorded at intervals of 2 seconds and aggregated over 60 seconds. [2]NS Not significant, *P≤0.05, ***P<0.001.

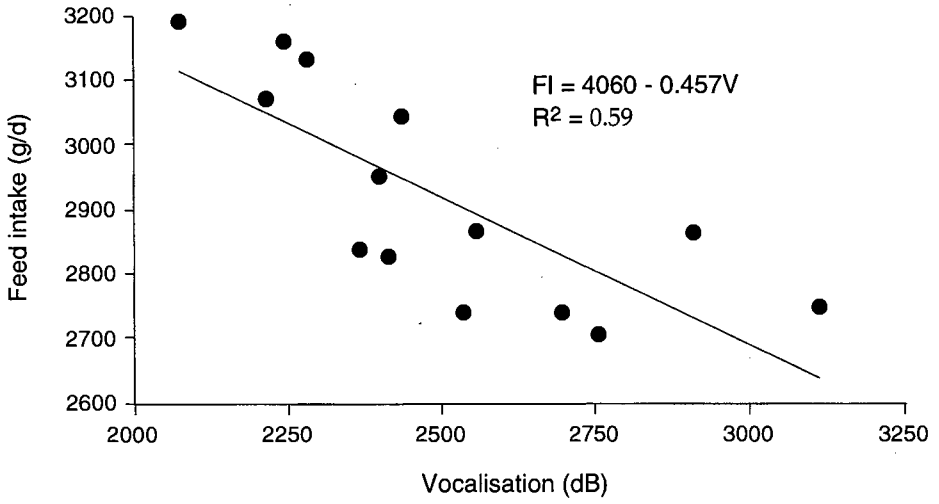

Figure 4. *Relationship between voluntary feed intake (FI, g/d) and vocalisation score (V, dB) for growing pigs in individual pens selected for a range in vocalisation scores (L.R. Giles unpublished).*

Similar differences in pig behaviour and performance have been observed in a comparison between entire male pigs and surgically castrated males from the same genetic background. Entire male pigs are known to grow faster than surgically castrated male pigs when housed in individual pens (Dunshea *et al.*, 1993). However, this is not the case when the pigs are housed in group-pens. McCauley *et al.* (2000) found the growth rate of groups of entire male pigs from 18 to 23 weeks of age to be 908 g/d compared with 944 g/d for surgical castrates. In the same experiment, Cronin *et al.* (2001) found that the entire male pigs spent less time at the feeding troughs than the surgically castrated male pigs and significantly more time performing socio-sexual behaviours of aggression and mounting. This experiment demonstrated the negative effect of aggressive behaviour on the performance of group penned entire male pigs, which is not seen when entire male pigs are housed in individual pens.

Differences between pigs in responsiveness to stress

Individual animals can differ widely in their responsiveness to stress. Hennessy and Jackson (1987) selected from 1200 pigs those animals with either the highest or lowest response in serum cortisol concentration following administration of adrenocorticotropic hormone (ACTH) and measured performance over 21 weeks when the pigs were placed in groups of 22-23 per pen. Female pigs with the low response in serum cortisol concentration following ACTH administration were significantly heavier after 21 weeks, weighing 78 kg LW compared with only 69 kg LW for the high responders ($P<0.01$). The low responders also had a significantly higher efficiency of feed conversion than the high responders. Differences of similar magnitude were observed for entire male pigs in the same experiment. Subsequently, Zhang *et al.* (1992) selected from a group of 120 animals, six pigs with a high, and six pigs with a low cortisol response to ACTH administration. When subjected to the stress of exercise on a treadmill the low responders had significantly lower plasma cortisol concentrations than the high resonders. A similar variation in plasma corticosterone concentration following the imposition of cold-stress in turkeys has been observed by Brown and Nestor (1973). Birds were selected for six generations on the basis of their corticosterone response to cold-stress at 4 weeks of age. After only four generations, birds with the low corticosterone response to cold exposure were significantly heavier at 4 weeks of age and, when mature, produced significantly

more eggs with higher fertility and hatchability than those with the high corticosterone response to cold-stress. The results from the experiment of Brown and Nestor (1973) show that the differences among animals in the responsiveness to stress are highly heritable.

Pig-human interactions

There is substantial evidence to show that the negative or unpleasant treatment of pigs by humans can significantly depress growth rate and the efficiency of feed utilisation. Gonyou *et al.* (1986) imposed four different handling treatments (Minimal, Positive, Negative or Aversive) on groups of female pigs for a period of 10 weeks and measured the effects on performance. The experimenter entered the pen only for essential cleaning with the Minimal treatment. For all other treatments, the experimenter entered the pen for two minutes each day for five days each week to impose the treatments. The Positive treatment involved the experimenter kneeling in the pen and stroking a pig when it approached and was receptive. The Negative treatment involved the experimenter standing for 1.5 min in the pen and touching an approaching pig on the nose or forehead with a leather-gloved hand, whereas for the remaining 30 sec the experimenter approached the pigs. The Aversive treatment was similar to the negative treatment except the pigs were shocked with a battery-operated prodder. The growth rate of the pigs receiving the Negative and Aversive treatments was 10-20% less than for the Minimal or Positive treatments during the first 3 weeks of the experiment (Table 4). Similarly, there was a significant depression in the efficiency of feed use with the Negative and Aversive treatments during the first 3 weeks of the treatment. However, the animals appeared to become accustomed to the unpleasant treatments and there were no significant effects of the unpleasant treatments on the performance of pigs during the last 4 weeks of the experiment. Acclimatisation of pigs to unpleasant treatments has been observed also by Hemsworth *et al.* (1987) and Hemsworth and Barnett (1991).

Table 4. Effects of handling treatments for 10 weeks on the performance of female pigs (Gonyou *et al.*, 1986).

	Treatment			
Pig performance	Positive	Negative	Minimal	Aversive
Gain (g/d)				
0-3 weeks	708[a]	595[b]	747[a]	633[b]
6-10 weeks	959	964	958	942
0-10 weeks	897[a]	813[c]	888[ab]	837[bc]
Feed:gain				
0-3 weeks	2.11[a]	2.33[c]	2.00[a]	2.25[bc]
6-10 weeks	2.92	2.75	2.73	2.96
0-10 weeks	2.54	2.69	2.54	2.60

[a,b]Means in the same row with different superscripts are significantly different (P≤0.05).

Inconsistent behaviour by humans with alternating pleasant and unpleasant treatment of pigs has been shown by Hemsworth *et al.* (1987) to produce performance responses in pigs similar to continual unpleasant treatment. In addition, pigs that have received unpleasant treatments remain fearful of humans throughout the experiments despite the effect of the treatment on performance declining. Minimal human exposure to growing pigs appears to be the best treatment for maximising pig performance under commercial conditions. Hemsworth *et al.* (1996) found that the daily injection of pigs using the technique recommended for the delivery of porcine somatotrophin, resulted in a pig-human withdrawal distance greater than for a Minimal or Positive treatment, but less than for a Negative treatment. Similarly, performance characteristics of the pigs receiving the daily injections were intermediate between the Minimal and Negative treatments.

Reasons for the depression in performance of pigs reared under commercial conditions

There is strong evidence that all the factors discussed above which reduce the performance of pigs raised in commercial environments act to increase the stress level of the pigs. The stressors can be divided broadly into three categories, social stress associated with the group penning of pigs, pig-human interactions and reduction in floor allocation for each animal, climatic stress and stress associated with microbial load. In most commercial environments several stressors are acting simultaneously. Research with both poultry (McFarlane *et al.*, 1989) and pigs (Hyun *et al.*, 1998) suggests that the effects of multiple stressors on performance are additive. For example, Hyun *et al.* (1998) subjected pigs to a high temperature thermal stress, a high stocking rate stress and a group mixing stress and found that growth rate was decreased by 10%, 16% and 11%, respectively, compared with unstressed pigs. When all three stressors were imposed simultaneously the growth rate of the pigs was depressed by 31%. Similarly, McFarlane *et al.* (1989) observed a linear decrease in growth rate of broiler chickens to less than 40% of the growth of control birds following the sequential addition of six stressors, which included a microbial infection. These observations of McFarlane *et al.* (1989) and Hyun *et al.* (1998) suggest that the removal of one stressor should have a positive effect on performance. However, there are other experiments, which indicate that the effect of several simultaneous stressors may not be additive and that some stressors may be of greater significance than others. For example, in the experiment of Lee *et al.* (1997) described above, the imposition of group penning did not depress further the performance of weaner pigs subjected to a dirty environment.

Physiological responses to stress

Environmental factors perceived by an animal to be a threat, stimulate physical, mental and behavioural responses which are mediated through the neural, endocrine and immune systems. Although the earlier belief was that responses to physical and psychological stress were mediated through the hypothalamic-pituitary-adrenal and adrenomedullary-sympathetic nervous systems and responses to microbial challenge were coordinated by cytokines of the immune system, it is now clear that all systems are stimulated and act synergistically irrespective of the stressor (Besedovsky and de Ray, 1996; Johnson, 1997). The complexity of the interactions among the systems is illustrated in Figure 5 on page 21.

Physical and psychological stressors stimulate neurotransmitters that act on the limbic and paraventricular structures of the brain to stimulate corticotropin releasing hormone (CRH) and ACTH which leads to the production of cortisol from the adrenal cortex. Following the initial exposure to stress, cortisol is known to inhibit the proliferation, migration and cytotoxicity of lymphocytes, leucocytes, natural killer cells and other immune regulating cells and to be generally immunosuppressive (Jain *et al.*, 1991; Elenkov and Chrousos, 1999). In addition, cortisol suppresses the release from immune cells of the pro-inflammatory cytokines interleukin-1 (IL-1), IL-6, IL-8, IL-12, tumour necrosis factor-α (TNF-α) and interferon (Petrovsky *et al.*, 1998). However, there is now strong evidence that glucocorticoid resistance occurs in tissues following prolonged social stress despite continuing elevation of cortisol (Avistsur *et al.*, 2001). Prolonged social stress reduces the expression of glucocorticoid receptors and depresses the normal negative feedback on cortisol production. This action further stimulates cortisol release and the production of pro-inflammatory cytokines particularly from the spleen, liver, lung and brain with increased susceptibility to endotoxic shock (Quan *et al.*, 2001).

There appear to be important differences between individual pigs in endocrine physiology and response to stress. Zhang *et al.* (1990) observed that pigs with a high cortisol response to ACTH administration had heavier adrenal glands and more adrenocortical cells than low responders. Differences were observed also in the kinetic properties of ACTH receptor proteins with the high responders having a greater B_{max} than the low responder (Zhang *et al.*, 1993). Nevertheless, the adrenocortical cells of the low responders produced less cortisol per cell than the high responders (Zhang *et al.*, 1990).

Figure 5. (see facing page). *A diagramatic representation of the interactions between the endocrine, immune and sympathetic nervous system stimulated by stress in animals. Broken lines represent negative feedback. ACTH, adrenocorticotropin; Ag, antigen; APC, antigen presenting cell; CNS, central nervous system; CRH, corticotrophin releasing hormone; GH, growth hormone; GHRH, growth hormone releasing hormone; IGF-I, insulin like growth factor-I; IL-1, IL-6, IL-8, interleukins; LC/NA, Locus ceruleus/noradrenaline-autonomic (sympathetic) system; LVP, lysine vasopressin; NA, noradrenaline; PVN paraventricular nucleus; Th, T helper cell; TNF-α, Tumour necrosis factor-α; SS, somatostatin.*

Some physical and psychological stressors initially stimulate neurotransmitters that act on the locus-ceruleus region of the brain to cause the release of the catecholamines, adrenalin and nor-adrenalin, from the adrenal medulla. The increase in activity of the sympathetic nervous system and subsequent catecholamine secretion is known to stimulate the release of CRH from immune cells and of pro-inflammatory cytokines such as IL-6 from peripheral tissues including the liver, spleen and pancreas (De Simoni *et al.*, 1990). Catecholamines also stimulate the production of TNF-α, IL-1 and IL-8 from lung mononuclear and epithelial cells via the action of the α2-adrenergic receptors (Linden, 1996; Le Tulzo *et al.*, 1997). There is evidence of an enhancing feedback with IL-1 from the brain increasing the concentration of plasma adrenalin (Rivier *et al.*, 1989) through the activation of adrenergic receptors in peripheral tissues (Finck *et al.*, 1997).

Direct activation of the immune system through increasing microbial load also stimulates the release of pro-inflammatory cytokines from the immune cells and other tissues to increase the production of ACTH and catecholamines (Johnson, 1997). The increased production of cortisol and pro-inflammatory cytokines has a major adverse effect on animal performance. Cortisol induces muscle protein catabolism whereas the pro-inflammatory cytokines accelerate muscle degradation and stimulate the synthesis of acute phase proteins in the liver. Interleukin-1 also inhibits the anabolic effects of insulin on skeletal muscle and reduces the production of growth hormone and insulin-like growth factor (IGF-I). The pro-inflammatory cytokines increase lipolysis and plasma triglyceride concentration. In addition, the pro-inflammatory cytokines, particularly IL-1, cause severe anorexia and have profound effects on the gastrointestinal tract secretions and motility. The pro-inflammatory cytokines cause fever, possibly through the stimulation of prostaglandins, induce hypersomnia and depress social behaviour (Johnson, 1997).

The physiological interactions described above suggest that the reduction in feed intake, increased production of acute phase proteins, decreased production of growth hormone and IGF-I with consequent reduction in skeletal muscle accretion, and increased lipolysis can result in a marked depression in the performance of pigs subjected to the stressors of a commercial environment. These responses are caused by the interactions between the hypothalamic-pituitary-adrenal and adrenomedullary-sympathetic nervous systems and the pro-inflammatory cytokines.

Evidence from the Growth Gap Program of physiological changes associated with stress

Research within the Growth Gap Program provides strong support for the theories proposed above about the physiological changes associated with decreased performance of animals subjected to a range of stressors. In one experiment, pigs were weaned at 3 weeks of age and housed either in individual pens or in groups of 10 in a clean or a dirty environment (Lee *et al.*, 1997; Knowles *et al.*, 1997b; Keys, 2001). Growth rate of the pigs housed in groups was depressed in the clean environment compared with the pigs in individual pens and the performance of pigs in the dirty environment was poorer than for pigs in the clean environment (Table 2). Endocrine, cytokine and immune cell responses in the pigs subjected to the treatments are given in Table 5. All of the blood parameters in Table 5 were measured in blood collected from male weaner pigs at rest at the end of the experiment [live weights for pigs in the clean (27.0 ± 0.93 kg) and the dirty (25.8 ± 3.05 kg) treatments (mean ± SD)].

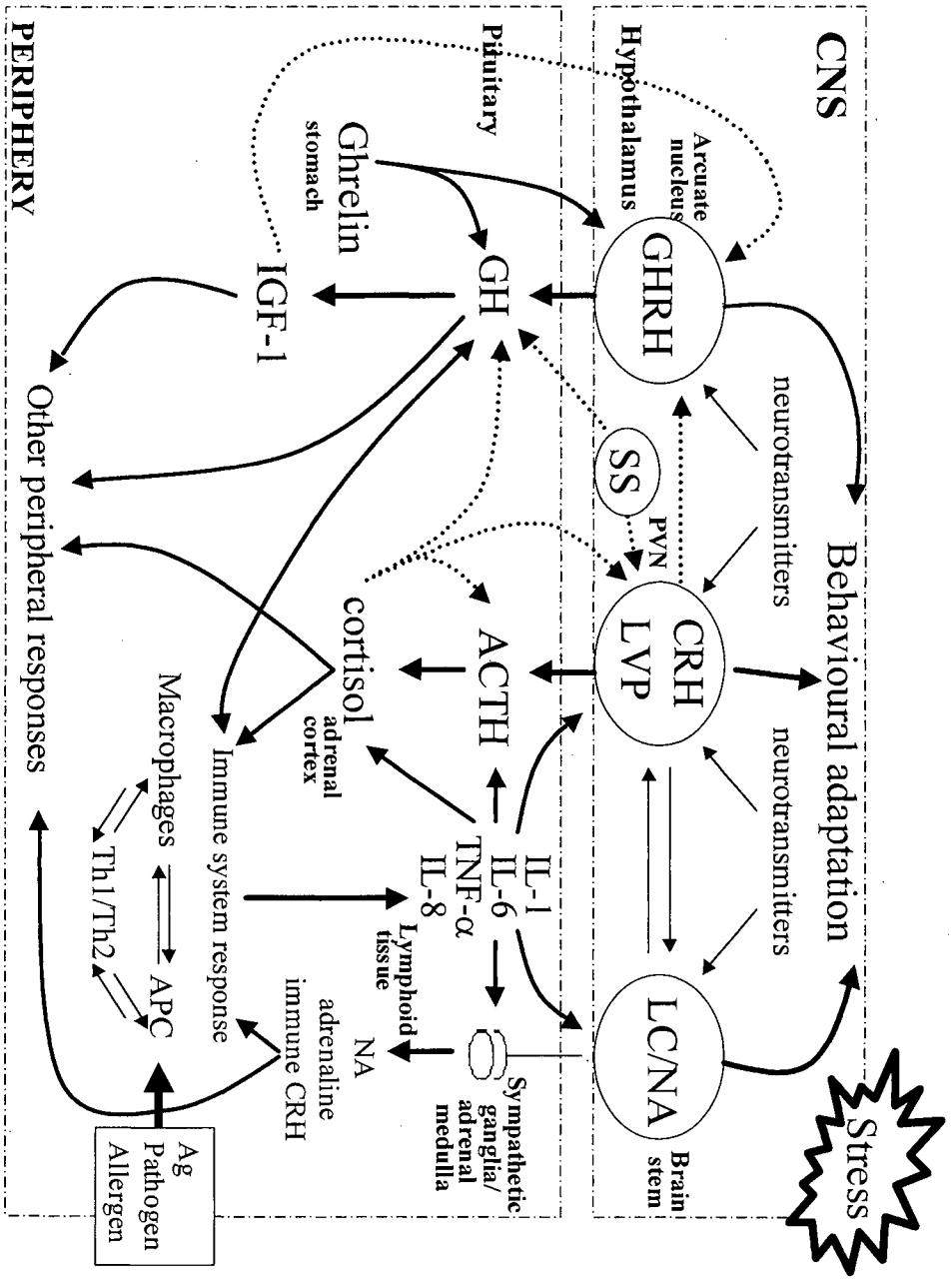

Figure 5. *See legend on facing page 20.*

Plasma cortisol concentrations were significantly higher and IGF-I concentrations significantly lower for pigs held in group-pens compared with those maintained in individual pens irrespective of the cleanliness of the environment. Activation of the sympathetic adrenergic system of the animals as measured by the tyrosine-phosphorylation of the β-adrenergic receptors, which was increased significantly when pigs were maintained in group pens in the clean environment and increased many fold when pigs were housed in the dirty environment. Group penning did not increase further the phosphorylation of the receptors for pigs in the dirty environment. There were also major changes in several immune response characteristics with the number of white blood cells and immunoglobulin (IgG) concentrations being significantly depressed when pigs were maintained in groups, irrespective of the environment. Other immune characteristics including neutrophil function, lymphocyte proliferation and the plasma concentration of the acute phase protein, C-reactive protein, were significantly higher for pigs raised in the dirty environment. Lymphocyte proliferation was also significantly lower and C-reactive protein significantly higher for pigs in group-pens compared with pigs penned alone. A similar trend was found for natural killer cell activity, which was depressed for pigs in group-pens and the dirty environment. The physiological changes presented in Table 5 support the observed depression in growth rate of pigs in a stressful environment with increases in cortisol and acute phase protein and decreases in IGF-I concentrations all contributing to a reduction in skeletal protein deposition. Similarly, many of the immune response characteristics were depressed in the stressed animals.

Table 5. Effects of group size and cleanliness of the environment on endocrine, cytokine and immune responses in weaner pigs[1].

Environment (E)	Clean		Dirty		Significance[2]	
Group size (G)	1	10	1	10	E	G
Growth rate (g/d)	611	573	534	544	*	NS
Plasma cortisol (ng/ml)	43	51	36	59	NS	**
Plasma IGF-I (ng/ml)	126	103	122	110	NS	*
β-AR phosphorylation[3]	100	1789	6234	5276	*	NS
White blood cell ($x10^6$/ml)	26.0	21.9	24.9	20.6	NS	**
Immunoglobulin G (mg/ml)	26.4	20.0	23.7	21.0	NS	**
Neutrophil function (%)	38.1	35.0	39.5	45.6	**	NS
Lymphocyte proliferation[4]	96	157	66	85	**	*
Natural killer cell activity[5]	62	46	43	50	NS	NS
C-reactive protein (ng/ml)	6.3	6.8	6.9	9.4	***	*

[1]From Lee *et al.*, (1997), Lee, C. (Unpublished), Knowles *et al.* (1997b) and Keys (2001). [2]NS, not significant; *P≤0.05, **P<0.01, ***P<0.001. [3]Tyrosine phosphorylation of the β-adrenergic receptor of lymphocytes (relative density). [4]Lymphocyte proliferation, stimulation index. [5]Natural killer cell activity, (%).

The effect of increasing environmental temperature on several physiological characteristics has been measured in two experiments. In the first experiment, pigs weighing approximately 60 kg LW were housed at 22°C in an environment where they were unable to wet their skin and then subjected to a temperature of 30°C for 24 hours

(Knowles *et al.*, 1997a; Keys, 2001). Feed intake of the heat stressed pigs was depressed by 40%, the tyrosine-phosphorylation of the β-adrenergic receptors increased 16 fold, immune function characteristics were significantly reduced and the synthesis of the pro-inflammatory cytokines, IL-6 and IL-8 increased substantially as determined from a semi-quantitative measurement of their mRNA concentrations (Table 6). These results confirm the interaction between the endocrine and cytokine systems and provide a reason why environmental stress increases an animal's susceptibility to disease by lowering immune competence.

Table 6. Effect of heat stress on feed intake, endocrine, cytokine and immune responses in pigs[1].

Temperature	22°C	30°C	Significance[2]
Feed intake (kg/d)	2.9	1.8	***
β-AR phosphorylation[3]	150	2400	***
Lymphocyte proliferation[4]	390	141	*
Phagocytosing neutrophils (%)	26.8	15.9	***
IL-6 mRNA levels[5]	-	++++	
IL-8 mRNA levels[5]	-/+	+++	

[1]From Knowles *et al.* (1997a) and Keys (2001). [2]NS, not significant; *P≤0.05, ***P<0.001. [3]Tyrosine phosphorylation of the β-adrenergic receptor of lymphocytes (relative density). [4]Lymphocyte proliferation, stimulation index. [5]Relative values from semi-quantitative reverse transcriptase polymerase chain reaction analyses.

Table 7. Mean (± SE) changes in plasma insulin-like growth factor I (IGF-I) concentration (ng/ml) for 96 male pigs grown from 75 to 90 kg live weight in four rooms[1].

Treatments[2]	Day				
	42[3]	42 to 49[4]	Significance[6]	49 to 57[5]	Significance[7]
Individual, 22°C	329±13.6	19±9.1	*	-13±13.8	NS
Individual, 30°C	369±14.0	-27±7.7	**	16±15.8	NS
Group, 22°C	339±13.8	-68±10.8	***	60±14.1	***
Group, 30°C	384±13.6	-140±10.3	***	105±9.5	***

[1]From the experiment of Kerr, C.A, Nicholls, P.J., Giles, L.R., Mathews, K.O., Wynn, P.C. and Jones, M.R. (unpublished). All pigs were housed in individual pens in four separate rooms held at 22°C for one week prior to day 42. Pigs were then maintained for one week in one of the following: in individual pens at 22°C, or in individual pens at 30°C, or in groups of six pigs per pen at 22°C, or in groups of six pigs per pen at 30°C. All pigs were then returned to individual pens at 22°C during days 49 to 57. Blood samples were collected by venipuncture from all pigs at day 42, 49 and 57 to measure plasma IGF-I concentration by radio-immuno assay.
[2]Treatments in each room from day 42 to 49.
[3]Mean values at day 42 for pigs in individual pens. [4]Mean changes during day 42 to 49. [5]Mean changes during day 49 to 57 for pigs in individual pens. Significant level of student t-test for mean changes during [6]day 42 to 49 and during [7]day 49 to 57, NS Not significant, *P≤0.05, **P<0.01, ***P<0.001.

In the second experiment conducted by C.A. Kerr, P.J. Nicholls, L.R. Giles, K.O. Mathews, P.C. Wynn and M.R. Jones (unpublished), male pigs were grown from 75 to 90 kg live weight and housed at 22°C in four separate rooms. The housing arrangement of the pigs in this experiment is described in the footnote[1] in Table 7. The results presented

in Table 7 show that there was a significant depression in IGF-I due to heat (27 ng/ml, $P<0.01$) and group housing (68 ng/ml, $P<0.001$). The effect of group housing plus heat appeared to have a highly significant additive effect on the depression in plasma IGF-I (140 ng/ml, $P<0.001$). Such a substantial reduction in IGF-I concentration would be expected to severely reduce the synthesis of skeletal protein and growth rate. When pigs were returned to individual pens, IGF-I showed a significant increase ($P<0.001$) in pigs housed previously in groups indicating that the IGF-I response was reversible.

The activation-state of lymphocyte genes from pigs subjected to a wide range of stressors has been investigated also within the Growth Gap Program (M.R. Jones, C.A. Kerr and K.O. Mathews, unpublished). Approximately 100 potential genes have been identified as indicators of stress from experiments involving lymphocyte L45 cell culture systems, L45 cell incorporation into nude mice and various stress treatments to pigs. In order to confirm that the activation state of these candidate genes is altered by stress, an experiment was conducted where pigs with an extremely high health status were subjected to different stressors, both individually and concurrently.

The treatments included intratracheal inoculation with *Actinobacillus pleuropneumoniae*, serovar 1 isolate HS54, (App) and exposure to high ambient temperatures (Kerr *et al.*, 1999). All App challenged pigs showed clinical signs of pneumonia within one day, but no clinical signs of disease were evident by day four. Feed intake of the App challenged pigs fell to almost zero two days following challenge and returned to near pre-challenge amounts by day seven. Plasma cortisol concentrations increased by 60% the day following challenge and then returned to values below the control animals. There were also substantial differences in the activation-state of lymphocyte genes between the treatments. Figure 6 shows the raw gene expression results throughout the course of the experiment for one gene in four animals for each of the four treatments (sham operated control, App on day one, heat on day six, App on day one and heat on day six). The gels show that there was no activation of the gene in the unstressed, sham operated pigs (Figure 6a). However, the gene was activated on the gel displayed for two of the four pigs on the day following inoculation with App (Figure 6b). The genes in these two animals remained activated for 2-3 days. The application of 30°C heat for 24 hours on day 6 resulted in a clear activation of the gene on day 6 for three of the four pigs displayed (Figure 6c), whereas inoculation with App on day 1 and application of heat on day 6 resulted in a sustained activation of the gene for one pig and a bimodal activation for the other pigs (Figure 6d).

The aim of the research is to identify genes in which the activation state is either increased or decreased by stressors associated with commercial pig production. Once the most appropriate genes have been identified, a rapid method for measuring their activation state in blood lymphocytes could be used to either quantify the stress status of any group of pigs in any environment or select pigs that are less susceptible to the stress of a commercial environment.

Potential strategies for improving the performance of pigs in commercial conditions

The evidence that the effects of multiple stressors on pig performance are additive suggests that the removal of any factor that causes stress should be beneficial for productivity. In theory, several different types of strategies could be used to ameliorate the effect of stressors on pigs in commercial environments. The stressor could be removed, the perception by the pig that the factor is a stressor could be reduced or the physiological response of the pig to the perceived stress could be modified. Each of these potential strategies for improving the performance of pigs reared under commercial conditions is discussed in relation to the three main categories of stress, climatic stress, microbial stress and social stress.

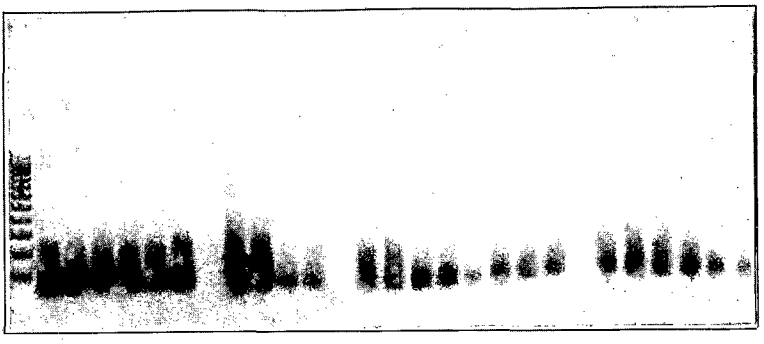

Figure 6a.
The pigs were sham operated on day 1 immediately after the blood sample was taken.

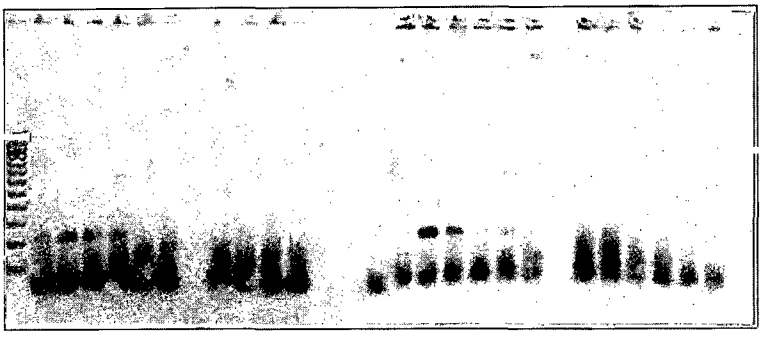

Figure 6b.
The pigs were inoculated with Actinobacillus pleuropneumoniae, serovar 1 isolate HS54 (APP) on day 1 immediately after the blood sample was taken.

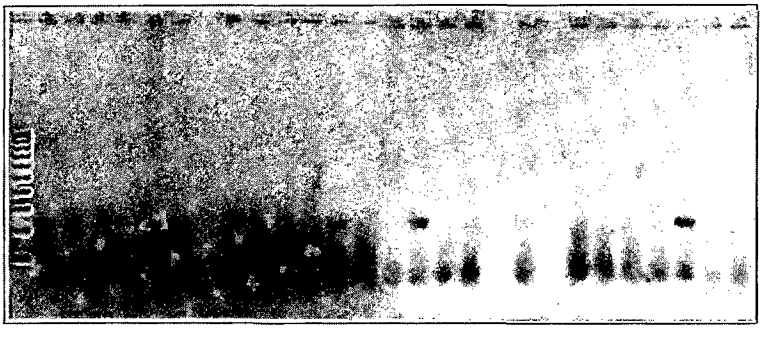

Figure 6c.
The pigs were sham operated on day 1 and subjected to 30°C heat for 24 h on day 6.

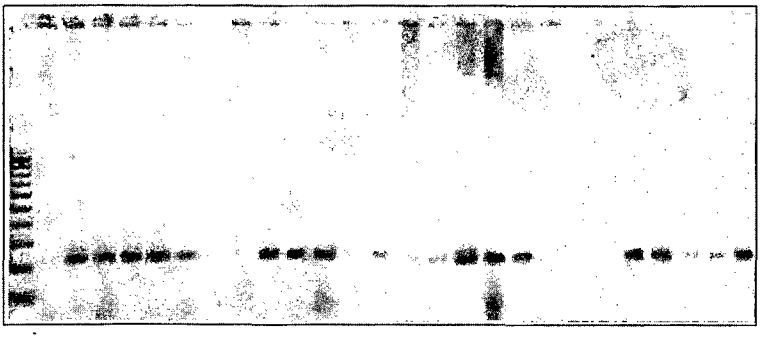

Figure 6d.
The pigs were inoculated with APP on day 1 (as in 6b) immediately after the blood sample was taken and subjected to 30°C heat for 24 h on day 6.

Figure 6. *Gel expression for a specific gene in four animals from each treatment. The lanes are from left to right: lane 1 = standards; lane 2 = day 1; lane 3 = day 2; lane 4 = day 3; lane 5 = day 6, lane 6 = day 7; lane 7 = day 8 for an individual pig. Lanes 9-14, lanes 16-21 and lanes 23-27 represent the same expression profiles of other pigs over the same time course, whereas lanes 8, 15, 22 and 28 are either negative controls or blanks. From M.R. Jones, C.A. Kerr and K.O. Mathews (unpublished).*

Removal of the stressor

The best method for overcoming stress in pigs reared in commercial environments is to remove the stress. Although most stressors can be removed, the action may not be cost effective and cost:benefit analyses may be required to determine which actions are profitable.

Climatic stress

Most pigs reared in Australia suffer from climatic stress (Banhazi *et al.*, 2000). High temperatures are particularly important for reducing feed intake (Giles and Black, 1991), whereas low or fluctuating temperatures, particularly with high humidity, induce changes to the immune system that increase the pig's susceptibility to disease (Hessing and Tielen, 1994; Granier and Massabie, 1996). Structural changes to buildings, which include the addition of spray cooling systems, blinds and other means for reducing draughts, heating for smaller pigs and changes to floor type are important for reducing climatic stress. The effects of various climate, animal and dietary factors on the heat exchange between a pig and its environment and the effects on animal performance are now well understood (Black *et al.*, 1998). The AUSPIG model (Davies *et al.*, 1993) is particularly useful for predicting the economic consequences for a pig production enterprise of changing factors known to reduce the impact of climatic stress.

Microbial stress

Coates *et al.* (1963) showed that chickens raised in germ-free environments grew substantially faster than birds reared in conventional environments. The more recent research with pigs described by Skirrow (1993), Lee *et al.* (1997), Cargill and Banhazi (1998) and Murphy *et al.* (2000) demonstrate clearly the importance of microbial load for reducing performance and the benefits from cleaning buildings and reducing the number of viable bacteria in the air. Building hygiene has been shown to be one of the most important factors associated with post-weaning enteric diseases in pigs (Madec and Leon, 1999). Effective strategies for reducing microbial load in commercial piggeries include all in/all out production systems, particularly when buildings are cleaned thoroughly between batches of pigs, increasing the floor area and air volume per pig, and limiting the number of pigs in a common air-space (Skirrow, 1993). However, there are reports of some experiments where cleaning pig sheds and filtering air have not improved pig performance (van't Klooster *et al.*, 1993).

Antibiotics provided either in the feed or water have proved to be extremely effective for reducing the microbial load of pigs and improving performance (Cromwell, 1991). However, antibiotics are not effective when used in germ-free or clean environments (Hill *et al.*, 1952; Roura *et al.*, 1992). A recent experiment conducted within the Growth Gap Program showed that growth rate for the first six weeks after weaning of pigs reared under commercial conditions was significantly higher ($P \leq 0.05$) for pigs receiving antibiotics, at 479 g/d compared to 425 g/d for pigs without antibiotics (A.D. Strom, A.G. Knowles and D.T. Harrison, unpublished). Dietary methods, such as feeding grains low in cell wall constituents, have also been employed for increasing digestion of nutrients in the small intestine of pigs and reducing the proliferation of microorganisms in the hind-gut. These strategies have been shown to reduce the incidence of enteric diseases such as colibacillosis and swine dysentery in pigs (Hampson *et al.*, 1999).

Social stress

The aim of modifying the environment in relation to social stress is to reduce adverse interactions between animals. The provision of adequate floor area of at least 0.034 $m^2/LW^{0.67}$ (Baxter, 1989) and feeder space of 1.1 times shoulder width (Baxter, 1991) appear to reduce aggression among animals. However, the performance of pigs housed under these conditions is still depressed compared with pigs reared in individual pens. Dominant animals appear to control access to feeders and reduce the intake of all pigs in

the pen. Nehring (1981) showed that the provision of partitions within a pen which were placed strategically in relation to feeders increased the efficiency of feed use, reduced aggression among animals and improved the cleanliness of pens. Similarly, Blackshaw (1981a) showed that weaner pigs, housed in a pen with a 1.2 m x 0.92 m box containing a small entrance, grew significantly faster than pigs in a pen without such a structure. The partitions were thought to create an opportunity for the more submissive pigs to avoid the dominant animals and obtain freer access to the feeders. However, a recent experiment by L.R. Giles, G.R. Furley, D.P. Collins and P.J. Nicholls (unpublished) showed that the intake and performance of pigs housed in groups with pen partitions or 'hides' did not differ from that of pigs in pens without partitions and was still well below the values recorded for pigs in individual pens.

Attempts have been made to modify feeder design and access to feeders to reduce aggression among pigs. Baxter (1991) found that a feeder with an opening that fitted closely to the profile of the shoulders of a pig reduced aggression among animals during feeding, reduced feed waste and tended to increase feed intake and growth rate compared with conventional feeders. Petherick *et al.* (1987) examined the effect of installing dividers that were the full length of the pigs perpendicular to the feed trough and found that aggression among non-lactating sows was reduced. However, measurements of feed intake and growth were not made. Giles *et al.* (2001a) compared a similar system of feed trough dividers with normal feeders for groups of six growing pigs per pen, but observed no positive effect on either feed intake or growth rate.

Human induced stress

Performance is depressed, at least initially, when pigs are exposed to either unpleasant or inconsistent treatment from humans (Gonyou *et al.*, 1986; Hemsworth *et al.*, 1987). Plasma cortisol concentrations are increased in pigs subjected to unpleasant treatment from humans (Hemsworth *et al.*, 1987). The research into the effect of human contact with pigs suggests that either minimal contact between humans and pigs or positive treatment of pigs will result in improved performance (Gonyou *et al.*, 1986; Hemsworth *et al.*, 1987; Hemsworth and Barnett, 1991).

Manipulation of the perception of stress

Several approaches have been used in an attempt to manipulate a pig's perception of stress. These experiments have been applied to relieve social stress and no examples could be found where attempts have been made to modify a pig's perception to either climatic or microbial stress. The most common approaches examined for manipulating a pig's perception of social stress include the use of distractions such as chains or toys, tranquilisers and methods to increase feeding opportunities for pigs at all levels of the social hierarchy. It may be possible also to select pigs with either a high or low perception of stress such as the pigs with the high and low vocalisation score observed by Giles and Kilgour (1999).

Novel objects

Anecdotal reports suggest that growth rate of pigs is improved when they are given access to novel objects such as bowling balls (Ashfield, 1984). However, Blackshaw *et al.* (1997) found there was no difference in performance of pigs given access to novel objects, hanging or free, compared to control pigs without such objects, despite the control group having a higher measure of aggressive behaviour.

Tranquilisers

Various tranquilisers have been used in an attempt to reduce the aggressive behaviour of pigs following the formation of groups and to increase their feed intake and growth rate. Although some experiments have shown a reduction in agonistic behaviour of tranquilised pigs following mixing (Andersson *et al.*, 1987; Bjork *et al.*, 1988, Gonyou *et*

al., 1988, Pluske and Williams, 1996), generally there has been no effect on either feed intake or performance (Blackshaw, 1981b; Andersson *et al.*, 1987; Gonyou, *et al.*, 1988; Pluske and Williams, 1996).

Hours and intensity of light

Pigs in single pens are known to the have more visits to feeders and spend a longer time eating each day than pigs in groups (de Haer and de Vries 1993; Nielsen *et al.*, 1996a). Consequently, several strategies have been investigated to encourage pigs to increase the frequency of feeding. Pigs prefer a bimodal, diurnal feeding pattern with feeding bouts occurring predominantly in the dawn and dusk periods. However, Nielsen *et al.* (1996b) observed that some pigs within groups that were forced to eat at night had reduced feed intakes. Consequently, Giles *et al.* (2001b) examined the effect on feed intake and performance of increasing the hours of light from 8 to 16 each day for pigs in groups of six per pen and for pigs in individual pens. The hours of light had no effect on either feed intake or growth rate of group or individual penned pigs and the performance of the individual pigs remained superior to the group housed animals.

Stimulation of feeding frequency

There is evidence that pigs offered liquid diets consume more dry matter and grow faster than pigs given the same diet in dry form (Hurst *et al.*, 2001). One anecdotal reason suggested for this observation from commercial piggeries is that the frequent, intermittent delivery of the liquid feed which is preceded by a loud noise increases the number of feeding bouts each day. There appear to be no reports of experiments examining this hypothesis by comparing the intake and performance of pigs housed in group pens with different frequencies of feed delivery with that of pigs in individual pens.

Breeding of pigs with passive temperament

Giles and Furley (1999) have demonstrated that individual pigs have different temperaments and respond differently to potentially stressful situations. Hessing *et al.* (1994) showed that pigs classified as having an active temperament reacted with an increase in heart rate when exposed to a novel object and had a higher plasma cortisol concentration than pigs with a passive temperament. Hessing *et al.* (1994) found also that the classification of pig temperament between 3 and 8 weeks of age remained remarkably consistent suggesting that pig temperament is under genetic control. Giles and Kilgour (1999) have shown also that the pigs with a passive temperament eat more and grow faster than pigs with an active temperament. Although the heritability of temperament has not been determined, it is highly probable that pigs with a passive temperament having a reduced perception of stress can be selected within breeding programs.

Manipulation of the response to stress

The marked advance over recent years in understanding the mechanisms controlling the response of animals to stress provides an opportunity to manipulate the physiology of animals and modify the adverse responses associated with exposure to environmental stressors. Although few commercial products are yet available, considerable research is currently being directed towards manipulating the endocrine and immune response systems of animals to improve their health status and performance when raised under commercial conditions. Advances in gene technology and gene therapy have significantly increased the ability to manipulate physiological factors controlling an animal's response to stress. Potential targets for manipulation include amelioration of the negative effects of increased cortisol, decreased growth hormone and IGF-I and elevated synthesis of the pro-inflammatory cytokines. It is probable that successful manipulation of the stress response systems will be beneficial under most stress inducing situations because of the similarity in the physiological response to many stressors. A number of promising research projects are currently subject to confidentiality

agreements and cannot be discussed. However, several methods for manipulating the response to stress have either been commercialised or the results published.

Modification of pig behaviour

Entire male pigs showing overt socio-sexual, aggressive behaviour grow more slowly than castrated male pigs when housed in groups, but not when held in individual pens (McCauley *et al.*, 2000). The aggressive sexual behavour of male pigs can be depressed substantially following vaccination with gonadotrophin releasing hormone, which has been shown to halve the weight of testes and reduce the serum concentrations of testosterone to around 2 nM (Dunshea *et al.*, 2000). The vaccine is now commercially available as a product named Improvac®. McCauley *et al.* (2000) found that the growth rate of Improvac® treated male pigs from 18 to 22 weeks of age was 1079 g/d compared with 908 g/d for entire male pigs and 944 g/d (sed=35 g/d) for surgically castrated animals. Feed intake was significantly higher for the Improvac® treated pigs ($P \leq 0.05$), but there were no significant differences in the efficiency of feed utilisation between the immunocastrated and entire male pigs. Back-fat thickness (P2) at slaughter was higher for the immunocastrates at 15.3 mm compared with 13.5 mm (sed=0.63) for entire male pigs. The decrease in testosterone production following vaccination also reduced significantly the concentration of androstenone and skatol in subcutaneous fat and is likely to reduce the incidence of boar taint (Dunshea *et al.*, 2000).

Immunisation against disease

Immunisation against disease is a classical method of altering an animal's response to disease challenge. Vaccines comprising live or attenuated disease-causing organisms, or some antigenic fraction of the organism, enhance the immune response by stimulating the production of antibodies specific to the organism. Enzootic pneumonia caused by *Mycoplasma hyopneumoniae* (Mhp) is one of the most important diseases associated with economic loss in the pig industry. Occurrence of the disease causes a depression of feed intake and growth rate and predisposes pigs to secondary bacterial infections. Recently, effective vaccines for Mhp have been developed. Trials using these vaccines show some variability in efficacy, but in most instances, there has been a considerable reduction in clinical symptoms, and an increase in feed intake and growth rate (Charlier *et al.*, 1994; Driesen *et al.*, 1998; Wallgren *et al.*, 2000).

Breeding of pigs with enhanced immune response

There is strong evidence that pigs and other animals can be selected for increased activity of the immune system. Wilkie *et al.* (1998) describe an experiment in which pigs were selected over eight generations for either high or low immune response. Selection of animals for immune response was based on estimated breeding values for serum IgG antibody response to immunisation with eggwhite lysozyme, cutaneous delayed-type hypersensitivity after immunisation with Bacillus Calmette Guerin and blood lymphocyte blastogenesis to the mitogen con-A. The experiment showed that pigs with the high immune response grew faster and had larger litters than the pigs with the low immune response. There was also evidence for increased protection against an outbreak of parvovirus in animals with the high immune response. Infection with *Mycoplasma hyorhinis* resulted in earlier antibody production and higher titres in the animals with high immune response than those with low immune response. However, pigs with the high immune response showed greater signs of arthritis than those with the low immune response and appeared to produce more pro-inflammatory cytokines in the synovial membranes. This result shows that the immune response of animals is highly heritable, but selection for a greater immune response may not be beneficial in all circumstances.

Breeding of pigs with low adrenal responsiveness

Experiments conducted in the 1970's showed that turkeys could be bred for a low corticosterone response to cold stress and that these birds had superior growth and reproductive performance than either unselected controls or birds selected for high corticosterone response (Brown and Nestor, 1973). Large differences among pigs in plasma cortisol concentration in the response to ACTH administration have been observed (Hennessy *et al.*, 1986), and the differences among animals are consistent over time (Hennessy *et al.*, 1988). Hennessy and Jackson (1987) showed that pigs with a low cortisol responsiveness to ACTH administration grew faster and had a greater efficiency of feed use than pigs with a high responsiveness. These observations suggest that there is an opportunity to select pigs on the basis of cortisol responsiveness to ACTH for reducing the impact of stressors and improving the performance of pigs raised under commercial environments.

Manipulation of cortisol release

Many of the adverse physiological effects of stress are mediated through cortisol, which is released from the adrenal cortex through the action of ACTH. Previous research with sheep has shown that immunisation against ACTH results in the generation of antibodies that inhibit ACTH activity and reduce the concentrations of plasma cortisol (Wynn *et al.*, 1994). Lee *et al.* (1999) used a similar approach for pigs. Ovalbumin was conjugated to ACTH and pigs were given a primary vaccination with two booster vaccinations 4 and 8 weeks later. The pigs were of high health status and reared in a clean experimental environment in groups of either one or six pigs/pen. Vaccination with ACTH did not affect the basal secretion of cortisol, but significantly reduced plasma cortisol concentration 10 minutes after the animals were subjected to the stress of being constrained with a nose snare for 1 minute (Table 8). Plasma concentrations of β-endorphin were significantly higher in the vaccinated pigs. Although pigs raised in group pens grew 10% more slowly than pigs in single pens, vaccination against ACTH did not improve growth rate of pigs in group pens. These results show that cortisol secretion can be depressed by vaccination against ACTH and the effects on pig performance require examination under a more stressful commercial environment.

Table 8. Effect of immunisation against ACTH on plasma cortisol and β-endorphin secretion in pigs[1].

Group size (G)	One pig/pen		Six pigs/pen		Significance[2]	
Vaccination (V)	Control	ACTH	Control	ACTH	G	V
Growth rate (g/d)	1166	1218	1025	1091	**	NS
Plasma cortisol (ng/ml) 0 min[3]	8	11	11	10	NS	NS
Plasma cortisol (ng/ml) 10 min[3]	20	12	21	12	NS	**
Plasma β-endorphin (pg/ml)	20	57	25	113	NS	**

[1]From Lee *et al.* (1999), live weight of pigs at the end of the experiment when blood samples were taken was 88.0 ± 7.3 kg (mean ± SD). [2]NS, not significant; ** P<0.01 using a log transformation for cortisol and β-endorphin. [3]Restraint for 1 minute and bled at 0 and 10 minutes.

Manipulation of response to catecholamines

Catecholamines liberated during stress from the adrenal medulla act by binding to receptors in a range of tissues, stimulating the automonic nervous system, increasing heart rate, depressing the immune cell responses and increasing the release of pro-inflammatory cytokines. In theory, it should be possible to block the binding of the adrenergic hormones to their receptors and change the adrenergic stimulated physiological response to stress. Keys *et al.* (1995) have determined the amino acid sequence of the β_2-adrenergic receptor in pig lymphocytes. The receptor has between 90%

and 93% homology with other species, including human, rat and dog. However, the sequence of the extracellular binding site was found to be distinctly different in the pig from other species and to have an unusual configuration due to a serine substitute in position 132 interacting with threonine at position 129. A peptide constituting the 13 amino acids of the active site was synthesised and conjugated to a carrier molecule. Antibodies to the conjugate were generated in rats and found to attenuate the cell signalling activity of a lymphocyte cell culture system. Pigs were then vaccinated with the antigen on three occasions with no apparent adverse effects on health. However, 66% of the treated pigs had significantly smaller hearts and excessive amounts of pericardial and peritoneal fluid. These results suggest that chronic exposure to β_2-adrenergic receptor antibodies may be detrimental to the circulatory system of the pig and may not be an acceptable method for manipulating the activity of catecholamines released during chronic stress.

Manipulation of response to cytokines

It may be possible to block the adverse effects of pro-inflammatory cytokines. The receptors for IL-1 and TNF-α have been identified in various regions of the brain of rats (Johnson, 1997) and several physiological responses have been altered by the administration into regions of the brain of an agonist to the IL-1 receptor. McHugh *et al.* (1994) showed that the depression in feed intake following acute colitis was prevented by the chronic intracerebroventricular infusion of the IL-1 receptor agonist. Similarly, Peisen *et al.* (1995) blocked the suppression of plasma growth hormone concentration following an intraperitoneal injection of bacterial lipopolysaccharide with prior infusion of the IL-1 receptor agonist into the third ventricle of rats. Other ways of manipulating the physiological response of pigs to the cytokines released during stress have been investigated in the Growth Gap Program with promising results.

Conclusions

Evidence that the effects of multiple stressors found in commercial piggeries are generally additive, suggests that the removal of any factor that causes stress should increase productivity. Some stressors are relatively easy to remove. Significant improvements in pig performance should result from removing climatic stress by the controlling temperature, air movement and ability of a pig to wet its skin. Similarly, improvements in the cleanliness of buildings and in air quality, particularly in microbial load, and ensuring adequate area and air volume per pig should result in a substantial reduction in stress for pigs. Minimal contact between piggery workers and pigs appears to result in fastest growth rates and best efficiency of feed utilisation. However, any contact between the pig and people should be positive, rather than negative for the animal.

There appears likely to be limited success in reducing adverse social interactions among pigs in group-pens by either increasing group size or altering pen and feeder design. Similarly, strategies such as distraction of pigs with toys, the use of tranquillisers or increasing the hours of light have generally failed to improve pig performance. Further investigations are required to determine whether the use of providing limited amounts of feed frequently 'on-cue' will reduce aggression associated with the feeding activity and stimulate intake and performance. The heritability of temperament also needs to be determined, because the selection of passive, less aggressive pigs may reduce the adverse social consequences of group-penning.

Results from experiments suggest that, in principle, pigs can be selected for enhanced innate immunity and the use of vaccines against specific diseases has been shown to have significant effects on productivity. Selection of pigs for reduced adrenal responsiveness to ACTH administration should result in animals that have lower concentrations of circulating cortisol and improved performance when exposed to the stressors of a commercial pig raising environment. There are several other examples where the response of pigs to stress has been altered by manipulation of the endocrine system. The vaccination of entire male pigs with gonadotrophin releasing hormone

reduces aggressive behaviour and improves performance of group-penned animals. Similarly, vaccination with ACTH reduces the stress-induced release of cortisol and may improve productivity of pigs in a commercial environment. Significant improvements in understanding the mechanisms of the stress response and in gene technology and gene therapy provide an opportunity to manipulate the endocrine and cytokine systems of pigs and improve productivity in commercial environments.

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VARYING LIGHT PATTERN WITH ON/OFF SWITCHING DOES NOT AFFECT PIG GROWTH FROM 40 TO 110 KG LIVE WEIGHT

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Tast *et al.* (2001) speculated that simple on/off lighting regimens could be used to change the influence of season on production. However, Andersson *et al.* (1998) found significantly lower growth for pigs maintained under a natural photoperiod compared with two contrasting artificial (on/off) light/dark patterns, for which growth did not differ. A study was designed to test whether two different light:dark ratios affected growth of pigs maintained in two different group sizes.

Eighty crossbred, male pigs were maintained in a 12 h light pattern (0600-1800 h) and allocated at 36 ± 4.4 kg (mean ± SD) live weight to a 2 x 2 split-plot design involving 2 light:dark ratios and 2 group sizes. Two adjacent air spaces were used, each containing one room kept at 16 h light (0400-2000 h) and a second room at 8 h light (0800-1600 h). Each light treatment was diagonally opposed and pen layout was reversed between air spaces. Each room contained a set of four individual pens and two group pens (8 pigs/pen) with similar mean initial weights. Light changes were abrupt with a simple on/off switch. Floor space (1 m^2/pig), floor type (concrete slats), temperature (22°C), feeder space (1/pen) and drinker number (1/pen) were similar in each room. The pigs were fed *ad libitum* a commercial, pelleted diet. The experiment was conducted for 10 weeks. Pig live weight and feed intake/pen were measured at intervals of 1 week. Repeated measures analyses (Verbyla *et al.*,1999) of weekly pen average live weight gain and feed intake assessed the effects and interaction of light pattern and group size over time, with initial weight as a covariate for individual pigs. There were error variance components for rooms, individual pigs and group pens for both measures, but none for room x group size or room x group size x light pattern.

Table 1. Effect of two light:dark regimes and two group sizes on mean feed intake and live weight gain (kg). There were four rooms with four individual pens and two group pens (8 pigs/pen).

	Week 0	Week 0-3		Week 3-6		Week 6-9	
Treatments	Weight	Intake	Gain	Intake	Gain	Intake	Gain
16:8[1] light:dark	43.4	44.8	20.1	60.4	21.1	70.4	20.5
8:16[2] light:dark	43.1	44.2	21.1	61.6	22.3	71.4	20.6
SED	0.80	1.68	1.07	2.10	1.16	2.62	1.17
Individual pen	43.6	47.4[a]	21.9[a]	65.0[a]	22.8[a]	74.0[a]	21.4
Group pen	43.0	41.6[b]	19.3[b]	57.0[b]	20.7[b]	67.8[b]	19.6
SED	0.62	1.68	0.75	2.10	0.88	2.62	0.88

Lights were on for either [1]16 h (0400-2000 h) or [2]8 h (0800-1600h). [a,b]Means within columns with different superscripts differ significantly ($P \leq 0.05$).

There were no significant effects of light:dark ratio on intake or weight gain, but significant effects of group size ($P \leq 0.05$) (see Table 1). Pigs maintained in individual pens ate more feed and grew faster throughout the study. There was no significant interaction of light:dark ratio and group size on intake or growth. Hence, no evidence was found to support the hypothesis that a difference in light:dark ratio using simple on/off switching would result in changes in intake or growth, for pigs maintained in two group sizes. These results support the findings of Andersson *et al.* (1998) that differences in lighting pattern using on/off switching do not affect pig growth.

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THE INFLUENCE OF HANDLING NEONATAL PIGLETS ON THEIR GROWTH TO WEANING

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Separation of infant animals from their dam for short periods of time (15-20 minutes) has been shown to permanently alter the responsiveness of the hypothalamic-pituitary-adrenal (HPA) axis to stressors (Gallagher *et al.*, 1999), allowing animals to grow more efficiently in commercial piggeries. This may be due to the transient activation of the thyroid axis which in turn stimulates serotonin turnover and glucocorticoid receptor expression in the hippocampus and pre-frontal cortex (Meaney *et al.*, 1996). Thus it was hypothesised that neonatally handled piglets would cope with stress more readily than non-handled animals presumably through sensitization of glucocorticoid negative feedback, and that this effect might be mimicked by injections of thyroid hormone releasing hormone (TRH) in the neonatal period.

Litters (n=40) of parity two Large White x Landrace sows (Bunge Meat Industries Ltd., Corowa, NSW) were allocated to one of four treatments on the basis of fostered litter weight (n=10 per litter). Two groups were subjected to acute handling, involving the twice-daily separation of piglets from the sow for 15 minutes for the first four days post-farrowing. In the first group this was achieved by placement of piglets in a steel feed trolley while in the second group a board was placed in the farrowing crate to keep piglets separate from the sow and away from the heat lamp. A third treatment group received twice daily TRH injections (50 μg/kg in 0.9% saline) for four days postnatally while the remaining group of control piglets was left undisturbed for the same period, with the exception that all piglets were weighed and ear-tagged at birth. Piglets were re-weighed at weaning and 80 animals underwent restraint stress in a supine position, with a single blood sample collected after 15 minutes. Data were analysed by analysis of covariance using birthweight and suckling order as covariates.

No significant difference was detected among treatments for live weight gain, as measured by weaning weight (P=0.94) and average daily gain to weaning (P=0.90). Blood cortisol concentrations following restraint, used as an indicator of stress, did not differ significantly among treatments (P=0.77).

Table 1. Weaning weight, average daily gain to weaning and log_{10}cortisol concentrations at weaning of piglets following neonatal handling or thyroid hormone releasing hormone (TRH) administration (mean ± SEM).

Treatment	Control	Handling: Trolley	Handling: Board	TRH administration
Weaning weight (kg)	6.89 ± 0.25	6.69 ± 0.25	6.70 ± 0.26	6.78 ± 0.26
Average daily gain (g)	224 ± 14	215 ± 13	214 ± 15	218 ± 14
log_{10}cortisol concentration (ng/ml)	1.77 ± 0.04	1.78 ± 0.04	1.83 ± 0.04	1.81 ± 0.04

This trial was conducted in mid-summer, when the mean shed temperature (28.4 ± 0.12°C) was similar to the thermoneutral zone of a newborn piglet (30-32°C). The study of Gallagher *et al.* (1999) was conducted in winter when the ambient temperature in sheds does not reach thermoneutrality. Since higher temperatures limit thyroid activity, a role of the thyroid in the growth response to neonatal handling has not been established. This is supported by the lack of a difference in cortisol response to restraint when handled. Thus the growth response may only be achievable in the winter season.

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EFFECT OF GROUP SIZE ON WEANER PIG PERFORMANCE

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Pig performance is limited by growth stasis following weaning. A study was designed to test for (a) a positive association between group size and weaner pig performance; and (b) a negative association between group size and variation in live weight gain of individual weaner pigs/pen.

The study was repeated in time as 2 runs. Each run consisted of 640 crossbred piglets (both sexes) obtained from 2 breeding units (1 and 2). The piglets were weaned at 24 ± 4 days of age and allocated on the basis of live weight at weaning to 2 blocks, 3 group sizes (20, 40 and 100 pigs/pen) and separate sexes. For both runs, piglets from Unit 2 were proportionally allocated to pens in block 2 only. In run 1, piglets in block 2 were lighter (5.8 ± 1.0 kg, mean ± SD) than in block 1 (8.4 ± 1.0 kg). In run 2 weaning weight was similar for both blocks (7.7 ± 1.4 kg). Both runs occurred in the same room kept at 27°C. There were 4 rows of pens with 2 rows/block. The 3 group sizes were randomised in each row and this pen arrangement was maintained in both runs. In both runs, 1 row in each block was allocated to males and the other to females, with the allocations in run 1 reversed in run 2. Floor type (metal slats), floor space (0.27 m^2/pig), feeder number (1/20 pigs), feeder spaces (5/feeder), nipple drinker number (2/20 pigs), feeder position and drinker position were maintained in each pen. Feed was offered *ad libitum* as a medicated, pelleted diet estimated to contain 15 MJ digestible energy and 12 g available lysine/kg. Run 1 and run 2 continued for 37 and 40 days respectively. At most 3 pigs were removed from any pen with the exception of group size 100 pigs/pen in run 1, where 20 males (block 1, 3; block 2, 17), and 8 females (block 1, 2; block 2, 6) were removed. Pig live weight was recorded at the start and finish of the run. Mean and standard deviation (SD) of live weight gain were calculated for each pen. Feed intake was recorded for each pen. Analyses of variance of all pen values assessed the linear and quadratic effects of final group size for each run x sex combination, using orthogonal polynomial contrasts and adjusting for effects of blocks within runs. There was an error variance component due to block x sex within runs for feed intake but not for live weight gain. Block x group size error variance components were not present.

Table 1. Predicted mean live weight gain and feed intake (kg/pig) from 24 to 64 days of age for weaner pigs maintained in three group sizes with sexes separate and repeated as 2 runs.

Run	Sex[1]	Live weight gain/pig				Feed intake/pig				Significance[2]			
		Original group size			SEM	Original group size			SEM	Gain[3]		Intake	
		20	40	100		20	40	100		L	Q	L	Q
1	M	15.2	16.2	15.7[4]	0.24	21.5	22.0	22.7[5]	0.35[8]	NS	*	NS	NS
	F	16.3	15.3	16.0[6]	0.27	22.6	21.4	22.6[7]	0.36[8]	NS	*	NS	*
2	M	18.7	17.9	17.1	0.27	26.8	26.3	25.6	0.38[8]	**	NS	NS	NS
	F	16.7	18.9	17.4	0.26	27.5	28.8	28.1	0.37[8]	NS	***	NS	*

[1]M, Male and F, Female. [2]NS, Not significant, *P≤0.05, **P<0.01, ***P<0.001. [3]L, Linear and Q, Quadratic contrasts among final group sizes. [4]SEM 0.37 and [5]SEM 0.52 due to removal of 20 pigs. [6]SEM 0.30 and [7]SEM 0.40 due to removal of 8 pigs. [8]SEM for within row comparison only.

There was no clear evidence of a positive association between group size and either live weight gain or feed intake. The only linear contrast that was significant, for live weight gain of males in run 2, was negative (see Table 1). All other significant contrasts were quadratic with no significant linear component. The data did not support a negative association between group size and variation in live weight gain within pens. Mean SD (±SE) in live weight gain between individual pigs was similar for 20 (2.9 ± 0.21 kg), 40 (3.5 ± 0.22 kg) and 100 (3.2 ± 0.25 kg) pigs/pen.

USE OF PIGLETS TO ASSESS MEAT IRON BIOAVAILABILITY

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Meat is a major source of haem iron. Haem iron is absorbed more efficiently than non-haem iron in humans and the present study was conducted to investigate if similar bioavailability patterns are observed in piglets with varying degrees of anaemia.

A total of 24 cross-bred piglets from four litters were included in this study. At birth two piglets from each litter received a normal iron injection (Gleptosil™, 200 mg iron), two a reduced dose (80 mg iron) and two no injection at all. Piglets didn't receive creep feed during the suckling period. They were weaned at 19 days of age, kept in individual metabolism crates in a temperature-controlled environment and randomly allocated within litter and iron status to one of the two experimental semi-synthetic diets. The control diet included 10% casein and 20% skim milk powder and the meat diet included 10% skim milk powder and 46.5% lean beef meat. The control diet contained 0 ppm haem iron and 53 ppm non-haem iron and the meat diet 9.3 ppm haem iron and 34 ppm non-haem iron. Blood samples were taken at 21, 28, 35 and 42 days of age from the vena jugularis and analysed for total serum iron, red blood cell count (RBC), and haemoglobin concentration (Hb). Blood data were statistically analysed by repeated measure analysis.

Piglets that did not receive iron at birth were 17% lighter ($P \leq 0.05$) at 21 days and then ate 18% less feed ($P \leq 0.05$), and grew 17% more slowly ($P \leq 0.05$) than piglets that had a normal or reduced dose of injectable iron. All blood parameters measured were different among piglets from different iron injection groups (e.g., for Hb in Figure 1; $P<0.01$).

No differences in growth performance or total serum iron were observed among piglets fed the control diet or the meat diet, but piglets fed the meat diet had higher RBC and Hb values than piglets fed the control diet. A significant interaction between age and diet for RBC and Hb indicated that the difference between diets increased over time. This increase is shown for Hb concentration in Figure 1.

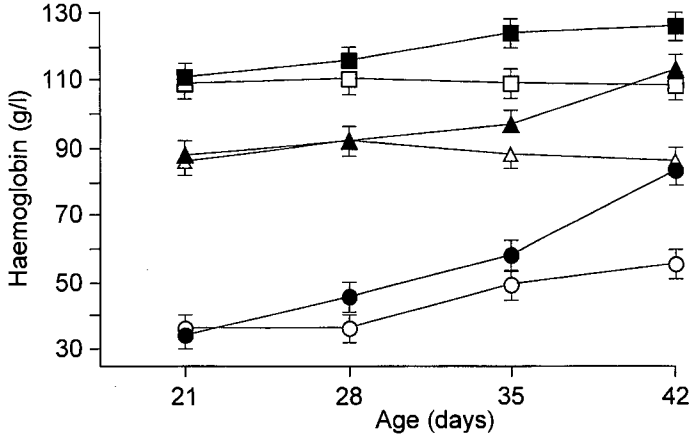

Figure 1. *Haemoglobin concentration (mean ± SE) for piglets injected with 0 mg (○, ●), 80 mg (△, ▲) and 200 mg (□, ■) of iron dextran at birth, fed either the control diet (○, △, □) or the meat diet (●, ▲, ■).*

In conclusion, iron in a meat diet had a greater bioavailability than iron in a milk diet, when fed to pigs. The similarity of this result to that observed in humans suggests that the anaemic piglet is a suitable model to estimate iron bioavailability for humans.

Under contract to Meat New Zealand

CONJUGATED LINOLEIC ACIDS CAN DECREASE BACK FAT IN PIGS HOUSED UNDER COMMERCIAL CONDITIONS

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Dietary conjugated linoleic acids (CLA) have been shown to decrease body fat content of individually-housed gilts (Ostrowska *et al.*, 1999) but little is known about the responses under commercial conditions. Therefore, the aim of these studies was to examine the effect of dietary CLA on growth performance and backfat thickness in boars and gilts housed under commercial conditions.

Two studies with similar experimental designs were conducted to evaluate the effect of CLA (Natural Lipids Ltd., Norway) using commercial genotypes. The studies were 2 x 2 factorial designs with the respective factors being sex (boar and gilt) and supplemental dietary CLA (0 and 4 g/kg). The first study was conducted with 144 pigs in 16 pens consuming a pelleted feed *ad libitum* for 6 weeks at Bunge Meat Industries, Corowa, NSW. In the second study, 160 pigs were obtained from a commercial source and placed in 20 pens in simulated commercial conditions and fed a mash diet *ad libitum* for 7 weeks at Medina Research Station, WA. The CLA preparation contained 104, 177, 143, 84 and 574 g/kg of cis-trans/tran-cis-11,13, cis-trans/trans-cis-10,12, cis-trans/trans-cis-9,11, cis-trans/trans-cis-8,10 isomers and total CLA isomers, respectively.

Table 1. Effect of sex and supplemental dietary conjugated linoleic acids (CLA) (4 g/kg) on performance of finisher pigs in Study 1.

CLA content (C)	CLA (0 g/kg)		CLA (4 g/kg)			Significance		
Sex (S)	Boar	Gilt	Boar	Gilt	SED	S	C	CxS
Rate of gain (g/d)	919	913	969	889	39.7	0.15	0.66	0.22
Feed intake (g/d)	2603	2685	2580	2583	76.5	0.27	0.45	0.48
Feed:gain	2.84	2.95	2.66	2.91	0.08	0.009	0.10	0.25
Carcass P2 (mm)	11.8	13.1	11.0	11.9	0.48	0.006	0.014	0.57
Estimated fat (%[a])	13.8	19.6	13.4	18.6	0.46	<0.001	0.049	0.34

[a]Estimated using a proprietary algorithm based on fat depths and carcass weight.

Data from Study 1 showed that, although CLA had no significant effect upon feed intake and daily gain, the small changes in both resulted in a tendency for a reduction in the feed:gain ratio (-0.10 g/g, P=0.10) (Table 1). Also, dietary CLA supplementation decreased carcass P2 (-1.0 mm, P=0.014) and estimated carcass fat (-7 g/kg, P=0.049). In study 2, CLA had no significant effect upon feed intake, feed:gain or most measures of back fat (data not shown). The exception was that dietary CLA decreased the rate of accumulation of fat at the shoulder, particularly in gilts, resulting in a significantly lower amount of shoulder fat at slaughter (-1.3 mm, P=0.044). Meat from CLA treated pigs tended to have a higher ultimate pH (5.40, vs 5.43, P=0.06). These data suggest that under commercial conditions dietary CLA can improve growth performance and decrease P2 in pigs of commercial genotypes.

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PORCINE SOMATOTROPIN TREATMENT OF NEONATAL PIGS ALTERS LIFETIME FAT BUT NOT LEAN ACCRETION

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Although porcine somatotropin (pST) increases lean tissue growth and decreases fat deposition in grower and finisher pigs (Campbell *et al.*, 1991), the response to pST is often much less in younger pigs. For example, pST administration at the doses used in finisher pigs (0.06 mg/kg live weight, LW) failed to increase plasma insulin like growth factor-I (IGF-I) or growth in sucking pigs (Dunshea *et al.*, 1999). In contrast, Wester *et al.* (1998) found that a relatively high dose of exogenous pST (1 mg/kg LW) increased plasma IGF-I and growth over the first 7 days of life in artificially-reared pigs. The aim of this study was to determine whether pST administration, at relatively high doses, to the sucking pig could alter current and subsequent growth and body composition.

Twelve mixed-parity Large White x Landrace sows with an average litter size of 10 piglets were used to nurse pigs for this study. On day 1 of lactation the median two male pigs from each litter were randomly allocated to one of two doses of pST (0 or 1 mg/kg LW per d) administered sub-cutaneously until weaning on day 21. Pigs were weaned and offered feed *ad libitum* until slaughter at 134 days of age. Body composition was measured using dual energy X-ray absorptiometry at 21, 49, 77, 105 and 133 days of age (Suster *et al.* 2000). Data were analysed by ANOVA with pST as the main effect and sow as a blocking factor.

Table 1. Effect of daily pST injection from day 1 until day 21 of age on current and subsequent rates of tissue deposition in male pigs.

	Age (days)	Saline	pST	SED	P-value
Lean deposition (g/d)	1-21	211	210	17.1	0.97
	21-133	611	598	17.9	0.48
	1-133	550	538	17.0	0.49
Fat deposition (g/d)	1-21	53	42	5.1	0.059
	21-133	144	125	7.8	0.045
	1-133	130	112	6.9	0.033

There was no significant effect of pST on growth rate between days 1 and 21 of lactation (258 vs 246 g/d for control and pST treated pigs, respectively, P=0.61). As a consequence there was no significant difference in live weight at weaning (7.13 vs 6.84 kg, P=0.59). However, fat deposition tended to be decreased prior to weaning (Table 1) and hence the percentage of fat in the body at weaning was significantly lower (16.7 vs 13.9%, P=0.008) in pigs treated with pST. Over the entire weaning to slaughter period, pST treatment of neonatal pigs decreased the rate of fat deposition, but had no effect on lean tissue deposition. Therefore, treatment of nursing pigs with high doses of pST for a short period before weaning may provide a means of reducing the fat content of pork.

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BOARS DEPOSIT MORE LEAN AND LESS FAT THAN BARROWS UNDER TWO HOUSING CONDITIONS

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While consumer preference is for pork from either gilts or barrows rather than boars, most Australian producers are reluctant to alter current practices and produce barrows as they grow less efficiently and deposit more backfat than boars (Campbell and Taverner, 1988). Very few studies have been conducted to describe the relationships between protein, bone and fat deposition, especially in current improved genotypes. The aim of the present study was to determine the relationships between the rates of tissue deposition and live weight, in boars and barrows under two housing conditions.

The experiment utilised 36 Large White × Landrace boars from eight mixed parity crossbred sows. A 2 × 2 factorial design was used with the respective treatments being sex (boar or barrow) and housing condition (individually housed (IH) or group housed (GH)). Surgical castration was performed at 7 days of age. Individually housed pigs were used to provide an estimate of potential growth and were weaned at 10 d into individual cages and provided with supplemental fermented skim milk for two weeks. Group housed pigs were weaned at 24 days of age and reared in group pens of boars and castrates (9 pigs per pen) typical for commercial production. Conventional weaner, grower and finisher diets were provided *ad libitum* to all pigs from weaning onwards. A Hologic QDR4500 dual energy X-ray absorptiometer was used to determine lean, fat and bone composition at four weekly intervals from 10 until 150 days of age (Suster *et al.* 2000). Statistical analysis was performed using ANOVA and nonlinear regression analysis (Genstat 5, 2000).

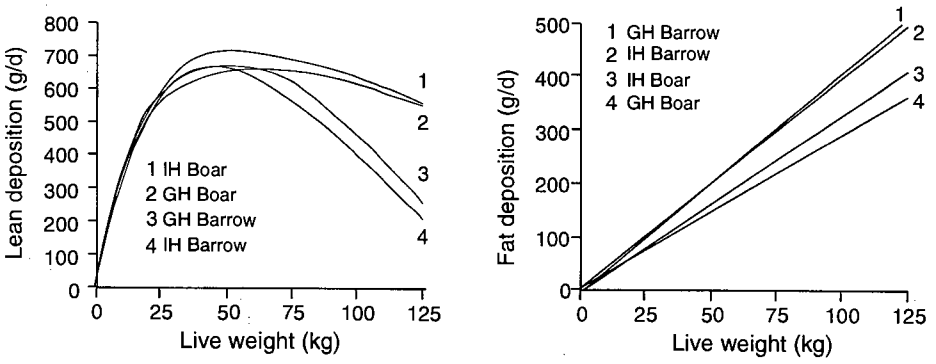

Figure 1. *Relationships between (a) lean and (b) fat deposition and live weight from 10 to 150 days of age in individually housed (IH) and group housed (GH) boars and barrows.*

Over the 20 weeks of the study, boars deposited less fat than barrows (127 vs 165 g/d, P<0.001) and GH pigs deposited less fat than IH pigs (137 vs 155 g/d, P=0.015). Boars deposited more lean tissue than barrows (535 vs 506 g/d, P=0.013) but there was no difference between GH and IH pigs (P=0.16). The effects of castration were most apparent over the final four weeks of growth when boars deposited 100 g/d more lean (P=0.002) and 90 g/d less fat (P<0.001) than barrows. These data may aid in the accurate prediction of the nutrient requirements and optimum slaughter weight for barrows.

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PERFORMANCE OF GRAZING PIGS IN SUMMER IN SOUTHERN AUSTRALIA

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Free-range pig production in Australia has generally been left to specialist enthusiasts or low input operations. Experience in Tasmania suggests that health problems in free range systems are comparable with the intensive system (Terry 1993). In southern Australia, however, summer temperatures and damage to soil by grazing pigs are regarded as major constraints. Nevertheless there is a growing consumer demand for a greener and chemical free pork product. The aim of this study was to examine the performance of free-range pigs in summer in southern Australian conditions using a movable eco-shelter.

A 4 ha paddock at Roseworthy Campus was divided into 8 plots (0.5 ha/plot). Four plots were sown with annual medic pasture (pasture) and 4 plots with barley under sown with medic (barley crop). An Eco-shelter divided into 4 sections was erected in the middle of the paddock. The pigs in one section (8/section) had access to only one plot. The grazing trial was a randomised design with 2 grazing treatments (pasture vs barley crop) and two replicates of pigs per grazing treatment. A replicate consisted of 8 pigs grazing a plot. The other 4 plots were grazed by sheep (data not reported). A total of 64 Large White pigs, 13 weeks of age were used (32 pigs/batch). The first batch of pigs grazed from December 2000 to February 2001 when pastures were dry and mature and the second group from March to April 2001 when some new seedlings had emerged. Pigs were supplemented with a finishing diet at 2 kg/d in the first batch and reduced to 1.64 kg/d for the second batch due to the availability of pasture seedlings. Wallows were supplied for cooling, especially when temperature was over 35°C. No mortalities occurred. Growth rate, hot carcass weight, backfat thickness and dressing percentage were measured. Data were analysed using Systat software (Table 1).

Table 1. The performance of pigs grazing barley and pasture paddocks in summer (mean ± SEM).

Treatment	Start weight (kg)	Daily gain (g/day)	Hot carcass weight (kg)	Backfat (mm)	Dressing percentage (%)
		Batch 1			
Barley crop (n=2)	43.9	751.5	79.2*	11.1	75.6*
Pastures (n=2)	44.1	661.3	71.9*	9.9	73.7*
SEM	0.20	18.9	1.12	0.58	0.35
		Batch 2			
Barley crop (n=2)	47.6	700.2*	65.1*	9.9	76.0
Pastures (n=2)	46.9	533.6*	56.8*	8.4	74.7
SEM	0.38	17.0	0.99	0.26	0.67

*Differences between mean values in a column within a batch were significant ($P \leq 0.05$).

The daily weight gain of the first batch of pigs ranged from 600 to 800 g, and the back fat was below 14 mm for all carcasses, the maximum thickness for premium pork. In the second batch, growth rate was lower compared with the first batch due to the lower level of supplementary feeding. However, for both batches, the average dressing percentage was over 74%. The pigs grazing the barley crop paddocks had a heavier hot carcass ($P \leq 0.05$) and tended to be fatter. The results of this study suggest free-range pigs could potentially be integrated into a cropping/pasture farming system, but the sustainability of this production system needs to be assessed.

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STAFF TURNOVER IN WESTERN AUSTRALIAN PIGGERIES

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Effective adoption of new technologies requires appropriately skilled staff. Whilst efforts to train staff vary across the industry, it is generally agreed that much of this skill is lost annually due to high staff turnover in piggeries. Anecdotal evidence suggests annual turnover of around 20% for piggeries. Published statistics show a turnover of about 8% for agriculture, but no details for sectors within agriculture (Cully and VandenHeuvel, 1999). No quantitative measures of turnover exist for the Australian pig industry. This paper presents the results of a study to quantify and explain staff turnover.

A survey was posted to 150 pig producers in Western Australia (WA) in 2000. Information was sought concerning the manager, the piggery and its location and staff who were either currently employed or had left in the last 12 months. Two of the larger piggeries that were identified from this survey as having either very high or low turnover were later used as case studies to explore qualitative aspects of employee motivation.

The 46 responses received represented 60% of pig production in WA. Quarter of the piggeries with 100-200 sows and 85% of piggeries with >200 sows responded. Seventy percent of piggeries in WA have <50 sows and are unlikely to have specialist pig staff.

The average turnover (separation rate) for the 300 staff in the survey was 34% for all piggery staff (including family members) and 46% for all employees. Whilst the average turnover in piggeries was nearly six times that of agriculture as a whole (Cully and VandenHeuvel, 1999), there was a wide distribution of results. Nearly half the piggeries had no turnover, roughly a quarter had a turnover of ≥100%, and one business recorded a 200% turnover.

Calculating turnover by the separation rate allows comparison with other sectors. However it appeared too crude for inter-farm comparisons. Small numbers of employees meant that turnover was often 0, 33, 50 or 100%. Average length of service (ALoS) was investigated as an alternative. Average length of service for all staff, including family members, was 90 months, which is equivalent to a 13% turnover. Average length of service for all employees (i.e., excluding family) was 33 months (equivalent to 37% turnover). Average length of service for staff leaving in the previous year was 12 months.

Multi-variate regressions were run to examine the effects on ALoS of ownership, sow numbers, distance and size of nearest town, manager's qualifications and experience. The regression equation is as follows:

$$\text{ALoS (in months)} = 247 + 5.27\alpha + 6.92\beta + 2.38\gamma - 0.22\delta - 0.42\varepsilon - 41.76\zeta \quad (r^2 = 0.58)$$

Where α = ownership; β = manager qualifications; γ = manager experience in years; δ = Ln population of nearest town; ε = distance to nearest town; and ζ = Ln number of sows.

Average length of service was positively correlated to manager's experience ($P<0.027$) and negatively correlated to sow numbers ($P<0.001$). No other variable was statistically significant. Insufficient data were returned to investigate the effects of wage.

The case studies of piggeries with very high or low turnover highlighted the importance of relationships between managers and staff as a crucial determinant of employee satisfaction. The high-turnover piggery had a young manager and, although the management practices and facilities could be considered best practice, the relationships between staff and management were clearly not as good as in the low-turnover piggery where facilities were older and the management was more experienced but traditional.

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SELECTION OF STOCKPEOPLE TO IMPROVE PRODUCTIVITY

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Research by Hemsworth and Coleman (1998) indicates that stockperson performance has a direct impact on animal welfare and farm productivity. However, pre-employment testing of stockpeople in Australia is rarely undertaken, due in part to the lack of validated measures currently available to farm managers for selecting stockpeople. Research by Coleman and Hemsworth (1999) also has shown that the pig industry has a relatively high staff turnover with 48% of stockpeople exiting their study within six months of recruitment. Anecdotal reports suggest that most managers of Australian pig farms tend to select staff based on intuitive and subjective measures. These usually take the form of personal recommendations, interviews (sometimes by telephone due to long distances) and curriculum vitae (CV). In particularly remote parts of Australia, employment may be given to itinerant workers with no formal CV, relevant experience or referees. In this situation the piggery manager has little to base his or her judgment on except "gut feelings" and hunches.

In the present study the suitability of pre-employment measures as predictors of performance for stockpeople in the Australian pig industry were evaluated. One hundred and forty-four inexperienced and 50 experienced stockpeople completed a series of computerised job-related questionnaires (Coleman and Hemsworth, 1999). Experienced stockpeople were those who had been employed in the piggery for at least 12 months, and inexperienced stockpeople were those who had been recruited to the piggery within the previous four weeks. After six months employment, inexperienced stockpeople were re-assessed. In addition, performance of all stockpeople was assessed by the supervisor and by an independent observer.

A positive attitude towards the characteristics of pigs was a significant predictor of positive behaviour towards pigs and technical skills and knowledge, but not of work ethic. This suggests that attitude towards pigs is a good predictor of performance relating specifically to working with pigs, but not to general work ethic. This is an important result because previous work by Hemsworth and Coleman (1998) showed that only attitudes towards interacting with pigs are good predictors of behaviour. When the definition of behaviour is broadened, as in the present study, more general attitudes appear to be better predictors. Another significant finding was that the PDI-Performance measure (this questionnaire is a pre-employment measure of potential performance; Personnel Decisions Inc., USA) is a good predictor of all measures of actual observed performance. A person scoring high on this measure is likely to adhere to rules, show stability of behaviour, take care while performing tasks and take responsibility. The results from the present study suggest that this measure may be a useful tool to help select stockpeople who will perform well in the ways studied here. The other main finding was that women appear to perform better on observed performance than do males. While this is a consistent result for these data, care needs to be taken that there are not other confounding factors. Females represented only 19% of the stockpeople in both the experienced and inexperienced groups. They may, therefore, have been a self-selected group, that is, a group who actively chose to enter the industry rather than doing so out of necessity. However the evidence obtained here is the first empirical support for the intuitively plausible assumption that women may be more nurturing and conscientious and therefore perform better in a commercial piggery.

These results may provide a basis for the development of selection and training strategies for stockpeople in the pig industry.

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IMPROVING AIR QUALITY IN WEANER KENNELS

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Although weaner kennels provide suitable accommodation for young pigs, concentrations of airborne particles in these facilities are usually higher than in traditional weaner buildings (Cargill *et al.*, 1995). As the negative effects of airborne particles on animal health, welfare and productivity are well documented (Cargill and Skirrow, 1997), there is a need to reduce concentrations of pollutants in weaner kennels. Spraying the pen floor with a mixture of oil and water has been used to reduce dust in traditional buildings (Banhazi *et al.*, 1999), but spraying inside weaner kennels is impractical and an alternative oil delivery system was evaluated. This study examined the effects of applying oil-impregnated sawdust on to weaner kennel floors on the concentration of airborne particles.

Air quality parameters were recorded for 16 days in six (three control - without sawdust and three experimental kennels - with oily sawdust) randomly selected weaner kennels housing approximately 12 pigs (mean live weight 7 kg) at the stocking rate of 0.18 m^2/pig. The floor of the experimental kennels was treated with approximately 4 litres of sawdust per week impregnated with 5% (w/w) canola oil. Sawdust from the previous week was not removed. Airborne viable bacteria, and respirable and inhalable particles were measured as previously described by Banhazi and Cargill (1997). The air quality parameters were compared between the treatment and control groups by pooling the data for analysis.

Although the concentrations of both respirable and inhalable particles were reduced, reduction in respirable particles was not statistically significant. However, there was a significant reduction ($P \leq 0.05$) in the concentration of airborne viable bacteria (Table 1).

Table 1. Concentrations of respirable and inhalable airborne particles and viable bacteria for the control and treatment kennels.

Treatment	Respirable particles (mg/m^3)	Inhalable particles (mg/m^3)	Viable bacteria (CFU/m^3)
Control	0.11^b	2.07^a	$44{,}000^a$
Treatment	0.09^b	1.57^b	$29{,}000^b$
Variation %	18	24	34

^{a,b}Values in the same column with different superscripts differ significantly ($P \leq 0.05$).

The experiment demonstrated the potential of using oil-impregnated sawdust to reduce the concentration of airborne particles in pig kennels. Although the reduction in the concentration of respirable particles was not significant, the average concentration recorded in the untreated kennels during the experiment was 50% less than the recommended maximum. It was hypothesised that some of the smaller airborne particles would adhere to the sidewalls of the kennels, reducing the effects of oily sawdust. Further studies are needed to evaluate the long term effects of sawdust on kennel environment, and to determine the optimum inclusion rate and the frequency of application of oily sawdust.

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THE EFFECTS OF HANDLING AND SPACE ALLOWANCE ON PERFORMANCE OF GROWING PIGS

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Research in the pig industry has shown that interactions between stockpeople and their animals can limit pig productivity and welfare (Hemsworth and Coleman, 1998). While these interactions may appear harmless, this research has shown that the frequent use of some of the routine behaviours used by stockpeople can result in pigs becoming highly fearful of humans. It is these high fear levels, through stress, that appear to limit pig productivity and welfare. Although human factors are considered to be important determinants of animal welfare and performance, most research has focused on the effects of housing systems. The present experiment examined the relative effects of human contact and housing on the performance and welfare of growing pigs.

One hundred and twenty male crossbred (Large White x Landrace) pigs averaging 68.8 ± 0.97 kg live weight were allocated to a 3 x 2 factorial experiment involving three handling treatments (positive, minimal and negative) and two space allowances, high (1.6 m^2/pig) and low (0.45 m^2/pig). Pigs were housed in groups of five. Handling treatments were imposed on each pig for 10 s per day and consisted of either patting or stroking the animal (positive), no handling (minimal) or shocking the animal with a battery-operated electric prodder (negative) if the pig approached the experimenter. Pigs were fed *ad libitum* a diet containing 14.3 MJ of digestible energy and 15.6% crude protein. After 4 weeks of treatment, the approach behaviour of pigs to a stationary experimenter was measured in a standard approach test to assess the pigs' fear of humans. Treatment effects were analysed using analysis of variance and the pen was used as the experimental unit.

Table 1. Main effects of handling and space allowance on daily gain, feed to gain ratio and time (s) to approach within 0.5 m of a stationary experimenter in the fear test of male pigs housed in groups of five pigs/pen.

		Handling				Space allowance		
	Weeks	Positive	Minimal	Negative	LSD	High	Low	LSD
Daily gain	2-4	1104^{ab}	1141^{b}	998^{a}	112.5	1134^{c}	1020^{d}	91.9
(g)	0-4	1042	984	965	66.3	1022	972	54.1
Feed:gain	2-4	2.61^{ab}	2.50^{a}	2.98^{b}	0.395	2.60	2.80	0.322
	0-4	2.75^{a}	2.89^{ab}	3.19^{b}	0.350	2.83	3.05	0.286
Fear test		26.0^{a}	31.5^{a}	93.8^{b}	31.10	42.0	58.8	25.39

$^{a,b;\ c,d}$Means in rows with different superscripts differ significantly P≤0.05

Both main effects influenced growth rate, but the feed to gain ratio of pigs was most affected by the handling treatments. There were no significant (P>0.05) main effects on feed intake. The behavioural responses of pigs to humans was affected (P≤0.05) by handling.

While both main effects affected growth performance, handling had the major effect. These results indicate that within the range of treatments studied, fear of humans is likely to have a greater impact on the growth performance of growing pigs than space allowance.

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THE BEHAVIOUR OF GROUP-HOUSED, MALE FINISHER PIGS

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The growth performance of entire male pigs in groups is less efficient than expected (e.g., compared to castrates and individually housed entire males), possibly due to greater motivation and/or opportunity for socio-sexual (aggressive and mounting) behaviour at the expense of feeding behaviour. The time pigs allocate to different behaviours, that is their time budget, may affect their productivity and differ for entire compared to castrated males in groups. This experiment focussed only on behaviour and tested the hypothesis that castration decreases time allocated to socio-sexual behaviour and increases time allocated to feeding behaviour in group-housed male pigs.

Twelve groups of 15 male pigs (Large White x Landrace commercial line) were formed at 14 weeks of age (47.1 ± 5.50 kg live weight, mean ± SD). Two time replicates of six pens were located in the same shed with natural lighting. Pig behaviour and feeder utilisation were compared among groups of entire males (EM), immuno-castrated males (IM, entire males treated with Improvac™ at 14 and 18 weeks of age) and surgically-castrated males (SM, castrated at 14 days old). A 24-h time-lapse (TL) video record was made for each pen of pigs at 17 and 21 weeks of age. Video-recording of the six pens occurred over two days with the use of three TL video-recorders. Each pig was spray-painted on its back for identification on the video record. Low-light cameras were mounted above each pen and night-time recording was assisted by 20 Watt fluorescent lights attached at roof level. Each pen contained 2 electronic, single space feeders that provided a pelleted, commercial diet *ad libitum*. The experimental unit was the pen of pigs and differences between the treatments were tested by one-way ANOVA blocked on time replicate.

Table 1. Socio-sexual and feeding behaviour of group-housed entire males (EM), immuno-castrates (IM) and surgical-castrates (SM) during 24 h at 17 and 21 weeks.

	17 weeks of age				21 weeks of age			
	EM	IM	SM	sed	EM	IM	SM	sed
Total activity (TA, % of 24h)	21.9^{a}	19.8^{a}	16.1^{b}	1.89	17.6	16.2	15.3	0.98
Visits to feeder (frequency/pig)	16.4	15.3	17.7	3.23	13.6	12.4	17.5	3.55
Time in feeder (% of TA)	32^{a}	33^{a}	47^{b}	4.1	30^{x}	48^{y}	47^{y}	4.6
Feeders utilised (% of 24 h)	51	49	53	4.9	40^{a}	56^{b}	50^{b}	5.7
Socio-sexual (% of TA)	16.6^{a}	9.0^{ab}	0.8^{b}	5.08	10.6^{x}	3.2^{y}	2.4^{y}	1.64

$^{a,b;x,y}$Values within rows for each age with different superscripts are significantly different at $P \leq 0.05$ and $P < 0.01$, respectively.

The EM pigs spent more time engaged in socio-sexual behaviour than SM pigs and the IM pigs at only 21 weeks (Table 1). In contrast the EM pigs spent less time in the feeder than the SM pigs but not the IM pigs at 17 weeks and less time than both groups at 21 weeks. This occurred despite there being no significant difference in the mean frequency of visits to the feeders. It is concluded that castration reduced socio-sexual behaviour and increased feeding behaviour in group-housed finisher pigs, thus supporting the hypothesis. The finding that 'sexually-active' males in groups spent about one-third of their active time in feeding behaviour compared to almost one-half of total activity by castrates has not been previously reported. The socio-sexual and feeding behaviour of IM was similar to SM following treatment with the immuno-castration vaccine.

PARTITIONS BETWEEN FEED TROUGHS CHANGES FEEDER PREFERENCES OF GROWING PIGS HOUSED IN GROUP PENS

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Many experiments have shown that feed intake increases when pigs are housed in individual pens compared to groups. A study was designed with partitions between feeders to provide an individual feeder space for each pig in a group pen. The first objective was to test whether the presence of partitions changed the distribution of feed disappearance among feeder positions. The second objective was to assess whether partitions between feeders increased mean daily feed disappearance per pig with a concomitant increase in pig growth.

Forty-eight crossbred male pigs were allocated at 46 ± 1.5 kg (mean ± SEM) live weight to two pen designs, with and without partitions between feeders. The pigs were housed in four rooms maintained at 22°C. Each room contained two adjacent pens with six pigs per pen. Each pen had six feeders placed along one side of the pen and the two pens were separated by a solid partition. In one pen of each pair, feeders were separated by partitions, 1 m in length, constructed from vertical metal pipes. The partitions were placed 600 mm apart. The second pen in each room had no partitions between feeders. Floor type (concrete slats) and floor space (1.5 m^2/pig) were similar in each penning arrangement. Pigs were fed a commercial, pelleted diet estimated to contain 13.9 MJ digestible energy and 8.0 g available lysine per kg. Feed was replenished during each day to maintain at least 500 g in each feeder. Water was provided from nipple drinkers located between feeders 1 and 2, 3 and 4, and 5 and 6. The experiment continued for 42 days. Pig live weight was recorded at the start and finish of the experiment. Feed disappearance per feeder was measured at intervals of one week. The differences in mean daily feed disappearance were calculated for each pen between (a) feeders 2, 3, 4 and 5, compared to feeders 1 and 6; and (b) feeders 3 and 4 compared to feeders 2 and 5. Analysis of variance was used to test the effect of partitions on the differences (a) and (b) (see Figure 1), mean daily feed disappearance and daily live weight gain per pig, using the pen as the statistical unit.

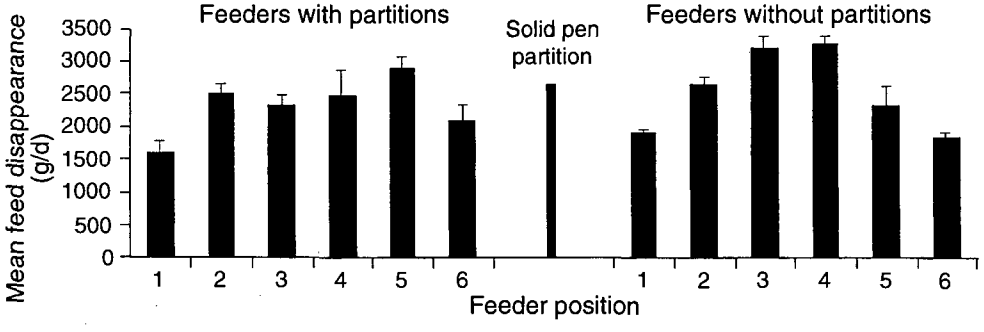

Figure 1. *Mean feed disappearance (g/day) for each feeder in pens with and without feeder partitions. There were 6 male pigs (46 to 88 kg live weight) per pen, replicated in 4 rooms.*

Feeder partitions evened out feed disappearance across the central four feeders (2 to 5). Mean feed disappearance was significantly greater ($P \leq 0.05$) for feeders 3 and 4 compared to feeders 2 and 5 in pens without partitions, but not for pens with feeder partitions ($P > 0.50$). Mean feed disappearance for feeders 2 to 5 was significantly greater ($P < 0.001$) compared to feeders 1 and 6 for both penning arrangements. There was no evidence to support the hypothesis that partitions placed between individual feeders increases pig performance when housed in groups. Group pens with or without feeder partitions had similar mean (± SEM) daily feed disappearance (2406 ± 96.5 g; 2477 ± 96.5 g) and daily live weight gain (1007 ± 24.9 g; 982 ± 24.9 g) per pig respectively.

A REVIEW - AUSTRALIAN AND INTERNATIONAL DEVELOPMENTS IN THE ASSESSMENT AND MANAGEMENT OF PIGGERY ODOURS

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Abstract

Odours remain a problem for the Australian pig industry. The Pig Research and Development Corporation (PRDC) of Australia funded a major review of odour emissions from piggeries and odour control strategies. Only dynamic olfactometry in accordance with the Dutch NVN 2820 or European CEN TC264 draft standard was included. Emission rates are the key data required for dispersion modelling with the AUSPLUME v4.0 Gaussian plume model, the only model considered. Data on odour emissions from piggery sheds and ponds were collated and interpreted. The data suggested that ponds emit 70% to 80% of the odour from Australian piggeries. Odour control strategies were reviewed. Odour emissions from 'standard' and 'modified' piggeries were modelled. It was shown that separation distances between 'standard' piggeries and receptors (neighbouring residences) could be reduced by 50% to 80% by the use of modifications, such as deep-litter systems and pond covering.

In the two years since the completion of the review, significant changes have occurred. A range of odour measurements have been made to the CEN standard or equivalent, dispersion modelling software has been improved and new odour impact studies have been completed. Some of the recommendations made in the odour review are already superseded by new information.

Introduction

Piggery odour regulations in Australia

While variations exist from State to State, a new or expanding large piggery in Australia requires planning approval from both local and State government agencies. The potential impact of odour from piggeries on nearby sensitive places that the public may use from time to time (receptors), such as houses, towns, parks, public roads, churches or schools is addressed by the provision of adequate separation distances between these receptors and the piggery. Guidelines using fixed distances are usually no longer sufficient. Modelling of odour emissions to predict the impact on neighbours is often required.

Piggery odour review

The Pig Research and Development Corporation (PRDC) of Australia has funded several research projects into pig odours. However, much of this research has not been as successful as possible, due to the old olfactometry procedures and the lack of associated data collected at the time odour measurements were collected. As a consequence, PRDC undertook a review of their own research, as well as a comprehensive review of pig odour research worldwide. The PRDC contends that the main use of pig odour research data in Australia is, ultimately, in dispersion modelling and this was the focus of the review. The present paper is a brief summary of the outcomes of the PRDC review and recent developments in piggery odour research worldwide. The literature review is comprehensive and covers not only odours from piggeries but also a review of dynamic olfactometry. The PRDC review is reported in two parts (Watts, 1999a; Watts, 1999b) and can be downloaded in full from www.fsaconsulting.net.

Background of odour emission determination and modelling

Olfactometry standards

There are many forms of olfactometry but, for various reasons, dynamic olfactometry is now the standard method used in Australia and Europe. The unit of odour measurement is the odour unit (OU). This is loosely defined as the number of dilutions of the odour sample at which 50% of the panel can just detect the presence of an odour. Within this method, there remains a wide range of measurement techniques. In the early 1990's, the Dutch developed the NVN 2820 standard (Dutch Normalisation Institute, 1990) that greatly improved the repeatability and reproducibility of odour measurements. Most, good-quality pig odour research has used this method. Recently, a draft European standard (CEN TC264) has been proposed (European Committee for Standardisation, 1997). This is the basis of the draft Australian standard. Although this should improve odour measurements, it is different from NVN 2820. A scientifically-rigorous conversion factor between the two standards has not been determined but it could range from 2-4. This presents a problem in converting NVN2820 (and other dynamic olfactometer) pig odour data to the new standard. Watts (1999a) showed that the sensitivity of dynamic olfactometers varies by at least a factor of 10. Hence, it is possible that one laboratory could measure the odour emission from a piggery shed to be 4 OUm^3/s per pig, while another laboratory could measure the same emission rate to be 40 OUm^3/s per pig simply due to differences in olfactometry. This variability is totally unacceptable when the data is to be used in environmental impact assessments or court cases. Hence, in the PRDC review, some time has been spent trying to define the performance of olfactometers used in various pig odour studies.

Electronic odour measurement

Electronic odour measurement devices are currently used in the food processing industry to detect malodours that may indicate problems with food quality. Preliminary testing of this technology for odour detection in intensive livestock industries has suggested some potential for application. Currently, electronic odour measurement devices need to compile a library of particular odours, correlated against olfactometry results. Their potential advantages lie in being able to provide larger volumes of information at lower cost, and with fewer time restrictions.

Young (2001) reported on trials completed in Australia on agricultural odours using an electronic nose. In trials on pig effluent odours, the AlphaMOS system (electronic nose) was able to discriminate between air samples collected from two different experimental treatments. Results effectively provide an indication of difference between samples. Hence, results for one treatment were shown relative to the other treatment as well as other samples of interest, e.g., air and standard gases. As these devices measure constituent gases, the similarity of a result to ambient air has the potential to provide an indication of the comparative offensiveness of the emissions from each treatment.

Emissions modelling

AUSPLUME (Lorimer, 1986) is the air dispersion model approved by regulatory authorities in Australia. It is used when the odour impact of a piggery on its neighbours is to be assessed. It is a conventional Gaussian plume model. In AUSPLUME v4.0, odour emissions can be from stacks, volume sources (buildings) or area sources (effluent treatment ponds, land-spreading areas). Odour emissions can be constant, or can vary according to: hour of the day; hour of the day and season; month; wind speed and stability class (atmospheric stability); or temperature. It is only possible to vary emission rate with one of these parameters at a time. For example, it is not possible to vary piggery shed emission rate with both temperature and wind speed (ventilation rate). In AUSPLUME v4.0, the meteorological data input file includes wind speed (e.g., at 10 m anemometer height), wind direction, temperature, stability class and other variables. The

review of available pig odour emission data considers the use of the data in AUSPLUME v4.0.

The latest version of AUSPLUME (v5.2) includes a number of changes that could affect odour modelling of piggeries. Area source algorithms have been changed to provide more accurate odour predictions close to the source and allow more accurate definition of area source shape. At distances further from the source, predicted odour concentrations from the new algorithm are similar to predictions from the old algorithm. As receptors are seldom located close to piggery area sources, neither of these changes will significantly affect current modelling practices.

Two other major changes were made to the AUSPLUME structure – the model is now able to read hourly variations in emission rates or source characteristics, as well as hourly variations in background concentration. Longer term, these changes should improve the accuracy of model predictions. Immediately, the challenge is to develop accepted standard odour emission profiles for different piggery odour sources. This is likely to require the collection of measurements from a cross-section of sources and the development of odour emission models providing real time estimates.

Improvements in computing power have increased the range of emission models available for people undertaking odour impact assessments. Ormerod (2001) reviewed some recent changes in modelling programs applicable to Australian conditions. Models designed to accommodate complex terrain include The Air Pollution Model (TAPM) developed by the Commonwealth Scientific and Industrial Organisation (CSIRO) and CALPUFF. The two models differ in the mathematical basis used by the model, but both require detailed meteorological and topographical data. This requirement has been a major limitation to the use of complex models in the past. However, TAPM is able to provide high quality meteorological data for sites where no measured data is available, increasing the range of situations where these complex models can be used. Ormerod (2001) demonstrated that considerable differences could be obtained for maximum and average predicted odour emissions using the same input data into the AUSPLUME and TAPM models.

Determination of odour emission rates

Problems of consistency also exist in sampling odours to determine emission rates from various sources. Naturally-ventilated sheds are difficult to sample in order to get an overall shed odour emission rate. The same applies for ponds. Methods are used that either sample directly over the surface or sample downwind of the pond. Full agreement on sampling methodologies has not yet been reached.

AUSPLUME models emissions from three different types of odour sources, viz., stacks, volume sources and area sources. The odour emission rate for each source is essentially the odour concentration times the volumetric flow rate. It is relatively easy to determine odour emission rate for point sources but it is more difficult for diffuse sources such as naturally-ventilated sheds and pond surfaces. Watts (1999a) outlined the issues involved.

Typically, volume sources are fugitive emissions from buildings. In piggeries, these are emissions from naturally-ventilated sheds. The problem is the determination of an appropriate gross ventilation rate for the shed. This is dependant on ambient wind speed and the physical dimensions and configuration of the shed. Smith *et al.* (1999) have reviewed the estimation of natural ventilation of piggery sheds. No further discussion is given here.

Area sources are the most difficult odour source from which to estimate odour emission rates because there is no way of directly measuring or sampling emissions from area surfaces such as pig ponds and cattle feedlot pens. The emission rate must therefore be estimated indirectly from the odour concentration of a sample of air following mixing with the emitting source. The major problems are that there is no substantial mass flow of air to sample and the emission rate typically varies both temporally and spatially. This issue has been researched extensively in Australia in recent years due to odour issues associated with intensive livestock systems (mainly cattle feedlots). In Toowoomba, the

University of Southern Queensland and the Department of Primary Industries have published numerous papers on the topic (Smith, 1993; Smith and Watts, 1994a, b; Smith, 1995; Smith, 1996). In Sydney, the Centre for Water and Wastewater Technology has also undertaken similar work (Jiang *et al.*, 1995). From this work, the possible odour sampling techniques are either physical surface sampling methods or downwind sampling methods. Most recent odour sampling from piggery area sources in Australia has been undertaken using the portable wind tunnel design developed by the Centre for Water and Wastewater Treatment (CWWT) at the University of New South Wales.

For area sources, wind tunnels and back-calculation methods have relative advantages and disadvantages.

Wind tunnels are most appropriate in the following cicumstances:

- Whenever a point measurement is required.
- In comparative trials on sample areas to assess the effect on emissions of individual variables such as temperature or wind speed.
- To assess the spatial variability of a particular areal source.

Back-calculation methods are most appropriate:

- When an average emission from a complex source is required.

Odour emission data for piggery housing

Odour emissions from conventional sheds

Odour emission data has been collected from conventional piggery sheds by numerous researchers, including Smith *et al.* (1999). They found that the range of odour emission rates from piggery sheds was from less than 10 OUm^3/s per pig to over 35 OUm^3/s per pig (NVN 2820 olfactometry standard).

Anecdotal information suggests that diet composition affects odour quality and possibly, odour strength. The effects of different animal types and stocking densities on odour emissions are not clear. Farrowing and weaner sheds are typically designed and managed differently to grower/finisher sheds. Design differences (not animal type) could affect odour emission.

To provide some understanding of the emission process, the distribution of odour concentrations within a naturally ventilated piggery building was measured by Smith *et al.* (1999) and it was observed that:

- Odour concentrations vary across the width of the building and generally are lower near the side vents and higher in the middle of the building.
- Odour concentrations decrease with height in the building due to convective mixing with the ventilation air.
- Odour concentration increases in the direction of the wind along the length of the building.

Previous work by Schulz and Lim (1993) suggested that the odour concentrations within buildings, and, by inference, the emission rates are dependant upon such factors as the internal temperature and humidity, the cleanliness of the shed (which may be indicated by such parameters as the time since flushing or the frequency of flushing) and the age of the shed. To assess the impact of these factors on emission rates, shed emission rates were measured at eight different piggeries, from a number of buildings of different function, age, design and management.

Smith *et al.* (1999) found that emission rate increased with increasing temperature, humidity, shed age and decreasing cleanliness. In no case were the results overwhelmingly conclusive. Of these variables, the two over which the piggery manager has some control are temperature and cleanliness. To minimise odour emissions, it was recommend that flushing should be undertaken at least twice daily and that internal

temperatures be maintained at or below 25°C. There is a significant increase in emission rate when temperature increases above 25°C. No correlation was found between ventilation rate and odour emission rate. Larger ventilation rates resulted in lower odour concentrations in the sheds but the gross odour emission rate remained similar.

The data of Smith *et al.* (1999) suggests that:

1. Any differences in emission rates due to shed type or function are insignificant compared with the impact of other variables.
2. Ventilation rate does not have any direct impact on emission rates.
3. There is a relationship between emission rates and the variables of temperature, humidity, and flushing frequency; and that dirty sheds, high temperatures and high relative humidity can lead to high odour emission rates. However in all cases the relationships were masked by the effects of the other variables on the emission rates.
4. There is a fairly strong relationship between emission rate and shed age, although it is probable that this merely reflects the effect of shed design and management, particularly those aspects that impinge on the cleanliness of the sheds.

Watts (1999a) recommended that the average odour emission rate from a new piggery shed in Australia be 12 OUm^3/s per standard pig unit (SPU) when the shed is ventilated. (In Queensland, the SPU is a unit of measurement for determining the size of a pig production enterprise in terms of its waste output. One SPU produces an equivalent amount of volatile solids to that produced by an average size grower pig, approximately 40 kg live weight). When no ventilation occurs, e.g., at night, the emission rate drops, say to 10-50% of the daytime emission. The effect of temperature could be accounted for by changing the emission rate by seasons. In winter, the emission rate could be 8 OUm^3/s per SPU, in summer, 16 OUm^3/s per SPU and in autumn and spring, 12 OUm^3/s per SPU. This provides an annual average of 12 OUm^3/s per SPU and has summer emissions twice as large as winter emissions. This is shown graphically in Figure 1.

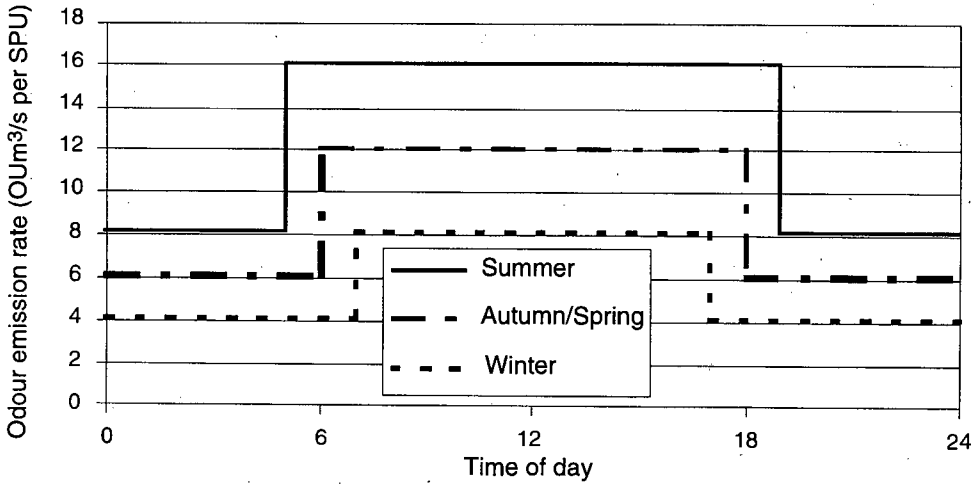

Figure 1. *Proposed odour emission rates for piggery sheds (night-time emissions ≤50% of daytime emissions).*

With the ability to input hourly variation in emission data into AUSPLUME, more accurate representations of the variation in odour emission from sheds is possible. Programs could be developed to adjust standard odour emission rates according to the major factors influencing shed emissions. These factors include shed design and management factors and climatic data for the area.

Shed emissions measured to the new CEN standard in the Netherlands were reported by Ogink and Groot Koerkamp (2001). While these measurements are not

directly relevant to the Australian situation, the results provide an idea of the change in values that might be expected under the CEN standard of olfactometry.

The measurements were taken from a variety of housing systems and for different classes of pigs. The housing systems for fattening pigs varied from partially slatted pit systems to flushed systems and included ventilated as well as ventilated and filtered outlet air. Dry sow systems included individually housed sows with manure pits and group housed systems on slatted floors with manure pits under the dunging areas. The emissions measured for the fattening pigs were in the range of 10–23 OUm^3/s per animal (CEN standards and 60 kg live weight average), with the flushing system giving 11 OUm^3/s per animal. Individually housed dry sows gave results of 19 OUm^3/s per animal, while group housed sows gave results of 7 OUm^3/s per animal.

Odour emissions from deep-litter sheds

Payne *et al.* (1997) and Pattison (1999) reported odour emission from deep-litter systems. The measured range of odour emission rates was from less than 1 OUm^3/s per pig to over 40 OUm^3/s per pig (NVN 2820 olfactometry standard). When standardized to rate per live weight, the range is from 1 to 25 OUm^3/s per 50 kg live weight. Several factors affect the odour emissions from deep litter sheds. The main factors are ventilation rate, air temperature, time of occupation and status of the manure/litter mix.

Watts (1999a) recommends that the average odour emission rate from a deep litter shed in Australia be 6 OUm^3/s per SPU (NVN 2820 olfactometry) when the shed is ventilated. The effect of temperature could be accounted for by changing the emission rate by seasons. In winter, the emission rate could be 4 OUm^3/s per SPU, in summer, 8 OUm^3/s per SPU and in autumn and spring, 6 OUm^3/s per SPU. This provides an annual average of 6 OUm^3/s per SPU and has summer emissions twice as large as winter emissions. When no ventilation occurs, e.g., at night, the emission rate drops to say, 10-50% of the daytime value. This could be included using the hour-of-day and season odour emission rate section in AUSPLUME. If sheds are closed during the periods of worst odour dispersion (night, early evening), then this should be accounted for in odour modelling. These recommendations are based on the following assumptions:

- The litter in the sheds is managed so that anaerobic conditions with high odour production do not occur.
- There are a number of deep-litter sheds at the location so that there is a range of pig occupation ages across the site and an average odour emission rate can be used.

An alternative approach would be to adjust shed emission rate against wind speed (ventilation rate) and stability class. This would be appropriate for naturally-ventilated sheds.

Odour emissions from ponds

Determining emission rates for odour modelling

Given the importance of pond odours in the overall odour emissions from Australian piggeries, very little work has been undertaken. The only data available is to be found in papers by Schulz and Lim (1993) and Smith *et al.* (1999). Theoretical analyses have been undertaken to extrapolate the limited data to a wider range of wind speeds and stability classes. However, the emission rates recorded apply to the wind tunnel measurements at a specific wind speed. Wind speed adjustments can be made using the methodologies outlined by Smith (1993).

The stability conditions in a wind tunnel can be most closely described as neutral as there should be no significant temperature gradient in the tunnel and solar radiation effects can be excluded. A logarithmic profile can be used for the wind speed adjustment with a roughness height of 0.03 m to represent the surface roughness of ponds. As outlined by Pollock (1997), the exponent for liquid surfaces should be 0.5 (as derived by UNSW). Some uncertainty exists as to the most appropriate exponent to use as the work of Smith and

Watts (1994) seems to indicate that the exponent is dependant on the physical dimensions of each wind tunnel.

Hence, for the wind tunnel data, the odour emission rate varies with tunnel wind speed according to:

$$E_v = E_m * (u_t/u_m)^{\wedge 0.5} \qquad \textbf{Equation 1}$$

where E_v = odour emission rate at tunnel wind speed, u_t
E_m = base odour emission rate measured at tunnel wind speed, u_m
u_t = wind tunnel speed (m/s)
u_m = tunnel wind speed for measurements, i.e., 0.3 m/s.
0.5 = adopted exponent

The formula to convert wind speed at 10 m (for example) to wind speed at 0.125 m (i.e., tunnel speed) in neutral stability is:

$$u_t = u_{10} * \ln(0.125/z_{0\text{-}2})/\ln(10/z_{0\text{-}1}) \qquad \textbf{Equation 2}$$

where u_t = wind tunnel speed (m/s)
u_{10} = wind speed at 10 m
$z_{0\text{-}1}$ = surface roughness for anemometer at 10 m (0.3 m)
$z_{0\text{-}2}$ = surface roughness for pond (0.03 m).

This reduces to

$$u_t = u_{10} * 0.41 \qquad \textbf{Equation 3}$$

It is accepted that atmospheric stability would also affect odour emission rate. This is because stability affects both the slope of the wind speed profile and the degree of turbulence. These two factors are partially co-dependant so accounting for both these factors would not be valid. Pollock (1997) and Kaye (1997) provided details of a methodology to deal with wind profile treatments and these were agreed by the Scone piggery commissioners to be valid. The Scone case concerned a large piggery proposal near Scone, NSW (CMPS&F, 1993) in which odour was the major concern. Ormerod (1991, 1994) provided details of a treatment to deal with turbulence effects based on vertical mixing heights. The Ormerod methodology would result in a 50% reduction in pond emission rate for F class stability and the Pollock method would result in a 60% reduction.

Kaye and Jiang (1999) used a different approach to the same problem. They agreed that Equation 2 represents the relationship between tunnel wind speed and odour emission rate. They then related tunnel wind speed to ambient wind speed using:

$$u_t = u_{10} * (0.125/10)^n \qquad \textbf{Equation 4}$$

where u_t = wind tunnel speed (m/s)
u_{10} = wind speed at 10 m
N = the wind profile exponent

The wind profile exponent, n, is assigned on the basis of the Pasquill stability class (measure of atmospheric stability). For their work, Kaye and Jiang (1999) used exponents in AUSPLUME for "Irwin Urban" conditions. The exponents for stability classes A, B, C, D, E, and F were 0.15, 0.15, 0.2, 0.25, 0.4 and 0.6 respectively. The AUSPLUME manual recommends using the "Irwin Rural" profiles for rural applications. The rural exponents for stability classes A, B, C, D, E, and F are 0.07, 0.07, 0.1, 0.15, 0.35 and 0.55 respectively. Hence, for neutral stability (Class D), n =0.15 (rural) and Equation 5 reduces to

$$u_t = u_{10} * 0.52 \qquad \textbf{Equation 5}$$

For the purposes of their study, Kaye and Jiang (1999) modified the wind speed categories in AUSPLUME to better reflect the importance of low wind speeds in odour situations. Table 1 shows the selected wind speed categories. Using equations 1 and 4, it is possible to calculate the relative pond odour emission rates for different wind speeds

and stability classes as compared to the wind tunnel measurements. Table 1 shows the relative pond odour emissions expressed as a percentage of a measurement made in a wind tunnel with an average height of 0.125 m at 0.3 m/s tunnel wind speed. For stability class F, the emission rate is 42% of the Stability Class D data. This is a similar result to the Ormerod methodology described above.

Table 1. Pond odour emissions versus wind speed and stability class.

Wind speed category	Speed rate (m/s)	Median wind speed (m/s)	Stability class A	B	C	D	E	F
			Relative odour emission rate* (%)					
1	0-0.6	0.3	86	86	80	72	46	30
2	0.6-1.2	0.9	149	149	139	125	80	52
3	1.2-1.8	1.5	192	192	180	161	104	67
4	1.8-2.4	2.1	227	227	213	190	123	79
5	2.4-3.0	2.7	257	257	241	216	139	90
6	>3.0	6.5	399	399	374	335	216	139

*Assumptions: Ambient wind speed measured at 10 m
Tunnel height – 0.125 m
Tunnel wind speed – 0.3 m/s
Equations 2 and 5 used.

Although important to odour modelling, the variation in emission rate with wind speed and stability class (Table 1) is completely theoretical and is not supported with experimental data. No pond odour emission measurements made under a range of wind speeds and stability classes were found that could confirm this analysis.

The data available does not allow any interpretation other than that primary treatment ponds emit more odour than secondary treatment ponds. Watts (1999a) recommended that a 'typical' standardized odour emission rate from an anaerobic pond would be about 30 OU/m^{2}s (NVN 2820 standard) while the emission from a secondary (or tertiary) pond would be about 5 OU/m^{2}s (NVN 2820 standard). Using a standardized odour emission rate of 30 OU/m^{2}s (NVN 2820 standard), for anaerobic ponds, adjustments can be made for wind speed and stability. Table 2 provides odour emission rates per unit area of pond surface.

Table 2. Pond odour emissions (primary pond) for AUSPLUME

Wind speed category	Speed rate (m/s)	Median wind speed (m/s)	Stability class A	B	C	D	E	F
			Odour emission rate (OU/m^{2}s)					
1	0-0.6	0.3	25.7	25.7	24.1	21.6	13.9	9.0
2	0.6-1.2	0.9	44.6	44.6	41.7	37.4	24.1	15.6
3	1.2-1.8	1.5	57.5	57.5	53.9	48.3	31.2	20.1
4	1.8-2.4	2.1	68.1	68.1	63.8	57.1	36.9	23.8
5	2.4-3.0	2.7	77.2	77.2	72.3	64.8	41.8	27.0
6	>3.0	6.5	119.8	119.8	112.2	100.5	64.9	41.8

Effect on odour emissions of pond loading rates

In the United States, the effect of loading rate on odour emission has also been researched at Purdue University. Heber (1998) reported odour emissions from piggery ponds, with odour concentrations measured to the NVN 2820 standard. Odours were sampled from the pond surface using a buoyant convective flux chamber (Heber *et al.*, 2001). The flux chamber sampling area was 0.76 m^2, with 2.4 m of contact between air and the emitting surface. Drawing the air through the chamber in a hairpin path facilitated this length of contact. The chamber is 1.22 m long with a total width of 0.6 m (two 0.3 m sections). The tunnel was operated with a surface velocity of 1.1 m/s. A conventional

anaerobic pond with aerators and a volume of 16.3 ML and a surface area of 9655 m^2 was used for the measurements. The organic loading matter rate was 142 g of volatile solids (VS)/m^3/day compared to the locally recommended loading rate of 96 g/VS/m^3/day. Over a four-day period, odour emission rates varied from 1.5 to 2.05 OUm/s with an average of 1.67 OUm/s. Odour emissions from non-aerated anaerobic ponds at two other piggeries were also measured. These ponds had organic loading rates of 80 and 51 g/VS/m^3/day respectively. Odour emission rates were 11.7 and 7.9 OUm/s respectively with an average of 9.6 OUm/s.

Heber *et al.* (2000) reported odour emission measurements from two anaerobic ponds with different loading rates. Two odour samples were collected from each of two locations on each pond at six separate visits. Samples were collected using the same buoyant convective flux chamber described above. Both ponds sampled were the first cell of a two-stage pond for a breed-to-wean piggery. Pond A was estimated to have a typical loading rate equating to 58.3 g VS/m^3/day. Pond B was estimated to have a light loading rate equating to 22.1 g VS/m^3/day. Odour samples were analysed using an AC'SCENT olfactometer using methods compatible with the 1999 CEN Olfactometry Standard. The mean odour emission from pond A was 6.2 OU/s-m^2 and from pond B was 2.9 OU/s-m^2. The results indicated generally higher emissions from pond A, although after statistical analysis of the data, no significant difference was found.

Due to the small amount of data obtained from this work, it is difficult to draw any conclusions. On most occasions, significant variation in odour emissions was found from the samples from different locations on the one pond on the same day. The design of the flux chamber used in the above studies to collect pond odour samples makes it difficult to provide meaningful comparisons of the results with Australian data.

Current work being undertaken by the Queensland Department of Primary Industries is investigating odour emissions from anaerobic piggery ponds as part of a project funded by the PRDC. The project has investigated the spatial variability of odour emissions across ponds, using a grid of sampling points across the pond surface. Results reported by McGahan (2001) show considerable variation across two ponds of different sizes, loading rates and locations (one located at Wacol, Qld and the other located at Allora, Qld).

Nine odour samples were taken from designated positions on the surface of the Wacol piggery effluent ponds. Six odour samples were also taken from the smaller Allora piggery effluent pond. These positions were established using a Trimble - Global Positioning System (Model TCD1) with an accuracy of 1 m. Odour samples were analysed utilising the 8 panellist, triangular, forced choice dynamic olfactometer developed by the Queensland Department of Primary Industries. Three rounds of the dilution series were run for each sample as per the Draft Australian/New Zealand Standard *"Air Quality – Determination of odour concentration by dynamic olfactometry* (EV/07-0600-451)".

Table 3. Mean, standard deviation and variance of corrected emission rates from two piggery effluent ponds.

Piggery	E^1 Mean (OU/m^2.s)	Range of E^1 (OU/m^2.s)	Standard deviation	Variance	Number of samples
Wacol	15	7 to 38	10	93	9
Allora	27	15 to 39	11	118	6

[1]E, emission rate corrected to 1m high and 1 m/s.

The odour emission spatial variations within the ponds were analysed using both graphical representation of the data and examination of the variance within the pond. The odour emission rate was also analysed using regression analysis to determine if there was a relationship with the distance from the loading point. An Analysis of Variance (ANOVA) was run on both pond results to determine if the pond emissions rates were statistically different from each other. A direct comparison of the odour emission mean (at a standardised velocity of 1 m/s), standard deviation and variance showed that at both sites, there was a large variation in odour emissions across the surface. This agrees with

results discussed earlier from the United States, Heber *et al.* (2000). Table 3 shows the mean, standard deviation and variance across the different pond surfaces.

Recently, odour emissions have been measured from ponds with different loading rates. Both FSA Environmental and the Queensland Department of Primary Industries are currently assessing odour emission data from anaerobic ponds under different loading rates.

Odour nuisance

Odours are only an issue when they become a nuisance to neighbours. The so-called FIDO factors of frequency, intensity, duration and offensiveness of odour impact define nuisance. It is important to understand the factors that cause odour nuisance so that control measures can be proposed. The factors involved are odour creation, odour emission, odour dispersion (source to receptor) and odour perception. There is little that can be done to change the perception of odours by neighbours. However, piggery operators have the ability to change odour creation, emission and dispersion. In almost all cases (except volatilisation of ammonia), odours from piggeries are the by-products of the anaerobic break-down of organic matter. Organic matter is primarily manure (urine and faeces) but can also include spilt feed, carcasses and any other organic matter on-site.

The University of New South Wales has recently completed a piggery odour impact study with funding from the Pig Research and Development Corporation. The study looked at a single piggery situated in a rural area with numerous close receptors (houses). The results of recent studies in the Netherlands are also likely to be available soon.

Odour minimisation

In principle, odours at piggeries can be minimised if anaerobic conditions are minimised or if complete, controlled anaerobic break-down occurs. Conceptually, odour minimization techniques include the following:

- keep waste organic matter dry;
- reduce the quantity of waste organic matter;
- reduce the nitrogen and sulfur content of wastes;
- keep waste organic matter aerated;
- ensure complete controlled anaerobic processes;
- adopt aerobic organic matter reduction methods.

Specifically, these odour minimization techniques can be achieved at a piggery by:

- diet modification to reduce the amount of waste produced;
- diet modification to reduce the nitrogen and sulfur content of wastes;
- addition of proprietary additives to the diet or treatment system to modify break-down;
- reduction in feed wastage;
- dry handling of wastes (dry scraping of manure, deep-litter systems);
- aerobic treatment of wastes (aerated ponds, aerobic composting);
- improved anaerobic digestion methods (high-technology digesters).

Watts (1999b) provided the following conclusions regarding odour reduction strategies for Australian piggeries:

- Diet modification may have a role for existing piggeries with a substantial odour problem but there is insufficient data to use diet modification as an odour reduction strategy for a new or expanding piggery.

- There is a wide range of odour control additives. As with diet modification, they may have a role for existing piggeries with a substantial odour problem. However, the scientific validity of their effectiveness is inconclusive.
- Oligolysis or ozone treatment is of academic interest only and has not been shown to have practical applications.
- Dry handling of wastes has good potential for significant odour reduction. Dry handling reduces or eliminates the need for treatment ponds that are the main source of odour. Deep-litter systems have proven odour reduction potential. Dry handling of waste in conventional piggery sheds also has potential but the practicalities of such a system need resolving.
- Biofilters are a proven method of odour treatment. While they have been shown to operate well in piggeries in Europe and North America, their applicability in Australia is limited as few sheds are mechanically ventilated.
- Biofilters for ponds (permeable, organic covers) have good potential for odour control at Australian piggeries. Experience in Canada suggests that ponds covered with straw should emit little odour. However, the practical issues of maintaining an intact straw cover throughout the year need to be addressed. Covering ponds with a floating organic material (such as fat from an abattoir) should be examined.
- Impermeable covers (that collect methane and odorous gases) have potential for odour reduction. The collected gas can be flared or use to generate power. However, as an odour control method only, the cost of durable, permanent pond covers may limit their use.
- Surface aeration of ponds, theoretically, offers good potential for significant odour control. In Australia, this concept was promoted as "stratified ponds" in the 1980's but the system was not widely adopted. As with straw covers, practical issues need to be resolved.
- Considerable anecdotal evidence suggests that the presence of purple sulphur bacteria in a treatment pond means low odour emission. However, the circumstances favouring the growth of purple sulphur bacteria are not known. Pond design and management to promote these bacteria should result in odour control.
- The effectiveness of tree barriers and other physical devices on odour dispersion are not clear.

Modelling odour emissions

Odour nuisance assessment criteria

Different Australian states have different criteria for allowable odour impact of new piggery developments. These criteria have been reviewed by Agapides and Welchman (2000). Table 4 summarizes the current criteria for New South Wales, Queensland and Victoria. Watts (1999b) undertook AUSPLUME modelling on a typical 2000-sow piggery using a climate file for Oakey, Queensland and assuming flat rural terrain to determine the separation distances required using the criteria specified for NSW, Queensland and Victoria. The results of this modelling are given in Table 5. Clearly, the Victorian guideline does not produce sensible results, as it requires an average setback of almost 30 km from the piggery to a receptor. The Queensland and New South Wales guidelines produce similar results to each other. Watts (1999b) makes no comment on the acceptability or otherwise of the setbacks produced by the modelling or the State assessment criteria. For subsequent modelling, the NSW criteria were used.

Table 4. Assessment criteria for odour impact (NSW, Queensland and Victoria).

Criteria	New South Wales	Queensland*	Victoria
Dispersion model	AUSPLUME V4.0	AUSPLUME	AUSPLUME V4.0
Allowable odour intensity	2 to 7 OU	10 OU	1 OU
Olfactometry standard	Draft Australian standard	Draft Australian standard	Victorian B2 method
Averaging period	0.1 to 1 second	1 hour	3 minutes
Allowable percentile occurrence	99.0	99.5	99.9

*Draft standard (QEPA, 1999)

Table 5. Effect of assessment criteria on setbacks.

Assessment criteria	Minimum setback distance (m)	Maximum setback distance (m)	Mean setback distance (m)
Queensland	3030	5910	4550
New South Wales	1690	5250	3330
Victoria	19830	44590	29920

Proposed odour control strategies

Given that Smith *et al.* (1999) have estimated that about 80% of all odours from a typical Australian piggery are emitted from the ponds, then options to reduce primary pond size should be the first odour reduction strategy examined. These methods include either reduction in size or elimination of ponds through dry waste handling (deep-litter systems) or the covering or aerating of ponds. This situation is completely different from Europe where van't Klooster and Voermans (1993) estimated that the total odour emissions from an animal facility to the atmosphere is composed of 50% from indoor exhaust air, 25% from manure storage and 25% from manure transport and spreading. The major sources at any particular piggery will obviously depend on the particular design, with the significance of the emissions from the effluent treatment ponds determined by pond surface area and possibly pond loading rate.

The effect on odour emissions of chemical additives has not been scientifically validated. Reported results vary widely for most products and the physical process facilitating the odour reduction is often unclear. None of these methods were seen as effective or consistent enough to test as a potential odour control strategy for piggeries. Instead, the main focus was placed on influencing the physical processes that contribute to odour emissions.

Watts (1999b) proposed four options for odour reduction at piggeries in Australia. They are:

Option 1 – Growers/finishers to deep-litter system

All pigs are grown-out in a deep-litter system while retaining the breeding herd in conventional housing. Deep-litter systems are best suited to all-in, all-out production. Weaned pigs from 10 to 23 weeks of age are housed in deep-litter systems. These pigs produce about 66% of the total waste. This waste no longer enters the pond system. Hence, the ponds can be reduced in size.

Option 2 – Covered, high-rate primary pond

The large primary treatment pond is replaced with a much smaller one. The smaller pond is more heavily loaded (200 g VS/m^3/day), has no provision for sludge accumulation and is deeper (7 m). This could be described as a high-rate anaerobic pond. To cater for the anticipated increased odour emissions, the pond would be covered with a straw biofilter. A system of frequent sludge removal using permanently installed sludge pump will be used.

Option 3 - Covered, high-rate primary pond and growers / finishers to deep-litter system

This option is a combination of Option 1 and Option 2 with all grow-out pigs in a deep-litter system along with the high rate primary pond.

Option 4 - Aerated primary pond

In this option, the sheds and ponds are the same as the standard 2000-sow piggery. The difference is that the primary treatment ponds have been surface-aerated. There is no data available on the odour emission rates from surface aerated primary ponds. However, the experimental observations support a significant reduction in emission rate.

Effect of odour control options

AUSPLUME modelling was undertaken on the typical 2000-sow piggery and Options 1 to 4 to determine the setbacks required using the NSW criteria (see Table 6 and Figure 2). Table 6 shows that substantial reductions in required setbacks are theoretically possible if odour reduction strategies are employed. In some cases, the odour emission data available to use in the modelling is limited and in other cases, some practical issues need to be resolved.

Table 6. Effect of odour reduction strategy on setbacks.

Odour reduction strategy	Minimum setback distance (m)	Maximum setback distance (m)	Mean setback distance (m)	Percentage (%)
Standard piggery	1680	5250	3330	100
Option 1	880	2540	1670	50
Option 2	510	1760	1130	34
Option 3	310	980	710	21
Option 4	480	1440	1020	31

Mean Separation Distance is calculated as the radius of a circle of equivalent area to that enclosed by the odour contours in

- Figure 2. That is, the distance is calculated from the centroid of the piggery complex, not from the edges.
- Maximum and minimum distances are measured from the edge of the piggery complex (sheds or ponds) to the furthest or closest part of the contour. Hence these columns effectively show the calculated setback for the prevailing and least common wind directions.
- Percentage is the mean distance for the option as a percentage of the mean distance for the standard piggery option.

Conclusions

A review of pig odour data was undertaken with an emphasis on its use in dispersion modelling. Recommendations were made for odour emissions from pig buildings and ponds. These data are applicable to the Australian regulatory regime. Odour modelling was undertaken to determine setbacks required for a 2000-sow piggery in different states. Odour control strategies were proposed and modelled. Separation distances could be reduced from 50% to 80% by incorporating odour reduction strategies, such as deep-litter sheds and pond covers.

New data that has become available since the completion of the odour review has resulted in some of the recommendations being superseded. Practical application of the new options available in odour dispersion modelling will provide the most significant improvement to assessment of piggery odours in the near future. New odour emission measurements from piggery ponds and piggery sheds are likely to slightly change the

rates recommended in the odour review. These measurements will provide greater certainty in the emission rates used in modelling and in conversion factors used to relate CEN standard emissions to NVN 2820 standard emissions.

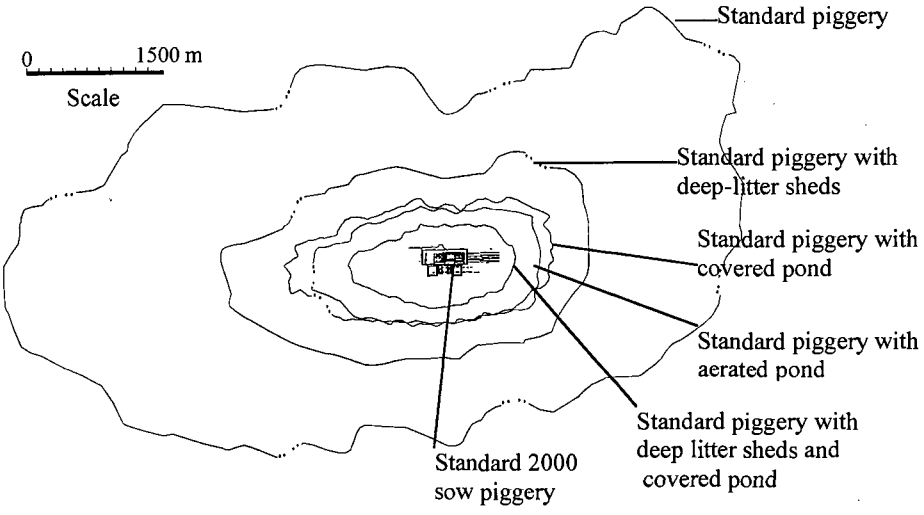

Figure 2. *Modelling results of odour reduction options (contour lines represent impact of odour emissions).*

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GROWTH RESPONSES TO DIETARY RACTOPAMINE ARE NOT MEDIATED BY PLASMA INSULIN-LIKE GROWTH FACTOR-I

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The β-agonist ractopamine (Paylean®, RAC) has recently been approved by the United States Food and Drug Administration for in-feed use to improve production efficiency in pigs. Dietary RAC increases lean tissue deposition but not insulin-like growth factor-I (IGF-I) in pigs fed protein-adequate diets (Dunshea *et al.*, 1993). In contrast, porcine somatotropin (pST) is thought to increase protein deposition through increased production of IGF-I. Therefore, the aim of this study was to investigate the interactions between dietary RAC, dietary lysine and time on plasma IGF-I concentrations.

Forty-eight Large White x Landrace gilts were allocated to a 6 x 2 factorial design with the respective factors being dietary lysine (0.29, 0.38, 0.47, 0.57, 0.66 and 0.75 g available lysine/MJ DE) and dietary ractopamine.HCl (0 and 20 ppm). Pigs were kept in individual pens and from 60 kg live weight (LW) were fed an average of 2.0 kg/d of their respective diets containing 14.8 MJ DE/kg until they reached 90 kg LW. Pigs were bled by venipuncture 3 h after feeding on days 7 and 21 after commencement of the study and again when they reached 90 kg LW. Plasma was analysed for plasma urea nitrogen (PUN), IGF-I and IGF binding protein 3 (IGFBP3) concentrations and the data analysed by repeated measures ANOVA.

Table 1. Effect of dietary ractopamine (R), dietary lysine (L) and day (D) on plasma IGF-I[1] and urea nitrogen concentrations in restrictively-fed (30 MJ DE/d) finisher gilts.

	Ractopamine	Day	Available dietary lysine (g/MJ DE)							
	(ppm)		0.29	0.38	0.47	0.57	0.66	0.75	SED	Significance
IGF-I	0	7	100	110	103	121	97	146	14.0	L***, D***
(ng/ml)		21	89	98	101	115	97	137		R***
		End	82	90	83	102	92	120		
	20	7	89	85	104	107	107	96		
		21	69	79	101	87	94	103		
		End	66	73	89	80	99	88		
Urea	0	7	7.1	9.6	12.5	18.9	22.3	21.5	1.21	L***, D***
(mg/dl)		21	7.6	10.8	13.5	16.3	22.0	23.8		R*, RxL***
		End	6.2	8.9	13.6	17.9	19.4	20.7		
	20	7	8.4	10.7	11.5	15.2	23.5	25.1		
		21	9.7	10.8	11.4	15.5	24.1	27.9		
		End	7.5	9.0	10.5	15.4	22.2	25.0		

[1]Insulin-like growth factor-I.

Plasma IGF-I increased with dietary lysine, decreased with time and was decreased by RAC treatment (Table 1). There were no significant effects on IGFBP3. Plasma urea nitrogen concentrations increased with dietary lysine and dietary RAC. However, there was a significant interaction between dietary lysine and RAC such that PUN was increased by dietary RAC at the two lowest and highest, but decreased at the intermediate dietary lysine contents. It is likely that at high dietary lysine contents, energy was limiting protein deposition and excess amino acids were converted to glucose to provide energy. It appears that pST and RAC exert their effects on lean tissue deposition through different mechanisms.

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DIETARY RACTOPAMINE INCREASES LYSINE REQUIREMENT OF GILTS BUT THE RESPONSE DIMINISHES WITH TIME

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The β-agonist ractopamine (Paylean®, RAC) has recently been approved by the United States Food and Drug Administration for use as a dietary ingredient to improve production efficiency in pigs. Dietary RAC increases lean tissue deposition and daily gain in pigs fed protein-adequate diets (Dunshea *et al.*, 1993a). Using protein accretion as the response criterion, Dunshea *et al.* (1993b) found RAC increased the lysine requirement of restrictively-fed gilts by approximately 0.10 g available lysine/MJ DE over the growth period from 60 to 90 kg live weight (LW). However, the growth responses were most apparent during the first three weeks of the study, then diminished with time. This raises the possibility that the lysine requirement also changes with time. Therefore, the raw data from Dunshea *et al.* (1993b) were reanalysed to determine the interactions between dietary RAC, dietary protein and time.

Forty-eight Large White x Landrace gilts were allocated to a 6 x 2 factorial design with the respective factors being dietary lysine (0.29, 0.38, 0.47, 0.57, 0.66 and 0.75 g available lysine/MJ DE) and dietary ractopamine.HCl (0 and 20 ppm). Pigs were housed in individual pens and from 60 kg LW were fed an average of 2.0 kg/d of their respective diets containing 14.8 MJ DE/kg until they reached 90 kg LW. To minimise confounding of the effects of energy intake, feed offered during the study was restricted according to a scale that increased with live weight. The relationship between daily gain and dietary lysine were fitted to an asymptotic model and the lysine requirement was calculated as the point where daily gain reached 0.95 of the asymptote (Dunshea *et al.*, 2000).

Table 1. Effect of dietary ractopamine and time on treatment on maximal growth rate and available lysine requirement in restrictively-fed (30 MJ DE/d) finisher gilts.

Treatment	Control		Ractopamine	
Period of treatment	0-3 weeks	3-6 weeks	0-3 weeks	3-6 weeks
Maximal daily gain[a] (g)	611	605	724	619
Available lysine requirement[b] (g/MJ DE)	0.53	0.35	0.67	0.39

[a]Plateau of asymptotic response between daily gain and dietary lysine. [b]Level of lysine where daily gain reached 0.95 of maximal daily gain.

Over the first 3 weeks of the study RAC caused a pronounced increase in both daily gain (18%, $P \leq 0.05$) and lysine requirement (26%, $P \leq 0.05$) (Table 1). However, over the subsequent 3 week period the increases in daily gain (2%) and lysine requirement (11%) for RAC treated pigs were considerably lower and not significantly different from control values. In practice, this means that if RAC is fed for more than 3 weeks, more than one diet may be required over the finisher phase to ensure that the pig's lysine (protein) requirement is met during the early part of the treatment period while ensuring that the diet is not over formulated for the latter part of the treatment period.

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PORCINE SOMATOTROPIN (REPORCIN®) DECREASES CARCASS AND BELLY FAT IN THE FINISHER GILT

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Although, over-fat pork bellies are cited as a limiting factor in the consumer acceptance of Australian pork, the evidence for this is anecdotal. While porcine somatotropin (pST) treatment improves growth performance and decreases backfat in finisher pigs (Campbell *et al.*, 1991), the effects of pST on the distribution of fat within the carcass have not been widely investigated. The present study was designed to determine whether pST (Reporcin®) reduces whole animal and belly fat.

The study utilised 24 Large White × Landrace gilts selected at 16 weeks of age with an approximate live weight of 80 kg and housed in individual pens. Gilts were stratified on live weight into 8 blocks and 1 pig from each block was assigned to either 0, 5 or 10 mg per day of Reporcin® (Alpharma Animal Health, Toorak, Australia). Pigs were fed *ad libitum* a wheat-based diet containing 200 g crude protein, 10.2 g available lysine and 14.6 MJ DE/kg, to ensure that responses to pST were expressed. Feed intake and live weight were measured on a weekly basis. An Hologic QDR4500 Dual Energy X-ray Absorptiometer (DXA) was used to determine lean, fat and ash composition of pigs initially and again 4 weeks later at the end of the experiment. Pigs were slaughtered after the final DXA scan and half carcasses were separated into belly, loin, shoulder and ham. These primal cuts were manually dissected to a retail level into fat, lean meat and bone.

Table 1. Effect of porcine somatotropin (pST) treatment on growth performance and body and carcass composition of finisher gilts.

pST (mg/d)	0	5	10	SED	P-value
Daily gain (g/d)	1170	1258	1259	97.9	0.59
Feed intake (g/d)	3440	2710	2537	163.0	<0.001
Feed conversion ratio	2.95	2.18	2.03	0.12	<0.001
DXA lean deposition (g/d)	620	839	873	66.9	0.004
DXA fat deposition (g/d)	384	218	176	32.3	<0.001
DXA ash deposition (g/d)	27.6	26.4	25.9	2.40	0.76
Carcass weight (kg)	91.8	93.1	91.6	1.70	0.64
Dissected carcass fat (kg)	19.3	14.6	10.9	1.41	<0.001
Dissected carcass fat (%)	24.7	17.8	14.0	1.63	<0.001
Dissected belly fat (kg)	2.04	1.35	0.85	0.17	<0.001
Dissected belly fat (%)	44.6	34.0	25.8	2.87	<0.001
Dissected ham fat (kg)	2.47	1.84	1.43	0.20	<0.001
Dissected ham fat (%)	18.7	13.2	10.8	1.27	<0.001
Dissected shoulder fat (kg)	2.21	1.90	1.46	0.25	0.03
Dissected shoulder fat (%)	16.8	13.3	10.4	1.52	0.003

Daily pST treatment decreased feed intake and decreased feed conversion ratio but had no significant effect on daily gain (Table 1). Pigs treated with pST deposited more lean tissue and less fat than control animals, but there was no effect of pST on ash deposition. While treatment with pST had no effect on carcass weight, pigs treated with 5 and 10 mg pST/d contained 5 and 9 kg less dissectible fat than the carcasses of control gilts, respectively. A dose dependent decrease in belly, ham and shoulder fat was also observed, although the proportionate decrease in belly fat was more pronounced than for the whole carcass and other primal cuts. In conclusion, pST treatment has the potential to decrease overall carcass, and especially belly fat, in pigs and increase consumer acceptance of Australian pork.

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EFFECT OF LIGHTWEIGHT PIG REMOVAL AND REMIXING ON WEAN-TO-FINISH PIG PERFORMANCE

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Recent research in the United States has suggested pigs housed in wean-to-finish facilities versus dedicated weaner houses followed by movement to dedicated finisher houses have similar performance from weaning to slaughter (Brumm *et al.*, 2000; Fangman *et al.*, 2001). A common management practice employed in wean-to-finish facilities is to overstock pens initially and then remove the lightest weight pigs, in the belief that removal and remixing of the lightweight pigs results in an improvement in overall pig performance and facility utilization. However, a recent study with growing-finishing pigs suggests no improvement in performance or facility utilization from such a practice (Brumm *et al.*, 2001). An experiment was conducted to test the hypothesis that removal and remixing of lightweight pigs at three weeks post-weaning improves growth and reduces variation in pig performance in a wean-to-finish facility.

The study was conducted using 225 newly weaned Danbred USA barrows (17 days of age, 4.8 ± 0.8 kg live weight, mean ± SD). Treatments were 15 pigs per pen from weaning to slaughter (15S), 20 pigs per pen for three weeks following weaning reduced to 15 pigs per pen (20/15), and 15 pigs per pen from three weeks following weaning to slaughter comprised of the five lightest pigs from each of three 20/15 pens per replicate (15M). There were three replicates. Corn-soya bean meal based diets in meal form were fed *ad libitum* following 1 kg/pig of a commercial pelleted pig starter. Pens measured 2.4 x 4.3 m and were fully slatted with cement slats having a slat width of 17.8 cm and a slot width of 2.5 cm.

Table 1. Effect of sorting and removal at 21 days post-weaning on pig performance from 21 – 158 days (Least Squares Means).

	Treatment			P values	
				Treatment	20/15 & 15M
	20/15	15M	15S		vs 15S
Coefficient of variation, within pen weight (%)					
21 d – pre-sort	— 19.5 —		17.0	0.137	
21 d – post-sort	13.7	11.3	17.0	0.009	0.003
158 d	7.6	7.9	6.9	0.732	0.443
Daily gain (g)					
Weaning – 21 d	— 196 —		223	0.028	
21 d – 158 d	783	756	771	0.009	0.809
Feed:gain (g/g)					
Weaning – 21 d	— 1.42 —		1.36	0.338	
21 d – 158 d	2.61	2.51	2.62	0.280	0.070

While sorting and removal of the lightweight pigs was effective in reducing within pen weight variation on day 21, it did not result in an improvement on day 158 post-weaning (Table 1). When comparing the population of pigs represented by the 20/15 and 15M treatment versus the 15S treatment, sorting and removal of lightweight pigs did not improve daily gain from 21 to 158 days post-weaning.

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EFFECT OF ALTERNATIVE FEEDING STRATEGIES ON WEANED PIGS HOUSED IN LARGE GROUP SYSTEMS

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Uptake of large group (LG) weaning systems by pig producers creates a number of complex nutritional challenges. Difficulties arise when defining an appropriate nutritional strategy to complement the variation in weaning weight of LG. The aim of this study was to demonstrate that specific nutritional feeding regimes will provide improved pig performance in LG of weaned pigs that vary in weaning weight.

A total of 1300 weaned piglets (Large White x Landrace) with a mean (± SD) weight of 7.4 ± 1.0 kg, age 24.7 ± 2.2 days were used in a randomised block design (group size 130) involving two treatments. Treatment 1 - Fixed feeding (FF) regime of four diets, each offered for a set number of days (Diet A-3 days; Diet B-11 days; Diet C-7 days; Diet D-14 days). Treatment 2 - Choice feeding (CF) regime, same four diets but offered in paired combinations over time (Diet A+B-day 0-7; Diet B+C-day 8-14; Diet C+D-day 15-35. All diets were commercially available and differed only in their nutritional value. Both FF and CF treatments were provided with eight identical feeders. For CF regime there were four feeders/diet, distributed sequentially within the pen. Pigs were housed in one building with slatted floors, and pen design layout was standardised. All pigs were weighed individually at weaning, day 7, 14, 21, 28 and 35. Age and sex at weaning were also recorded.

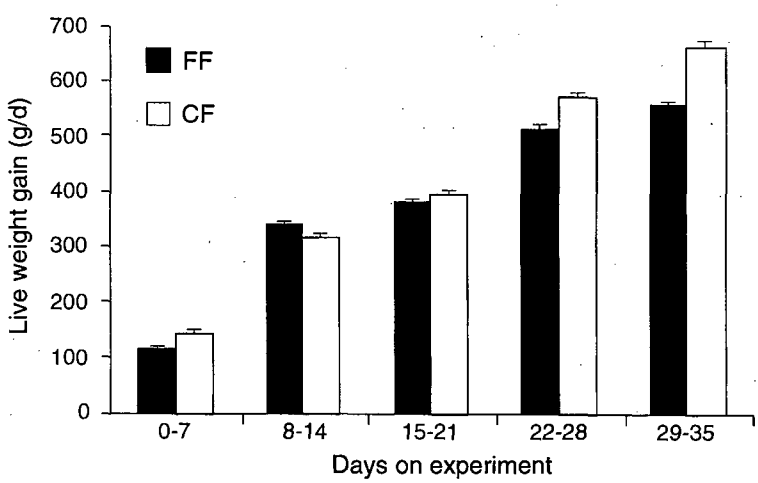

Figure 1. *Performance of pigs on fixed feeding (FF) and choice feeding CF) regimes during 35 days on experiment.*

Weight Gain (WG) during day 0-7 was significantly reduced for FF compared to CF, 0.117 vs. 0.143 kg/d (P<0.01). From day 8-14 WG for FF was significantly higher than CF, 0.340 vs. 0.315 kg/d (P<0.01). CF produced a significant WG response between day 21-28 and 28-35 (P<0.01). Live weight at day 35 was significantly lower for FF compared to CF, 19.9 vs. 20.7 kg (P<0.01). Pigs on a CF regime showed strong evidence of being able to select towards the higher nutrient diet, based on percentage of diet consumed, during day 0-7 A-86 vs B-14 %; day 15-21 C-64 vs D-36 %; day 22-28 C-66 vs D-34 %; and day 29-35 C-67 vs D-33 %, but not between day 8-14 B-51 vs C-49 %.

These data, demonstrate that a choice feeding regime may provide additional benefits when trying to accommodate the wide variation in weaning weight of large groups.

THE EFFECT OF PEN AND FEEDER SPACE RESTRICTION ON THE FEEDING BEHAVIOUR OF PIGS IN A DEEP-LITTER SYSTEM

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Pigs housed in large groups on deep-litter have longer feeding bouts with less disruption from other pigs compared to pigs maintained in conventional housing systems. Sargent et al. (1999) speculated that this change in feeding behaviour is associated with increased fat deposition and feed conversion ratio. An experiment was designed to test the hypothesis that reduction in pen and feeder space in large groups of pigs maintained on deep litter will produce shorter, more frequent feeding bouts, reduce carcass fatness and improved feed conversion.

A 2x2 factorial experiment examined the effects of pen space and feeder space from 10 to 23 weeks of age, using 2460 Large White x Landrace entire male pigs. Pen space was either unrestricted (1m2/pig) or restricted (0.45, 0.55 to 0.74 m2/pig). Feeder space was either unrestricted (15 pigs/feeding space) or restricted (9 pigs/feeding space). There were 12 pens of pigs, each with a group size of 205 pigs. Bedding consisted of rice hulls (0.7 kg/pig/day). Pelleted feed was offered ad libitum using double spaced, wet-dry feeders (82 cm wide). Four treatments were replicated three times. Ten animals/treatment/replicate were selected at random as focal animals for behaviour observations. Feeding behaviour was observed between 0530 to 1900 hours using time-lapse video for one week at 10, 17 and 23 weeks of age. Treatment effects were analyzed using analysis of variance with the group used as the experimental unit.

Table 1. Mean effects of pen space and feeder space on the feeding behaviour of focal pigs and growth performance of all pigs at 23 weeks of age. There was no significant interaction between the main effects.

	Pen space		Feeder space		SED
	Unrestricted	Restricted	Unrestricted	Restricted	
Total time feeding (s)	1620	1560	1546	1634	210.82
Number of feeding bouts	24.8	23.6	27.3	21.1	3.55
Mean duration of feeding bouts (s)	70.3	69.5	57.3^{a}	82.4^{b}	5.70
Social tactile interactions at feeder	59.5	61.6	71.1	50.0	9.80
Live weight at 23 weeks of age (kg)	104.8	104.0	104.6	104.2	0.54
FCR[1] from 10-23 weeks of age	2.55	2.55	2.46^{a}	2.64^{b}	0.05
Carcass P2 (mm)	12.5^{c}	11.6^{d}	12.1	12.0	0.06

$^{a,b;c,d}$Means in the same rows with different superscripts are significantly different at $P \leq 0.05$ and $P < 0.01$ respectively. [1]FCR = Feed conversion ratio.

Reducing pen space reduced ($P < 0.01$) carcass backfat (Table 1). This effect appears unrelated to feeding behaviour since pen space did not affect feeding behaviour. Reducing feeder space increased ($P \leq 0.05$) the average duration of feeding bouts and increased ($P \leq 0.05$) the feed conversion ratio, which may be the result of feed wastage. There was no evidence to support the hypothesis that reducing either pen or feeder space produces shorter, more-frequent feeding bouts. In conclusion, reduced backfat when pen space was reduced was not associated with changes in feeding behaviour. Social stress resulting from reduced pen space may be implicated.

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DECISION SUPPORT FOR PIGGERY WASTE MANAGEMENT

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Waste management practice in the Australian pig industry is under increasing pressure due to changing community expectations, urban encroachment, and tighter regulatory controls. While there are numerous waste treatment technologies available to pig producers, many lack information on how these technologies will affect their waste management practice. Hence, it is difficult for producers to rationally choose appropriate technology.

Current decision support tools focus on conventional treatment technologies and a narrow range of environmental criteria, i.e., the fate of liquid effluent, and the entrained nutrients and salt, from an intensive piggery using lagoons and land application. Thus, there is need for further information on a broader range of environmental concerns and a broader range of technologies. GreenPig is a decision support tool that aims to supplement the information provided by current tools.

GreenPig utilizes the pig-herd model in PigBal (McGahan *et al.*, 2000) to provide manure characteristics. Like PigBal, GreenPig uses mass-balances with linear performance assumptions within a spreadsheet environment. Default performance data is provided from a range of sources such as the publication by Kruger *et al.* (1995).

Options incorporated into GreenPig include intensive housing and eco-shelters, four solid processing operations, nine liquid treatment operations, and three disposal options. Housing, processing, and disposal options can be combined to assess various waste management systems (WMS).

GreenPig contains assumptions regarding the environmental emissions of the various technologies for example the nitrogen volatilisation, and ammonia to nitrous oxide ratios from lagoons and composted solids. All assumptions are highlighted and can be modified by the software operator to better reflect their experience or as a part of the sensitivity analysis. Indeed, analysis of the sensitivity of the waste management choices to variations in model parameters is central to determining the confidence with which the results can be viewed.

GreenPig uses the performance assumptions to complete a mass and energy balance over the specified waste management system. From this an inventory is compiled of resource consumption including energy, land, and water requirements as well as the pollutant load to air, land, and water. Life Cycle Impact Assessment (LCIA) is then used to calculate the environmental burden of the system providing information on issues such as global warming, soil toxicity, acidification, and eutrophication.

GreenPig is currently being upgraded to include economic data. This will allow the explicit trade-off of economic and environmental objectives when selecting a WMS. Hence, GreenPig will provide a platform to consider the impact of environmental taxes on the cost effectiveness of waste management alternatives.

Multi-objective optimisation is being investigated to enable computational selection of optimal housing, treatment, disposal and cropping choices for a given piggery's WMS.

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THE EFFECT OF CROSS-FOSTERING ON GROWTH DIFFERS BETWEEN PIGLETS OF HEAVY AND LIGHT BIRTHWEIGHTS

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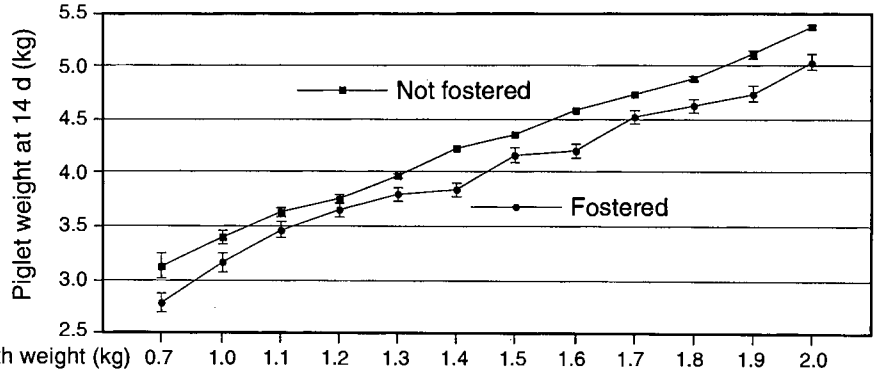
Cross-fostering of piglets at birth has been recommended in order to optimise the rearing capacity of the sow and to standardise piglet weights at weaning (English *et al.*, 1977). However, repeated cross-fostering is often practiced in industry which is stressful for the sow and her piglets resulting in lower weaning weights (Robert and Martineau, 2001). The effect of cross-fostering on piglet growth may differ among piglets with high or low birthweights, which could provide avenues to optimise cross-fostering practices.

Individual piglet weights at 14 days (IWT14) were available for 13640 piglets from 1615 sows raised in a commercial production system. Overall, 10.8% of piglets had been identified as being cross-fostered before 14 days. The model included the significant fixed effects of week of farrowing, line and parity of the sow, cross-fostering and birthweight of the piglet (IWTB) grouped in 100 gram classes along with the three-way interaction of parity of the sow, cross-fostering and IWTB (GLM, SAS 1988). This model explained 42% of the total variation for IWT14. Overall, cross-fostering reduced IWT14 by 0.262 kg. Fostered piglets born in first, second and third and later parity litters had a 0.100, 0.288 and 0.399 kg lower IWT14 than their non-fostered littermates. Cross-fostering reduced IWT14 most for runt piglets, which may have been cross-fostered repeatedly, and had a larger effect on IWT14 in heavier piglets that have a greater growth potential. Light to medium weight piglets were least affected by cross-fostering (Figure 1).



Piglet birth weight (kg)	0.7	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
No. not fostered:	80	206	426	788	1208	1499	1676	1614	1403	1130	777	1339
No. fostered:	78	75	99	143	144	147	159	163	151	109	93	109

Figure 1. *Least Square Means (± SE) of piglet weight at 14 days for fostered and not-fostered piglets with differing birthweights together with numbers of piglets in each category.*

Cross-fostering reduces piglet growth. English *et al.* (1977) suggested cross-fostering to accommodate the rearing capacity of the sow. In such cases, cross-fostering should be limited to the first day after farrowing, moving only piglets with light to medium birthweights in order to minimise the detrimental effect on piglet growth.

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THE EFFECTS OF FEAR OF HUMANS AND PRESLAUGHTER HANDLING ON MEAT QUALITY

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Human-animal interactions are a common feature of modern livestock production and these interactions, through stress, may have marked consequences on animal productivity and welfare (Hemsworth and Coleman, 1998). This study, using 90 Large White x Landrace female pigs aged 24 weeks, examined the relationships between the handling that pigs received immediately prior to slaughter and some measures of meat quality.

Two days prior to slaughter, the approach behaviour of pigs to a stationary experimenter was measured in a standard approach test to assess the pigs' fear of humans. The pigs were slaughtered in a commercial abattoir following transport and 12 h of lairage. Cameras were located along the route from the forcing pen to the stunning area to provide video records of the behaviour of the stockpeople and pigs immediately prior to slaughter. A 10-ml blood sample was collected from each pig from the carotid artery, which was severed on exsanguination. The blood samples were subsequently analysed for plasma cortisol, lactate and glucose concentrations. As described by King (1996), the meat quality characteristics of the pig carcasses were assessed by measurement of pH and light scatter using a Fibre Optic Probe at 6-8 hours post-slaughter in the loin (*M. longissimus dorsi*, at the P2 site) and the ham (*M. semimembranosus* adjacent to the *tuber ischii*). Human tactile interactions with the pigs were subsequently recorded from the video tapes as either positive, such as pats, strokes or the hand resting on the back of the animal; moderately negative, such as slaps and pushes; or highly negative, such as prods with an electric goad.

A number of significant correlations were found between the behaviour of the stockperson and the meat quality of the pigs. The number of highly negative interactions received by the pigs was correlated with plasma glucose concentrations ($r=-0.27$, $P<0.01$), plasma lactate concentrations ($r=0.25$, $P\leq0.05$) and the light reflectance of the ham ($r=0.31$, $P<0.01$). While the use of highly negative interactions was correlated with ham lightness and to a lesser extent ham pH ($r=0.16$, $P>0.05$), no such relationships existed between these negative interactions and loin characteristics. The number of highly negative interactions received by the pig, plasma lactate concentration and the time to physically interact by the pig with the experimenter in the standard fear test were significant ($P<0.001$) predictors of ham lightness. These variables accounted for 18% of the variance in ham lightness.

It is concluded that there are some important associations between the behaviour of the stockperson and post-slaughter muscle physiology of pigs. While no significant associations were found between stockperson behaviour and ham pH, the correlations between stockperson behaviour, plasma lactate and glucose and muscle lightness reflect increased muscle glycogenolysis presumably associated with increased handling stress prior to slaughter. Such results indicate the opportunity to manipulate the behaviour of stockpeople prior to slaughter to improve meat quality.

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BOAR FAT HAS BOTH PLEASANT AND UNPLEASANT ODOURS

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The significance of androstenone (5α) and skatole (Ska) as primary causes of boar taint remains controversial (Bonneau, 1998). A detailed analysis of pork fat aroma was conducted with the aim of identifying the major chemical components (as detected by GC-MS) and the extent of their correlation with the sensory analysis of boar taint.

Fat samples (200-400 g) were collected from the full depth of the subcutaneous abdominal region from 24 Large White x Landrace boars and gilts (132-156 days of age) with a dressed weight between 71-75 kg. The concentrations of 5α and Ska as detected by HPLC analysis were found to be elevated in boars, while gilts had low to undetectable concentrations of these compounds. Fat was stored at –20°C until 10 g samples were placed in a 250 ml bulb attached to a Dreschell tube and heated for 1 h between 180-220°C. The volatile organic compounds (VOCs) were purged with ultra high purity nitrogen (200 ml min^{-1}) and concentrated on to a Tenax trap. The VOCs were then extracted with a solvent and analysed by GC-MS (Rius and Garcia Regueiro, 1998). The sensory analysis involved 10 g of fat in a 100 ml beaker that was wrapped in aluminium foil. Three fat samples were heated at 200°C for 1 h in an oven under moist heat. Eleven panellists, pre-screened for their ability to detect the odour of 5α and Ska, were engaged for 32 sessions, and assessed three samples per session. After cooking, the samples were presented to the panellists, to assess the overall odour on a scale of 1 (unpleasant) to 10 (pleasant).

Table 1. Compounds with a significant impact on the odour of fat from boars.

GC-MS Peak	Gradient[1]	Sensory Effect	P –Value
Compound I	1.9	Positive	0.000013
Compound II	3.1	Negative	0.0015
Compound III	10.8	Positive	2.5×10^{-6}
Skatole	5.7	Negative	0.00013
Androstenone	7.4	Negative	0.029

[1]Gradient values from linear regression analysis of GCMS peak area and sensory data.

The odour of fat from boars was significantly lower in quality (P=0.015) and varied more than that from gilts. A regression analysis was conducted among the GC-MS peak areas of 35 major compounds and the sensory analysis data. Five major compounds were identified as contributing to the odour of fat from boars (Table 1). Compound III had a strong positive impact on odour followed by 5α and Ska which both had a negative impact. Compound II had the smallest negative impact and Compound I had a slight positive effect. The majority of the variance in boar odour (85.6%) was accounted for by these five compounds, but only 37.2% of the total variance was due to 5α and Ska. Clearly, compounds other than 5α and Ska contributed to the odour of pork from boars, and would need to be considered when screening for boar taint. Of the compounds that influenced odour perception in a positive fashion, Compound III warrants further investigation with regard to the factors that affect its presence in pork fat.

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THE INCIDENCE OF PORK QUALITY DEFECTS IN 16 MAJOR AUSTRALIAN ABATTOIRS IN 2001

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Inconsistent meat quality costs the Australian pig industry in excess of $22 million per year (Whan, 1993) with this loss being largely attributable to a condition called pale, soft, exudative (PSE) pork in which the colour is paler than normal, has a soft texture and a wet surface. Recently, King (1996) examined and reduced the incidence of PSE pork in four participating abattoirs by 38%. A project is currently assessing the incidence of pork quality defects in the major pork abattoirs in Australia and making recommendations in an effort to reduce the incidence of PSE and another quality issue, dark firm and dry (DFD) pork.

The current project has the participation of 16 of the major abattoirs in Australia, covering approximately 80% of the pigs slaughtered nationally. Audits were performed over two consecutive days at each abattoir to determine the incidence of PSE and DFD pork. Abattoir procedures and facilities such as lairages, stunning facilities, time from stunning to entry into chiller, scald temperature and duration, and chiller temperature and management were assessed each day. Muscle pH was measured at two sites on the carcass; the loin (*M. longissimus dorsi* at the last rib) and the exposed anterior end of the ham (*M. semimembranosus* adjacent to the *tuber ischii*) at 6-8 hours post slaughter. Meat quality was described as PSE if the pH was ≤ 5.6, normal if the pH was >5.6 and <6.0 and DFD when pH ≥ 6.0. (Joo *et al.*, 1995). Carcasses were described as having an extensive quality defect if the condition was found in both the loin and ham, or localised if the condition was found in only one of the two sites. The incidences of quality defects at the initial surveys, as well as some historical data, are shown in Table 1.

Table 1. The incidence (%) of meat quality defects in 16 major Australian abattoirs.

State	Abattoirs	No of pigs	Ext[1] PSE	Loc[2] PSE	Normal	Loc[2] DFD	Ext[1] DFD
NSW	5	1493	19.2	21.7	44.8	9.2	5.1
Qld	2	362	0.8	3.9	47.3	22.9	25.1
Vic. and Tas.	5	1652	11.0	17.6	27.8	24.5	19.1
SA	2	564	11.1	19.1	35.0	18.7	16.1
WA	2	430	24.2	19.8	44.4	6	5.6
Weighted mean[3]	16	4501	14.2	18.2	37.5	16.8	13.3
				PSE	Normal	DFD	
King (1996)	4			33	49	18	

[1]Extensive. [2]Localised. [3]Incidence of PSE, normal and DFD carcasses averaged by state over the two days and weighted for the number of pigs measured per abattoir.

The incidence of both PSE and DFD are still at significant levels within the industry and require considerable attention. Potential causes of these high levels were identified as poor facilities, excessive use of electric goads preslaughter, double stunning, overcrowding of chillers and poor chilling profiles. Future audits will determine the effect of recommendations made as a result of this survey and the reductions in poor meat quality attributes subsequently achieved.

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IMPROVED RETAIL SHELF LIFE OF PORK IN THE EXPORT MARKET

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There are several quality assurance (QA) systems in place in links of the export supply chain for chilled pork to Singapore. Connecting these programs, and establishing programs in sections that currently have no QA, are important support strategies for the market. The aim of this study is to demonstrate, in one supply chain, that the microbiological quality of meat can be improved by linking QA from farm to retailers in an export market.

Briefly, a supply chain was chosen that had been studied previously (Coates, 2000). Improvements in the elements of the chain were implemented; including commissioning a new quality assured cutting plant, with improved cold chain and hygiene practices, in the Singapore market. The changes should have improved the cold chain and thus the shelf life of the meat leaving the Singapore cutting plant. The microbiological quality of the meat leaving the new cutting plant (Table 1) was determined by Total Viable Counts (TVC), estimation of coagulase positive staphylococci (CPS), *Escherichia coli* (EC) and *Pseudomonas* spp. (PS). A predictive model (Food Spoilage Predictor, Gemini Data Loggers™) was applied to the *Pseudomonas* data and the remaining shelf life, at 4°C, calculated. Results were compared to those for similar testing conducted in the same supply chain prior to introduction of the new quality assured cutting plant. In addition the hygiene of surfaces, which has a significant impact on the microbiological load of meat (Coates *et al.* 1995), was compared (Table 2).

Table 1. Microbiology [counts per gram; mean (SEM)] and shelf life at 4°C (SL) of Australian chilled pork exiting cutting room X in Singapore before and after the establishment of a quality assured (QA) cutting room.

	Log TVC[1]	Log CPS[2]	EC[3]	Log PS[4]	SL (hours)
Before implementation of QA	6.641 (0.328)	Not tested	70.77 (85.04)	6.620 (0.554)	7.3
After implementation of QA	4.450 (0.148)	1.991 (0.131)	<5	3.409 (0.148)	77.4

[1]TVC = Total viable count. [2]CPS = coagulase positive staphylococci. [3]EC = *Escherichia coli*. [4]*Pseudomonas* spp.

Table 2. Microbiology [counts per cm^2; mean (SEM)] on boards in cutting room X in Singapore before and after establishment of a quality assured (QA) cutting room.

	Log Total viable count
Before implementation of QA	5.1271 (0.449)
After implementation of QA	2.899 (0.842)

The data showed a marked decrease in the microbiological load on meat and on the surfaces that it contacts. The microbiological quality after implementation of QA is similar to that of meat leaving export plants in Australia. Notably, the estimated remaining shelf life increased 10-fold. This prediction does not include an estimate for lag time. If lag time, which is 6.7 times the generation time at any given temperature, were included, the change in predicted shelf life is from 44.2 hours (before QA) to 114.3 hours (post QA). This increase is an important quality attribute that will assist on-going success of the product in the export marketplace.

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DIETARY MANIPULATION OF PORK FATTY ACID PROFILE

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Polyunsaturated fatty acids (PUFA) have a wide range of beneficial and protective effects on human health, especially against heart disease. The ideal ratio of PUFA to saturated fatty acid (SAT) in diets for humans is 0.7, and the ratio between C18:2 (linoleic acid) and C18:3*n-3* (linolenic acid) should be below 6.0 (Enser *et al.*, 2000). It is well known that the fatty acid profile of pork is changed when soya bean, canola or fish oils are included in the diets (Leskanich *et al.*, 1997). The aim of this study was to investigate whether linseed oil had similar properties, as it is a cheap source of C18:3.

Fifty-five Large White x Landrace pigs (57 kg ± 2.5 kg live weight, LW ; mean ± SD) were randomly allocated to one of the four experimental barley/soya bean based diets (14.5 MJDE/kg and 10.7 g available lysine/kg). Diet S contained 6 % tallow and Diet P contained 4 % soya bean oil and 2 % linseed oil. Vitamin E was included (100 ppm) in one diet of each type, to investigate its effect on lipid oxidation during storage (data not shown).

Pigs were housed individually and slaughtered at 88.2 ± 5.9 kg LW. Feed allowances ($0.11 \times LW^{0.75}$) were adjusted following weekly weighing. Diets, backfat (subcutaneous fat) and loin (intramuscular fat) samples were analysed for their fatty acid composition. Diet P contained 38 mg/g C18:2 and 15 mg/g C18:3 and diet S 15 mg/g C18:2 and 2 mg/g C18:3.

Neither the dietary fat type (P or S) nor vitamin E supplementation had a statistically significant effect on growth rate (1070 ± 15 4 g/d), feed conversion ratio (2.47 ± 0.34) or backfat thickness (11.8 ± 1.9 mm). Because Vitamin E supplementation did not affect fatty acid profiles, results for diet type only are presented (Table 1). Pigs fed diet P had more linoleic, linolenic and PUFA in loin and backfat tissues than pigs fed diet S. In both tissues, feeding diet P increased the PUFA:SAT ratio and reduced the C18:2/C18:3 ratio. Enser *et al.* (2000), who included linseed in the test diet, reported a reduction in C18:2/C18:3 but no increase in the PUFA:SAT ratio.

Table 1: Fatty acid profile (including phospolipids) of loin and subcutaneous fat of pigs fed a diet rich in saturated (S) or polyunsaturated fatty acids (P).

	Loin (mg/g meat)			Backfat (mg/g fat)		
	S	P	SED	S	P	SED
C18:2[1]	1.24	2.02	0.06***	70	145	4.4***
C18:3[2]	0.09	0.32	0.02***	13	51	2.2***
Saturated	3.93	4.22	0.26	334	322	9.9
Monounsaturated	5.15	4.77	0.40	454	386	10.0***
Polyunsaturated	1.67	2.70	0.08***	83	197	6.5***
PUFA:Saturated	0.44	0.66	0.03***	0.25	0.61	0.02***
C18:2/C18:3	18.2	6.5	2.59***	5.6	2.8	0.23***

[1]C18:2, Linoleic acid. [2]C18:3, Linolenic acid. *** Indicates significant difference between diets at P<0.001

Increasing the C18:2 and C18:3 content in the "finisher" diet increased their concentration in both intramuscular fat and subcutaneous fat tissue, and changed the PUFA:SAT and C18:2/C18:3 ratios towards the recommended values for human diet. It should also be noted that pork with a higher C18:3 content is more sensitive to oxidation.

Supported by New Zealand Pork

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CHANGES IN FATTY ACID PROFILE IN PORK FAT OVER TIME

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The polyunsaturated fatty acids (PUFA) content of pork can be changed toward a more "healthy" profile by the inclusion of an edible oil in the diet. Considering that the inclusion of oil in a diet increases its energy content, and that the optimal energy concentration in the diet decreases as the pig grows, it would be more practical to include oil in the diet at the beginning of the growing period instead of at the end. However, Warnants *et al.* (1999) reported a reduction in PUFA content in pork when a diet with a low PUFA content was fed after a diet with a high PUFA content. But Vogg-Perret (1989) found that the PUFA content in pork is proportional to the total PUFA fed to the animal, independently of when it was fed during the growing period. The aim of this study was to investigate the change in PUFA content in pork fat by feeding the same amount of PUFA at different times during the growth period.

Two diets were formulated (14.4 MJ/DE and 10.4 g available lysine/kg). Diet S contained 5 % tallow and Diet P 2 % soya bean oil and 3 % linseed oil. Twenty-eight pigs (23.3 ± 2.7 kg live weight; mean ± RSD) were randomly allocated to four treatment groups. Over the 55-day experimental period each pig received a total of 103.5 kg feed divided into three lots of 34.5 kg. Pigs in Group 1 (G1) had only diet S, Group 2 (G2) had two lots of diet S followed by one lot of diet P at the end, Group 3 (G3) had diet S, diet P and diet S in that order and Group 4 (G4) had diet P at the start followed by two lots of diet S. After slaughter (73.3 ± 4.4 kg), backfat (both layers together, subcutaneous fat) samples were collected and analysed for their fatty acid composition.

No statistically significant differences in growth rate (908 ± 64 g/d), feed conversion ratio (2.08 ± 0.15), backfat thickness (9.0 ± 1.9 mm), saturated (SAT 328 ± 23 mg/g fat) and monounsaturated (482 ± 35 mg/g fat) fatty acids were observed among groups. Feeding 34.5 kg of diet P at the beginning, in the middle or at the end of the growth period increased (G1<G2=G3=G4) the C18:2 (linoleic acid), C18:3 (linolenic acid), PUFA contents and PUFA:SAT ratio by 33%, 366%, 160% and 70%, respectively; and decreased the C18:2/C18:3 ratio by 300% (G1>G2=G3=G4).

Table 1: Fatty acid profile of subcutaneous fat for pigs fed diets rich in saturated (S) or polyunsaturated fatty acids (P) at different times during the growth period.

	G[1]1 (SSS)	G2 (SSP)	G3 (SPS)	G4 (PSS)	SED
C18:2[2] (mg/g fat)	99[a]	134[b]	131[b]	129[b]	7.8
C18:3[3] (mg/g fat)	13[a]	50[b]	48[b]	45[b]	3.1
PUFA[4] (mg/g fat)	111[a]	185[b]	180[b]	171[b]	10.3
PUFA/ SAT	0.32[a]	0.58[b]	0.56[b]	0.53[b]	0.04
C18:2/C18:3	7.89[a]	2.68[b]	2.72[b]	2.84[b]	0.38

[1]G, Group. [2]C18:2, Linoleic acid. [3]C18:3, Linolenic acid. [4]PUFA, Polyunsaturated fatty acids. [a,b]Values within rows with different superscripts are significantly different (P≤0.05, LSD).

The results showed that the fatty acid profile in pork fat at slaughter is primarily influenced by the total dietary PUFA intake and not by the time when high PUFA diets are fed. Thus, it is concluded that healthier pork can be produced commercially by including edible oil in the diet fed at the beginning of the growth period, when the optimal dietary energy concentration are high.

Supported by New Zealand Pork

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ANTIMICROBIAL EFFECT OF BOTANICAL EXTRACTS AGAINST SPOILAGE BACTERIA ISOLATED FROM PIG MEAT

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With increased targeting of export markets and the move to central packaging in domestic pork, Australian chilled pork must have a consistent shelf life with maximum potential. Several strategies are employed to extend shelf life, including the application of chemical treatments such as organic acid washes (Dickson and Anderson, 1992). Consumer concerns about chemical interventions in food indicate a potential market for more 'natural' products.

The antimicrobial properties of naturally occurring essential oils of plants have been well documented in the literature (Cowan, 1999). There has been little work on the use of natural antimicrobials to extend the shelf life of pork (Greer *et al.*, 2000). This study utilises a modification of an *in vitro* assay developed by Mann and Markham (1998), to determine the minimum inhibitory concentration (MIC) of 32 botanical extracts against food spoilage organisms.

Briefly, the assay used the compound Resazurin (blue) which is reduced by replicating bacteria to Resorufin (pink). The lowest concentration of the botanical extract under test, which does not result in a colour change from blue to pink, is considered to be the MIC. Thirty-two extracts were emulsified in Meuller/Hinton Broth or Brain Heart Infusion Broth (appropriate to the bacterial strain in this assay), containing 0.15% agar to stabilize the emulsion. The organisms were isolated from pork except *Brochothrix thermosphaca*, which was obtained from the American Type Culture Collection.

The MIC for 19 extracts was determined for each of the bacterial strains; the other 13 extracts tested had no inhibitory effect. Those inhibiting the growth of three or more strains are shown in Table 1.

Table 1. The minimum inhibitory concentrations (% v/v), of botanical extracts active against three or more food spoilage bacteria commonly found on pork. The highest concentration tested was 0.25%.

Organism tested*	BT	LC	LP	LL	AH	P
Bay	0.25			0.25	0.25	
Clove	0.25		0.25	0.25	0.25	0.25
Green Tea Catechin	0.03	0.25		0.03		0.16
Pinene (oxidised)	0.25		0.25	0.25		
Scandalwood W Aust	0.032		0.032	0.25		

*BT = *Brochothrix thermosphaca* ATCC 11509, LC = *Leuconostoc cremoris*, LP = *Lactobacillus plantarum*, LL = *Lactococcus lactus*, AH = *Aeromonas hydrophilia*, P = *Pseudomonas spp.* biotype 10.

The resazurin assay developed was robust and was used on a small pool of target botanical extracts to identify candidates that will be used in further work. The essential oils, clove, bay, scandalwood and the extracts of green tea and pinene have inhibitory effects that could be useful in prolonging the shelf life of pork products. However, the results will need to be validated by using these natural antimicrobials in shelf life studies, probably using vacuum packaged pork loins.

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DUAL ENERGY X-RAY ABSORPTIOMETRY PREDICTS LEAN YIELD IN THE HALF CARCASS AND PRIMAL CUTS OF THE PIG

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Grading on the basis of P2 fat depth alone may not allow the end use of carcasses to be optimised because of the variability in fat distribution throughout the carcass. Therefore, there is a need for a reliable grading system based upon lean meat yield in the whole carcass. One reliable and convenient method for determining both total and regional body composition is dual energy X-ray absorptiometry (DXA) (Lukaski et al., 1999) for which recent advances have markedly improved scan speeds and accuracy. The aim of the present study was to determine whether DXA could be used to predict composition in the half carcass and primal cuts of pigs dissected to a retail level.

The Hologic QDR4500 DXA was used to determine carcass composition in 144 half carcasses. The DXA regional analysis function was used to measure the composition of the ham, middle and shoulder regions. After scanning, the half carcasses were broken into the primal cuts of shoulder, middle and ham. Each primal was manually dissected to a retail level into fat, lean meat and bone. The weights of lean, fat and bone mineral (BM) estimated by DXA were compared with weights determined by manual dissection in the half carcass and primal cuts. Fat depth at P2 was measured directly and compared with manually dissected fat weight in the half carcass.

Table 1. Relationships between half carcass and primal cut composition as determined by DXA1 and manual dissection (y=Ax+B where y is dissected and x is DXA prediction).

	A	*B*	RSD[a]	R^2
Half Carcass				
Lean (kg)	0.81	-2.74	1.17	0.93
Fat (kg)	1.34	-2.40	0.87	0.87
Bone (kg)	5.24	1.80	0.57	0.64
Middle				
Lean (kg)	0.76	-0.93	0.60	0.87
Fat (kg)	1.48	-0.59	0.43	0.90
Bone (kg)	7.43	0.68	0.17	0.75
Ham				
Lean (kg)	0.84	-0.89	0.35	0.94
Fat (kg)	1.05	-0.35	0.28	0.76
Bone (kg)	5.78	0.12	0.25	0.68
Shoulder				
Lean (kg)	0.69	0.08	0.36	0.94
Fat (kg)	0.94	-0.13	0.31	0.70
Bone (kg)	5.87	0.33	0.30	0.64

[1]DXA, dual energy X-ray absorptiometry. [a]RSD, residual standard deviation.

The lean, fat and BM weights of the half carcass, middle ham and shoulder, as predicted by DXA, were highly correlated with dissected lean, fat and bone (Table 1). Bone mass was underestimated by DXA due to the estimate of BM being compared to whole bone weight which includes some water, fat and protein. The correlation between P2 fat depth and dissected fat in the half carcass was not as strong (R^2=0.58, RSD=3.12) as the DXA prediction. These data demonstrate the potential of DXA to determine whole carcass and primal cut composition at a retail level.

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CARCASS DAMAGE AT SLAUGHTER IS REDUCED EQUALLY BY SURGICAL AND IMMUNOLOGICAL CASTRATION

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Most male pigs in Australia are marketed as boars and are sexually mature at slaughter. The mixing that occurs during transport and lairage before slaughter can lead to aggression among unfamiliar pigs and result in physical injuries such as lameness and bruising (Grandin, 1980). The stress associated with mixing can also affect meat quality by the depletion of muscle glycogen, elevation of ultimate pH, ultimately leading to an increased incidence of dark firm dry pork (D'Souza *et al.*, 1999). As part of a recent study into the effect of castration on performance of entire male pigs, the incidence of carcass bruising as an indicator of aggression in entire boars and surgically or immunologically castrated males has been recorded.

The experiment involved a total of 180 Large White x Landrace pigs in 12 groups of 15 animals, with equal groups of entire males (EM), immunocastrated males (IM), entire males treated with Improvac® at 14 and 18 weeks of age) and surgically-castrated males (SM, castrated at 14 days old). The groups remained together until transport for slaughter, which occurred at 23 weeks of age. Pigs were subject to transportation of short duration and held overnight in lairage before slaughter the next morning. Carcasses were identified by tattoo and each carcass was photographed using simple autofocus cameras, with inbuilt flash and Fujicolor 200 film at a standard position and orientation just before entering the chiller. Photographs were analysed by two assessors without reference to the treatment the pig had undergone. The degree of bruising was assessed, principally on the neck and shoulder region. A numeric score of 0 was assigned to unmarked carcasses, 1 if it was considered that there might be one or two bruises, 2 if there was obvious bruising of the shoulder and 3 if there was severe bruising involving the shoulders and other parts of the carcass. The scores were averaged for all the pigs in each pen and subjected to analysis of variance.

Average pen scores for fighting damage were significantly (P=0.007, SED 0.20) higher for EM (1.01) than for IM (0.30) and SM (0.26). The frequency of pigs with fighting scores of two or greater ranged from 35.6% for EM, 3.6% for IM, and none for SM. All but one of the 12 pigs with fighting scores of three were EM. Clearly, castration markedly affected the extent of carcass damage, probably due to a decrease in aggression during lairage. The lower incidence of carcass lesions are consistent with the lower levels of aggressive behaviour observed in these same castrated pigs before transport to the abattoir (Cronin *et al.*, 2001). Cronin *et al.* (2001) found significantly lower levels of aggression in group-penned, SM at week 17 and week 21, compared to EM. The same levels of aggression were found in IM and EM at week 17, but following the second vaccination, these levels declined and were significantly lower by 21 weeks of age. The ability of surgical and immunological castration to suppress aggression among male pigs during the mixing that occurs before slaughter may provide benefits in improved meat quality.

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THE INCIDENCE OF PORK QUALITY DEFECTS IN MAJOR WESTERN AUSTRALIAN ABATTOIRS

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The National Pork Quality Improvement Program (NPQIP) was established in 1995/96 to reduce the incidence of pork quality defects especially pale soft exudative pork (PSE), a condition that causes large economic losses to the Australian pork industry each year. The NPQIP program reduced the incidence of PSE pork in participating abattoirs by 38% (King, 1996). However, the incidence of PSE in Australian abattoirs is above 20 % (King, 1996) and needs to be reduced to consistently provide both the domestic and export markets with quality pork.

Audits were performed at two major Western Australian pork abattoirs to evaluate the incidence of PSE and dark firm dry (DFD) pork in the respective abattoirs. Potential abattoir procedures contributing to the incidence of PSE and DFD were also identified. The audits were performed over two consecutive days at each abattoir to determine the incidence of PSE and DFD. On each day abattoir procedures and facilities were assessed, including lairage and stunning facilities, time from stunning to entry into chiller, temperature of scald tank and duration of scald and chiller temperature and management. On both days, twenty four hours post slaughter, pH and temperature measurements were made in the loin (*M. longissimus dorsi* at the last rib) and the exposed anterior end of the ham (*M. semimembranosus* adjacent to the *tuber ischii*) of 20% of the carcasses (Martin *et al.*, 1981). Pork was considered to be PSE when pH $\leq$ 5.6, normal when pH was >5.6 to <6.0 and DFD when pH $\geq$ 6.0 (Joo *et al.*, 1995). Combining the results for the loin and the ham allowed carcasses to be described as: extensive PSE or DFD (if same defect occurred in loin and ham); localised PSE or DFD (if one of the defects occurred at one of the sites); normal (if no PSE or DFD at all in the carcass). The incidence of PSE and DFD at the abattoirs is shown in Table 1.

Table 1. Incidence (%) of PSE and DFD in pork from two Western Australian abattoirs.

	Abattoir A			Abattoir B		
	Day 1	Day 2	Weighted mean*	Day 1	Day 2	Weighted mean*
Extensive PSE	14	6	10	18	60	36.9
Localised PSE	18	21	20	18	22	19.6
Normal	63	62	62.5	38	17	28.4
Localised DFD	3	8	5.5	11	1	6.5
Extensive DFD	2	3	2.5	15	0	8.2
Total no. pigs	101	101		125	103	

*Incidence of PSE, normal and DFD carcasses averaged over the two days and weighted for the number pigs measured per day.

Both abattoirs had a high and variable incidence of PSE. Electric prodder use just prior to stunning and the overcrowding of carcasses in the chillers was identified as potential factors that may affect the incidence of pork quality defects in Abattoir A. The high frequency of pigs double stunned (electrical stunning) and the use of electric prodders just prior to stunning were identified as potential factors that may affect the incidence of pork quality defects in Abattoir B. Future audits will be conducted to determine if recommendations targeting the potential problem areas at the abattoirs arising from the initial audits were implemented and were successful at reducing the incidence of PSE and DFD pork.

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THE EFFECT OF USING ELECTRIC PRODDERS ON PORK QUALITY

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Electric prodders are used to facilitate the movement of pigs during loading on-farm, unloading at the abattoir and from the lairage yards into the stunner. The use of electric prodders on-farm or just prior to slaughter can result in inferior pork quality and an increased incidence of pale, soft, exudative (PSE) pork (D'Souza *et al.*, 1998). Producers and processors at the Australian Pig Industry Quality Program (APIQP) Standards Workshop (1998) debated whether the use of electric prodders on-farm, or during transport or at the abattoir should be banned. It was concluded that the research investigating the influence of electric prodders on pork quality was not representative of the commercial environment. Hence, the aim of this study was to determine the influence of electric prodders as used on commercial farms and abattoirs on pork quality.

The study involved two farms, two transporters and two abattoirs each from Western Australia and Victoria. The four handling treatments were (1) pigs moved without the aid of electric prodders on-farm or at the abattoir; (2) electric prodders used to load and unload pigs from the truck only; (3) electric prodders used to move pigs from lairage to stun area only; and (4) electric prodders used throughout to move pigs on-farm and at the abattoir. Pig boards and paddles were used to move pigs in treatments not requiring the use of prodders. The study consisted of 3 replicates per farm (80 pigs/replicate). Ultimate muscle pH (pHu), surface exudate (filter paper method) and lightness (L*) were determined on loin muscle samples removed at 24 h post slaughter. Analysis of variance was used to analyse the main treatment effects within farm only.

Table 1. Effect of electric prodders as used on farms and abattoirs on pork loin quality

	WA Farm 1			WA Farm 2			Vic. Farm 1			Vic. Farm 2		
Handling treatment	pHu	L*	Exudate (mg)	pHu	L*	Exudate (mg)	pHu	L*	Exudate (mg)	pHu	L*	Exudate (mg)
1	5.54^{a}	54.1	52.6	5.38^{a}	55.5	41.9^{a}	5.52	49.2	40.6	5.43^{a}	52.5^{a}	49.1
2	5.57^{a}	53.9	46.0	5.38^{a}	55.9	42.2^{a}	5.55	48.7	44.5	5.45^{ab}	50.8^{b}	46.7
3	5.47^{b}	54.8	51.8	5.34^{b}	57.1	45.5^{ab}	5.58	48.1	37.1	5.49^{b}	50.7^{b}	50.9
4	5.54^{a}	54.8	59.8	5.41^{a}	56.7	53.1^{b}	5.57	48.7	36.8	5.34^{c}	51.3^{b}	51.2
l.s.d.	0.047	1.55	9.42	0.036	1.50	8.80	0.058	1.16	6.83	0.053	1.09	13.2
P-values	0.001	0.535	0.042	0.002	0.166	0.046	0.280	0.358	0.095	0.001	0.003	0.898

^{a,b,c}Values within columns with different superscripts differ significantly ($P \leq 0.05$).

The pork quality results are presented in Table 1. In Western Australia, the use of electric prodders to move pigs from lairage to the stunner resulted in lower loin muscle pH. The use of electric prodders on-farm and at the abattoir resulted in increased surface exudate (WA Farm 2). In Victoria (Farm 2), electric prodder use at all times on-farm and at the abattoir resulted in lower muscle pH. Electric prodders used to move pigs on farm (Victoria, Farm 2) and at the abattoir resulted in paler muscle colour compared to that when pigs were moved without using electric prodders.

The results, although variable, indicate that electric prodder use on commercial farms and at abattoirs has the potential to affect pork quality. Observations made during this study indicate that the major factors affecting pig movement requiring the use of electric prodders were the steep angle of loading/unloading ramps on multi-tiered trucks, lack of anti-slip cleats on ramps, poorly designed raceways leading to stunners and inadequate stockperson skills of truck drivers.

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ULTIMATE pH IS A POOR PREDICTOR OF PORK EATING QUALITY

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Due to excessive drip loss from pale, soft, exudative (PSE) pork, it is commonly considered that pork of low ultimate pH (pHu<5.6) can be tough and dry when cooked. In US sensory research, Miller *et al.* (2000) found that consumers preferred loin and ham chops from a high pHu category for juiciness, tenderness and overall liking than the two lower pHu categories. It was suggested that ultimate pH may have more potential than other meat quality attributes in classifying pork based on consumer eating quality categories. In a study of the consumer acceptance of eating quality of Australian pork, the relationship between ultimate pH and sensory attributes of pork loin steaks was investigated.

A total of 144 female pigs (Large White x Landrace) ranging in live weight from 75-110 kg from one producer were slaughtered over two days at three different abattoirs. Loin muscles (*M. longissimus thoracis et lumborum*) were aged for 48 h post-slaughter and pHu was measured. Six steaks of 2.5 cm thickness were sliced from the caudal end of each loin, individually coded and frozen. Each steak was assessed for tenderness, juiciness, flavour and overall liking using a consumer taste panel, with two consumers assessing each individual steak. Each consumer evaluated five half steaks from different loins. Pork steaks were cooked at 190°C for five minutes to a degree of doneness between medium/well done and well done. A total of 852 consumers evaluated a total of 1728 steaks (3456 half steaks). Ultimate pH (pHu) of the loin was measured at 48 h post-slaughter and correlated with consumer scores for each sensory attribute. Linear regression was used to model pHu on the mean scores for the eating quality attributes.

Ultimate pH of pork loins in this study ranged from 5.30 to 5.96. The distribution of ultimate pH of loins was as follows: ultimate pH<5.5 - 35%; pH 5.51 - 5.60 - 40%; pH 5.61 -5.70 -16.3% and pH>5.71 - 7.3%. Ultimate pH was poorly correlated (P>0.05) with all sensory attributes of the cooked steaks.

Table 1. Percentage variance (R^2) accounted for, and standard error (SE) of, the regression models using ultimate pH to predict the sensory attributes of tenderness, juiciness, flavour and overall liking of pork loin steaks.

	Tenderness	Juiciness	Flavour	Overall liking
R^2	1.7	11.6	2.6	1.7
SE	11.4	8.8	6.9	8.5

The measurement of ultimate pH was poorly related to pork eating quality of loin steaks grilled to a medium/well done to well done degree of doneness (Table 1). Although the fitted pHu term was significant (P≤0.05) in each of the regression models, the large standard error indicates that pHu would not accurately predict consumer ratings of tenderness, juiciness, flavour and overall liking of pork. This study suggests that, in addition to pHu, other meat quality attributes may be required to provide industry with a useful model for sorting pork into different eating quality classes.

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AGEING PERIOD IMPROVES EATING QUALITY ATTRIBUTES OF LOIN STEAKS FROM PIGS OF VARYING DUROC CONTENT

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Intramuscular fat content of pork has been associated with improvements in eating quality. Previous studies have shown that the Duroc breed produces pork with a higher intramuscular fat content relative to other breeds commonly used for commercial pig production in Australia. The objective of this study was to determine the effect of percentage Duroc content in crossbred Large White x Landrace female pigs on the eating quality attributes of pork loin steaks. A total of 42 female pigs were grown to a live weight of 102 ± 4.9 kg. Pigs were 0%, 50% or 100% Duroc, with a total of 14 pigs in each genotype group. All pigs were slaughtered at a commercial domestic abattoir over two slaughter days. Boneless loin muscles (*M. longissimus thoracis et lumborum*) from the right side of each carcass were individually vacuum packaged at 24 h post-slaughter. At 48 h post-slaughter, eight steaks of 2.5 cm thickness were sliced from the caudal end of each loin, individually coded and allocated to an ageing period of either 2 or 7 days post-slaughter. Pork steaks were cooked at 190°C for five minutes to a medium/well done and well done degree of doneness. Each loin was assessed for tenderness, juiciness and overall liking using a 100-point line scale to assess eating quality attributes. A total of 336 steaks (672 half steaks) were evaluated by 144 consumers over two tasting sessions. Each consumer evaluated five half steaks. Intramuscular fat content of the LTL muscle was also determined. All data was analysed using ANOVA.

Tenderness and overall liking of pork steaks were not influenced by Duroc content (Table 1). Steaks from 100% Duroc pigs were juicier (P=0.051) compared with those from 0% and 50% Duroc pigs. Overall, intramuscular fat content from 100% Duroc pigs was higher (1.84%, P=0.013) compared with 50% and 0% Duroc pigs (1.40% and 1.25%, respectively (SED 0.197)). However, the correlation between intramuscular fat content and juiciness was relatively poor (r=0.193). Tenderness and overall liking of loin steaks was improved (P≤0.05) by ageing pork steaks for 7 days post-slaughter.

Table 1 Effect of Duroc content (D; 0%, 50% or 100%) and ageing period (AP; 2 or 7 d post-slaughter) on tenderness[1], juiciness and overall liking of pork loin steaks.

	0% Duroc		50% Duroc		100% Duroc		SED	P value		
	2 d	7 d	2 d	7 d	2 d	7 d		D	AP	DxAP
Tenderness	49.9	55.1	48.9	55.7	53.7	55.7	3.72	0.697	0.006	0.479
Juiciness	57.5	61.0	58.5	60.3	65.1	65.1	3.11	0.051	0.189	0.572
Overall liking	56.5	59.7	56.6	60.1	58.7	61.2	2.85	0.692	0.027	0.943

[1]100-point scale: Higher scores = more tender, juicier and of higher overall liking.

These findings suggest that the production of 100% Duroc pigs will not improve tenderness and overall liking of pork, particularly at the concentrations of intramuscular fat recorded in this study. In contrast, D'Souza and Mullan (2000) reported that juiciness and tenderness of pork from 50% Duroc pigs was improved compared to pigs of <25% Duroc. In conclusion, ageing may improve eating quality attributes of pork more easily compared with increasing percentage Duroc content of Australian pigs.

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A SYMPOSIUM - MANAGING THE EATING QUALITY OF PORK

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Introduction

The Australian pig industry has long-focused on improving the quality and consistency of pork. It has done this with some success by the initiation of the National Pork Quality Improvement Program in 1994, which was reported by Warner (1997) to have reduced the occurrence of Pale, Soft Exudative (PSE) pork in participating abattoirs by 40%. Subsequently the Australian industry has implemented the Australian Pork Industry Quality Program (APIQ). While APIQ is focused on assuring customer needs for food safety and animal welfare, there is an increasing awareness that an Australian Pork Quality Standard must account for all aspects of pork quality throughout the value chain. There is therefore, an industry discipline, if not a framework, into which appropriate procedures to assure pork eating quality might be applied to Australian pork production.

In recent years, other countries have promulgated national industry guidelines for the production of lean and tender pork. In the UK, there was the Meat and Livestock Commission's "Blueprint for Lean and Tender Pork" and in the USA, the National Pork Producer's Council have produced Quality Targets for eating quality attributes (NPPC 1998). The latter system is described in part of this symposium (Meisinger, 2001). In Denmark, where producers, packers and processors are linked in a co-operative structure, Hofmeyr *et al.* (1998) describe how processors define the feed, genetics and production specifications of pigs that they require.

There is therefore an increasing international body of information to describe the hazards to good and consistent eating quality along the pork value chain. This value chain includes each sector of the pork industry, from pig breeding companies and producers through to the processors and retailers, whose activities both separately and jointly, can affect pork quality and add value to the product. Given that eating quality is essentially subjective and best measured by sensory panels involving consumers from the market of interest, it is important to have research with Australian consumers. The first two papers in this Symposium (D'Souza and Mullan, 2001; Channon 2001) include Australian data and begin to develop management strategies that address the critical controls to pork eating quality for the Australian industry.

In their APSA symposium on Pork Quality in 1997, Dr Warner and her colleagues suggested that by 2010, there will be precise definitions of the critical control points between conception and consumption which influence quality using a 'Palatability Analysis of Critical Control Points' approach (Warner, 1997). In 2001, this symposium on Pork Eating Quality describes the progress that has been made to this endpoint, both from a scientific and from a whole of chain viewpoint.

MANAGING THE EATING QUALITY OF PORK – WHAT THE PRODUCER CAN DO

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Abstract

Meeting the consumer's need for lean, tender, juicy pork that is free from off-flavours and aromas is imperative to the future success of the Australian pork industry in an ever changing, highly competitive and global food market. Pork consumption globally has increased, however *per capita* pork consumption in Australia has remained relatively static for the last decade. Significant changes to pork production have been implemented to provide health conscious consumers with lean and nutritious pork. However, it could be that many of these changes have been detrimental to the eating quality of pork and possibly to pork consumption in Australia. The introduction of the Halothane gene in Australian herds for increased carcass leanness has resulted in a higher incidence of pale, soft, exudative (PSE) pork and a negative impact on the tenderness and juiciness of pork. The use of entire male pigs has seen an increase in consumer complaints regarding 'boar taint' and toughness of pork. The increased use of metabolic modifiers on-farm as management strategies to reduce carcass fatness has also been shown to have a detrimental influence on the eating quality of Australian pork. The effects of metabolic modifiers on eating quality are discussed. Also discussed is the use of specific pig breeds such as Duroc that have higher intramuscular fat levels and consequently better flavour, juiciness and tenderness. The effect of dietary magnesium and vitamin E supplementation in pig diets and their positive influence on pork quality are also discussed as effective on-farm strategies for producers to implement to improve the eating quality of Australian pork.

Introduction

Over the last ten years the introduction of 'New-Fashioned Pork' in keeping with the increased consumer health awareness has seen the overall fat content of pork reduced by 60-65% (Barnes *et al.*, 1996). In addition, comparisons between cooked meats have indicated that 'New-Fashioned Pork' is not only significantly lower in fat compared to the leanest cuts of beef and chicken but also represents better nutritional value compared to other major animal protein products (Barnes *et al.*, 1996). The National Heart Foundation Food Approval Program currently approves 14 of the 22 cuts of 'New-Fashioned Pork' (Heart Foundation, 2001). In order to achieve this the Australian pork industry has had to implement significant changes to its production systems to produce leaner and 'healthier' pork. This has seen the introduction of leaner genetic lines, improved feed formulations, the use of in-feed antimicrobial agents, metabolic modifiers to improve carcass leanness, entire male pigs instead of castrated male pigs which are fatter, and heavier slaughter weights. Yet, the increase in pork consumption in more recent years has for the most part been minimal (ABS, 2000). Against a backdrop of increased global pork consumption in comparison with other meats, *per capita* pork consumption in Australia still lags well behind countries in North America and Europe (AMI, 1999), countries that in many instances have similar demographic profiles to Australia. Overseas research has shown that changes to production systems similar to that adopted by the Australian pork industry have had a negative impact on the many quality attributes of pork and this may explain why pork consumption in Australia has not increased significantly over the last decade.

Eating quality of Australian pork

A study conducted in 1994 by the Australian Meat and Livestock Corporation comparing beef, lamb, pork and chicken found that only 15% of consumers considered pork to be tender and juicy, whilst 32% of consumers stated that pork was inclined to be dry (AMLC, 1994). Consumers also rated pork as being the toughest and driest of all meats assessed. In 1997, a survey of Melbourne butchers and supermarkets identified considerable variations in pork tenderness, with 54% of pork loins purchased reported to be unacceptably tough (Hofmeyr, 1998). An "Eating Quality Assurance for Pigmeat" feasibility study (1997) found that consumers consider pork to be tough and dry in comparison to other meats due to inadequate intramuscular (IM) fat, the high incidence of pale, soft, exudative (PSE) pork, cold shortening (shortening of muscles due to over-effective chilling of hot pre-rigor carcasses), inadequate ageing and overcooking (Bennett, 1997). The study also identified boar taint in fresh and processed pork as the most significant cause of consumer complaints. The above studies quite clearly emphasise that consumers do not rate the eating quality of Australian pork highly in comparison with other meats.

Production factors affecting eating quality of pork

Pork eating quality is characterised by sensory or palatability traits such as tenderness, juiciness, flavour and aroma (Wood, 1993) and can be influenced by a range of production and processing factors. This paper will focus on the production factors with the emphasis on what pork producers can do to improve the eating quality of Australian pork.

Genotype

Halothane gene

Pigs carrying the Halothane (Hal) gene (homozygous recessive – nn (reactors); heterozygous – Nn (carriers) are leaner, grow faster and have better carcass conformation compared to 'normal' (homozygous dominant – NN) pigs (Wood, 1993). However, the introduction of the Hal gene in pig breeds has coincided with an increase in the incidence of pork quality defects such as PSE pork (Wood, 1993). Pigs carrying the Hal gene (nn and Nn) are stress susceptible (Porcine Stress Syndrome) due to disorders in muscle Ca^{2+} regulation, which results in the muscle being hypersensitive to stimulation by various stressors (Fuji *et al.*, 1991). Conditions during transport and at the abattoir that cause no stress to 'normal' pigs can stress Hal pigs causing a rapid rate of pH decline post-slaughter while muscle temperature is still high (>36°C), resulting in PSE pork (Briskey and Wismer-Pedersen, 1961). Pale, soft, exudative pork is characterised by its unusually pale colour, soft or sloppy texture and excess exudation (Bendall and Wismer-Pedersen, 1962; Channon *et al.*, 2000). Carcasses exhibiting PSE pork carcasses also tend to have a higher incidence of colour variations between portions of the same muscle (especially in the hams) and between adjacent muscles of PSE carcasses; this is referred to as 'two-toning' (Briskey and Kauffman, 1971). Consumers are hesitant to purchase pork that is pale or 'two-toned' and relate such pork to be of inferior eating quality. Most studies also indicate that PSE pork has inferior eating quality with reduced tenderness and juiciness (Bejerholm, 1984; Sather *et al.*, 1991). Studies have also shown that the improvements in tenderness associated with ageing of pork are not applicable to PSE pork (Fernandez and Tornberg, 1994; Warner, 1997, Channon *et al.*, 2000).

While the Hal gene is not wholly responsible for the high incidence of PSE pork in Australia, a survey of major pork processors in Australia found that the incidence of PSE was 51% (Eldridge *et al.*, 1993). A national program implemented in Australia has seen a dramatic decrease in the incidence of soft, exudative pork to 38 % (King, 1996). This, however, is still high and PSE remains a major problem affecting the eating quality of Australian pork. More recently, pork producers are becoming increasingly aware of the

link between genetic lines carrying the Hal gene and the incidence of PSE pork. As a consequence, major pig breeding companies are selecting for carcass leanness and using fast growing pig genetic lines that do not have the Hal gene. A recent survey in Western Australia indicated that majority of producers supplying pigs for export were using genotypes that did not have the Hal gene (D'Souza, unpublished data).

Hampshire gene

The Hampshire gene or the 'Rendement Napole' (RN) gene is a dominant gene and was first found in two commercial pig bloodlines in France (LeRoy *et al.*, 1990). The RN gene was found at a higher frequency in Hampshire pigs compared to other breeds such as Large White, Landrace, Yorkshire and Peitran. Pigs carrying the RN gene were found to have significantly higher muscle glycogen concentrations (70%) compared to 'normal' pigs (Estrade *et al.*, 1993). As a consequence RN pigs exhibit an extended period of muscle pH decline post slaughter leading to an extremely low ultimate muscle pH and water holding capacity, rather than the increased rate of pH decline and protein denaturation observed in PSE pork (LeRoy *et al.*, 1990). While the RN gene reduces muscle pH and water holding capacity of pork, the RN gene has been shown to improve pork tenderness and juiciness (Lundström *et al.*, 1998).

The incidence of the RN gene in Australian pig herds is unknown. However, as the number of Hampshire herds in Australia is low, it may be assumed that the impact of the RN gene on the eating quality of Australia pork is minimal. However, a detailed study will be needed to quantify the incidence of the RN gene in Australian herds and its potential influence on the eating quality of Australia pork.

Breed

Duroc and intramuscular fat

It is generally accepted that higher levels of intramuscular fat or marbling in pork have been shown to positively influence the juiciness, tenderness and flavour of pork (Wood, 1993, Table 1). This relationship is by no means clear-cut, with some studies reporting no effect of marbling on the eating quality of pork (Goransson *et al.*, 1992). The production of leaner pigs in Australia over the last 30 years has seen marbling levels at <1% (Channon and Baud, 2000), which is below the levels of 2 - 2.5% required for optimal eating quality of pork. This has coincided with deterioration in the eating quality of Australian pork.

Table 1. Effect of increasing intramuscular fat % on eating quality of loin pork chops (Wood, 1993).

Intramuscular fat %	Flavour[1]	Tenderness[1]	Juiciness[1]	Acceptability[1]
1.47	2.5[a]	1.3[a]	1.7[a]	0.6[a]
2.89	2.9[b]	3.1[b]	3.2[b]	2.0[b]
4.34	2.8[b]	2.4[c]	2.5[c]	2.0[b]

[1]Taste panel scores on a scale from -5 to 5 with low = undesirable. [a,b,c]Values within columns with different superscripts differ significantly (P≤0.001).

Comparative consumer studies indicate that meats such as chicken, beef and lamb that are considered to have better eating quality than pork (AMLC, 1994), also have significantly higher levels of marbling (Table 2).

Fast growing 'white' European pig breeds (Large White, Landrace, Yorkshire) have lower levels of marbling compared with the darker skinned breeds, such as Duroc (Wood, 1993; NPPC, 1995) and Berkshire (NPPC, 1995). The Meat and Livestock Commission, UK, evaluated the Duroc breed and found that tenderness of pork was improved in pigs with Duroc gene proportions above 50% while juiciness increased when the proportion of

Duroc genes was increased to 75% (MLC, 1992, Table 3). Similar improvements in juiciness, tenderness and flavour were also reported by the National Genetic Evaluation Program (NPPC, 1995). In addition, Candek-Potoker *et al.* (1996) reported that pork from Duroc pigs not only had higher marbling levels but also better colour and texture compared to Large White and Landrace pigs.

Table 2. Intramuscular fat in lean portions of beef, lamb, chicken and pork (g/100g).

	Beef[1]		Lamb[1]	Chicken[2]		Pork[3]
	Fillet	T-Bone	Loin	Drumstick	Breast	Loin
Intramuscular fat %	4.3	4.2	5.6	5.6	2.5	1.0

[1]MLA (2001); [2]Reppel (1986); [3]Channon and Baud (2000).

Table 3. The influence of % Duroc genes on pork eating quality (MLC, 1992).

	% Duroc genes				
	0	25	50	75	Approx LSD
Tenderness[1]	4.96	5.03	5.32	5.38	0.25
Juiciness[1]	4.09	4.11	4.18	4.38	0.17
Flavour[1]	3.88	3.99	3.96	3.98	0.12

[1]Evaluated on an 8 point scale (lower = undesirable)

Studies also indicate that the inclusion of Duroc bloodlines in predominantly 'white' European breeds can also result in improvements in pork eating quality. Recent studies conducted in Western Australia, indicate that Large White x Landrace x Duroc crossbred pigs with a high proportion of Duroc genes (50%) had higher marbling values, better juiciness, tenderness and flavour compared to pork from Large White x Landrace x Duroc crossbred pigs with a low proportion of Duroc genes (<25%) (D'Souza and Mullan, 2001).

Sex

Most Australian pig producers moved away from castration of entire male pigs about 30 years ago to harness the production benefits associated with entire male pigs. As a consequence 10 – 15% of entire male pigs produce pork that has a perspiration or urine like smell or 'boar taint' when cooked (Hennessy and Wan, 1993). The major compounds responsible for boar tainted pork are androstenone and skatole (Patterson *et al.*, 1990). Research conducted by the Meat and Livestock Commission (1989) found that while tenderness, juiciness and flavour was unaffected by sex, abnormal pork odours were higher in pork from entire male pigs.

The export of Australian pork to Asia, which only accepts pork from female and surgically castrated pigs, has meant that the likelihood of domestic consumers purchasing boar-tainted pork has also increased. Recent results indicate that pork from males pigs castrated by using the immunological castration vaccine Improvac® had lower androstenone and skatole concentrations, higher marbling levels and lower surface exudate compared to pork from entire male pigs (D'Souza *et al.*, 2000). Although the effects of boar taint have not been as conclusive with consumer taste tests as with objective assessment of pork quality, D'Souza *et al.* (1999b) reported that pork from entire male pigs tended to have poorer odour compared to pork from surgical and immunological castrates (Table 4).

Pork from surgical castrates has also been reported to have superior eating quality compared to pork from female pigs. Unruh *et al.* (1996) reported that at 127 kg live weight, pork from the *Longissimus* muscle from surgical castrates had more visible marbling, less moisture exudate and less thaw loss compared to pork from female pigs.

Table 4. The effect of sex (entire male - EM, surgical castrate male - SCM and immunological castrate male - ICM) on eating quality of pork loin steaks (D'Souza *et al.*, 1999b).

Sex (S)	EM	SCM	ICM	LSD	P-value
Odour[1]	56	62	62	6.13	0.093
Flavour[1]	58	62	66	7.01	0.101
Tenderness[1]	52	59	62	7.44	0.016
Juiciness[1]	60	59	64	7.05	0.304
Overall acceptability[1]	58	62	67	6.41	0.025

[1]Acceptability score (line scale) for all attributes, 0 = dislike extremely and 100 = like extremely.

While many Australian consumers may not find boar taint objectionable, it appears from anecdotal observations that most of the Asian populations in Australia and overseas discriminate against pork from entire male pigs. This concern has prompted a number of producers in Australia to move towards castration of entire male pigs using Improvac®. Currently in Western Australia, Improvac® pigs are marketed under the brand name Flavasure™ that guarantees pork to be free of boar taint.

Feeding regimes

Ad libitum feeding

The benefits of *ad libitum* versus restricted feeding in terms of growth performance and carcass quality are significant. Pigs fed *ad libitum* during the grower and finisher phase (30 – 100 kg live weight) grow faster (Trezona, 2001). The *ad libitum* feeding of protein deficient diets 30 days prior to slaughter improved the eating quality of pork by increasing marbling levels in the loin (Cisneros *et al.*, 1996). The increase in marbling reported by Cisneros *et al.* (1996) however, was also accompanied by an increase in carcass fatness. Studies have also shown that feeding high energy diets, especially in the latter stages of growth, can elevate the rate of protein synthesis and degradation which may accelerate *post mortem* proteolysis and improve the tenderness of pork (Tarrant, 1998).

Dietary fats

The trend towards leaner pigs has also resulted in problems with the quality of fat in the carcass that can affect both the appearance and eating quality of pork. Problems with fat quality include soft or 'floppy' fat, fat and lean tissue separation, and flavour taints (Sather and Jones, 1996). The amount of fat in pig carcasses increases rapidly during growth, originating both from the diet and from synthesis. Feeding diets high in unsaturated fats was found to increase the concentration of unsaturated fatty acids in carcass fat resulting in soft fat (Wood, 1984).

The problem of fat and lean tissue separation is often called 'lacy' fat because of its appearance in pork products such as bacon rashers. Lacy fat results from the strands of connective tissue that separate both between the fat layers, and between the fat and lean tissues during further processing of pork cuts (Bailey and Light, 1989). The cause of fat separation, unlike soft fat, appears to be due to the immature nature of the adipose connective tissue rather than to the degree of unsaturated fatty acids present in adipose tissue (Bailey and Light, 1989).

The inclusion of fishmeal in pig diets above 5%, has an adverse effect on the eating and keeping qualities of pork and pork products (Coxon *et al.*, 1986). While fresh pork from pigs fed fishmeal may be free of 'fishy' flavours and odours, almost invariably, stored processed products such as bacon and ham, will show unacceptable levels of rancidity particularly after freezing. Researchers from a number of countries have

recommended that diets should contain no more than 5% fish meal or 0.5% fish oil and that they should not be fed within two weeks of slaughter (Davies, 1939; Karrick, 1967). Because of cost, the use of fishmeal or fish oil in pig diets is not a common practice in Australia. However, these oils may be included in feeds inadvertently through other sources such as inclusion of waste cooking oils.

Feed additives

Magnesium

Magnesium (Mg) has a relaxant effect on skeletal muscle and has been shown to depress skeletal muscle activity by antagonising calcium, which is required for neurotransmitter release and muscle contraction. This reduces the secretion of neurotransmitters by motor-nerve impulses, which in turn reduces neuromuscular stimulation (Hubbard, 1973; Hagiwara *et al.*, 1974). Studies have since shown that dietary magnesium supplementation alleviates the effects of stress by reducing plasma cortisol, norepinephrine, epinephrine and dopamine concentrations (Niemack *et al.*, 1979; Kietzman and Jablonski, 1985). Consequently, studies have been conducted to investigate the influence of dietary Mg supplementation on reducing the effects of stress and improving pork quality.

Numerous studies have shown that dietary Mg supplementation in pigs resulted in improved pork quality. Otten *et al.* (1992) examined the use of long-term dietary Mg supplementation and reported slight improvements in pork colour and initial pH, whereas Schaefer *et al.* (1993) studied short term dietary magnesium supplementation and reported reduced initial pH and % drip loss. D'Souza *et al.* (1998) have shown that dietary magnesium aspartate supplementation at 3.2 g elemental Mg for 5 days pre-slaughter significantly improved pork quality in pigs by reducing the drip loss and improving pork colour and muscle pH (Table 5). The effects were such that there were no PSE carcasses in the magnesium supplementation treatment groups, irrespective of the type of pre-slaughter handling (D'Souza *et al.*, 1998). Dietary supplementation using inorganic Mg sources such as $MgSO_4$ and $MgCl_2$ (D'Souza *et al.*, 1999a) and magnesium mica (Apple *et al.*, 2000) have also been shown to reduce drip loss, improve colour and reduce the incidence of PSE pork. The use of dietary organic magnesium supplementation as a viable method to improve meat quality in pigs was validated under commercial conditions in Victoria, Australia (Hofmeyr *et al.*, 1999). In this study, organic magnesium supplementation significantly reduced the incidence of soft, exudative pork in all three replicates.

Table 5. The effect of dietary magnesium aspartate (MgAsp) supplementation and pre-slaughter handling on meat quality indicators of the *Longissimus thoracis* muscle 24h post-slaughter (D'Souza *et al.*, 1998).

Diet (D)	Control		Mg Aspartate		
Handling (H)	Minimal	Negative	Minimal	Negative	Significance
Ultimate pH	5.48	5.51	5.61	5.57	D**
Surface lightness L*	48.7	49.1	45.2	47.4	D**
% Drip Loss	4.0	6.4	3.5	3.5	D**; H*
% PSE	8	33	0	0	D*

*P≤0.05; **P<0.01; ***P<0.001.

Although the use of dietary magnesium supplementation has been shown to improve objective measures of pork quality, there are no data relating the improvements in objective measures of pork quality with improved pork eating quality. However, as the relationship between low water holding capacity and increased meat toughness is well established (Lawrie, 1998), it is reasonable to assume that the reduced drip loss and the

lower incidence of PSE observed with dietary Mg supplementation could have a positive influence on the eating quality of pork.

Vitamin E

Dietary vitamin E (*all-rac-α*-tocopheryl acetate) supplementation has been shown to reduce drip loss, improve colour stability and reduce the off-flavours of both fresh and processed pork products (Asghar *et al.*, 1991; Monahan *et al.*, 1992). While dietary vitamin E supplementation can have a positive impact on the eating quality of fresh pork, the real benefits are the improved lipid and colour stability and improved water holding capacity in pork products which require frozen storage for extended periods. There are a range of factors that contribute to the deterioration in pork quality and loss of shelf life as a consequence of lipid oxidation occurring in pork and pork products. These factors include the state and content of pro-oxidants such as iron and myoglobin; the level of antioxidants such as α-tocopherol and enzymes such as glutathione peroxidase, superoxide dismutase and catalase present in muscle; the composition and amount of muscle lipids; and the storage conditions of meat and meat products (Lawrie, 1998).

Asghar *et al.* (1991) and Monahan *et al.* (1992) attributed the reduced drip loss and improved colour stability of pork from pigs fed vitamin E supplemented diets to a reduction in lipid oxidation in muscle cell membranes. The reduced lipid oxidation in muscle cell membranes reduced the movement of water across the cell membrane post-slaughter. Duthie *et al.* (1989) however, attributed the reduction in drip loss and colour stability to alterations in muscle cell membrane permeability to calcium resulting in a reduced rate of glycolysis and muscle pH decline. If so, then the increased oxidative stress encountered by Hal pigs (nn and Nn) may be alleviated by dietary vitamin E supplementation. However, Warner *et al.* (1995) found that feeding vitamin E to Hal pigs did not prevent the PSE condition and had no major effect on the water holding capacity of pork.

Metabolic Modifiers

Porcine somatotrophin

Intramuscular administration of porcine somatotropin (pST) is an effective management strategy to reduce backfat in pigs (Campbell *et al.*, 1990) and is one that is quite widely used in Australia. Porcine somatotrophin increases protein deposition and decreases subcutaneous, intermuscular and intramuscular fat deposition resulting in leaner carcasses (Dunshea, 1994). Studies by Lefaucheur *et al.* (1992) and Ender *et al.* (1992) have reported reductions in both carcass fat and marbling levels in pork from pigs administered pST without any detrimental effects on the eating quality of pork. The above studies (Lefaucheur *et al.*, 1992; Ender *et al.*, 1992) are in contrast to that reported by D'Souza *et al.* (2001) who found that pork from pigs administered pST had lower consumer preference scores for tenderness, juiciness and overall acceptability. Solomon *et al.* (1990) reported that pST administration increased muscle fibre size and subsequent shear force, an objective measure of tenderness, of fresh pork. The use of pST has also been reported to reduce calcium-activated proteolysis in the *Longissimus* muscle, thereby preventing improvements in tenderness during the ageing process (Weikard *et al.*, 1992).

Porcine somatotrophin administration remains an important management strategy enabling Australian pork producers to better meet the demands of the consumers for leaner pork. However, the Australian pork industry must pay additional attention to the potential negative influence of such management strategies on the eating quality attributes of pork.

Chromium

Chromium supplementation in pig diets was found to improve feed efficiency, lean meat yield and reduce backfat thickness (Page *et al.*, 1993). However, limited research has

been conducted on the effects of dietary chromium supplementation on pork quality. In a recent study by Matthews *et al.* (1999), dietary chromium proprionate supplementation in finisher pigs increased the level of marbling and reduced the purge loss in the loin muscle. However, the reasons for the increase in marbling and the reduced purge loss are unknown. In contrast, O'Quinn *et al.* (1998) reported that the use of chromium picolinate supplementation had a detrimental effect on pork colour. As it is possible that the source of chromium may be responsible for the varied effects of chromium supplementation on pork quality, these effects should be further investigated. Dietary chromium supplementation is another management strategy to reduce carcass fatness that is widely used by Australian producers. While the research to date has yet to elucidate the effect of chromium supplementation on the eating quality of pork, early indications are that it may have a negative impact.

Betaine

Betaine is an active methyl donor with a lipotropic effect (Barak *et al.*, 1993). Adding betaine to pig diets has shown to reduce and change the distribution of carcass fat (Cadogan *et al.*, 1993; Henman, 1995; Dunshea and Walton, 1995). Xu *et al.* (1999) reported that betaine supplemention resulted in improved carcass quality and improved subjective colour and marbling scores. In contrast, Øverland *et al.* (1999) reported no effect of betaine supplementation on objective meat quality. While the effects of dietary betaine supplementation on objective pork quality are varied, there is no information regarding the effects of dietary betaine supplementation on the eating quality of pork.

Conjugated linoleic acid

The use of dietary conjugated linoleic acid (CLA) supplementation has also been shown to be an effective management strategy in reducing backfat in pigs (Dunshea *et al.*, 1998; Thiel *et al.*, 1998). Studies by Dunshea and Ostrowska (1999) and O'Quinn *et al.* (1998) found that dietary CLA supplementation had no effect on objective pork quality measures such as surface lightness, muscle ultimate pH, drip loss or cooking loss. Dietary CLA supplementation in pigs was also reported to increase marbling levels (Carroll *et al.*, 1999; Dugan *et al.* 1999; Weigand *et al.*, 2000). However, D'Souza *et al.* (2001) reported that pork from control pigs had better eating quality compared to pork from CLA fed pigs. The influence of dietary CLA supplementation as an effective strategy to reduce carcass fatness is well established. However, the impact of dietary CLA supplementation on the eating quality of pork is somewhat less clear-cut and this warrants further investigation.

Ractopamine

Ractopamine is a β-agonist that increases the protein deposition rate in pigs (Dunshea and King, 1994; Dunshea *et al.*, 1993; Dunshea and Walton, 1995). Ractopamine has recently been registered as a feed additive to improve carcass leanness (Paylean®) for use in the United States of America and is currently under consideration for registration in Australia. Dietary ractopamine supplementation had no effect on muscle pH, colour, water holding capacity or marbling levels (Dunshea *et al.*, 1993; Sainz *et al.*, 1993; Xu *et al.*, 1998; Xiao *et al.*, 1999). Smith *et al.* (1995) reported that loin muscle from female pigs had higher muscle pH, lower cooking loss and darker colour, while that from entire male pigs fed ractopamine had higher drip loss and paler colour. A negative effect of ractopamine on objective measures of tenderness was also reported by Uttaro *et al.* (1993).

Conclusion

There is tremendous opportunity for the Australian pork industry to build on its export market in Asia and at the same time increase its domestic market. However, significant steps must be taken to consistently produce pork that is lean, tender, juicy and free of unpleasant flavours and aromas. The production factors described in this paper

indicate that producers can go a long way to improving the eating quality of Australian pork. The use of pigs with a high proportion of Duroc bloodlines, castration of entire male pigs and the elimination of the Hal gene from Australian pig herds are just some of the ways pig producers can influence the eating quality of pork. However, the implementation of such changes will add to the cost of production especially if backfat thickness and carcass weight continue to form the basis of payment to pig producers in Australia. Therefore, the Australian pork industry must look to larger pork producing countries such as USA, Denmark and The Netherlands and adopt their 'whole industry approach' to pork production and implement similar eating quality standards as part of an overall quality assurance system to produce pork that is lean, tender, juicy and free of unpleasant flavours and aromas.

Symposium continued on next page

MANAGING THE EATING QUALITY OF PORK – WHAT THE PROCESSOR CAN DO

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Abstract

The competitive nature of the Australian food industry requires that pork is produced efficiently and with consistently high quality. The future of the Australian pork industry depends on its ability to meet consumer demands and produce pork that is lean, tender, juicy and has an acceptable flavour. Food safety concerns, meal convenience, price, dietary health status and consistency of eating quality all collectively influence customer satisfaction with pork. Australian consumers generally consider pork to be tough and dry in comparison to other meats. This may be due to the high incidence of pale, soft exudative (PSE) meat, inadequate intramuscular fat, cold shortening, inadequate ageing, and overcooking of pork by consumers. In other countries processing practices such as electrical stimulation, aitchbone or pelvic suspension, ageing of pork and the enhancement of pork quality by addition of brine solutions, are being used to reduce the variability and improve the consistency of eating quality attributes of pork. Currently, Australian processors are not routinely utilising such practices for pork destined for the domestic market. This may be due to the lack of economic incentives since payment systems generally used for pigs are primarily based upon hot carcass weight and fat depth at the P2 site.

Introduction

Hofmeyr (1998) highlighted that considerable variability existed in the tenderness of Australian pork when measured objectively using Warner Bratzler (WB) shear force. In a survey of Melbourne butchers and supermarkets conducted from December 1996 to June 1997, 54% of pork loins purchased were found to be unacceptably tough. This was based on a WB peak shear force value of 5 kg being the maximum for consumer acceptability (Shorthose *et al.*, 1986). As stated by Hofmeyr (1998), the high incidence of tough pork identified in this survey should be of considerable concern to the Australian pork industry. As sensory evaluations were not conducted as part of this study, it is not known if the pork loins were acceptable to consumers based on their sensory characteristics. Furthermore, a survey of Australian consumer comparing attitudes to beef, lamb, pork and chicken, found that only 15% of consumers reported pork to be tender and juicy whilst 32% of consumers stated that pork was inclined to be dry (Australian Meat and Livestock Corporation, 1994). It is not clear whether these problems in eating quality attributes of pork are causing a decline in the domestic consumption of fresh pork.

Hofmeyr (1998) identified that the Australian industry has problems producing pork that will consistently meet the requirements of processors and consumers of pig meat. Pig carcasses in Australia are generally graded and classified according to carcass weight and fat depth at the P2 site, with producer payments linked directly to these specifications. However, this grading system does not reflect pork quality characteristics.

Pork of inconsistent quality costs the Australian pig industry in excess of $20 million per year (Whan 1993) mainly due to high drip losses from pork with the pale, soft, exudative (PSE) quality defect. Pork with the PSE condition remains a major problem facing the Australian pork industry with 16-51% of pork classified as PSE (Eldridge *et al.*, 1995; Hofmeyr *et al.*, 1997; Channon *et al.*, 2000). It is also generally perceived that PSE pork will be tougher than normal pork due to its lower water binding capacity. However, costs associated with declining consumer satisfaction due to inconsistent eating quality attributes of pork have not been quantified.

Many factors associated with processing have been shown to influence pork eating quality, particularly tenderness. These factors include pre-slaughter stress, transport factors, duration and time off feed, length of time in lairage, stunning method, chilling management, electrical stimulation and rate of pH and temperature decline post-slaughter.

Transport and handling factors influencing eating quality of pork

Martoccia *et al.*, (1995) stated that pig transport was the most influential pre-slaughter factor that influences pork quality. Transportation involves factors that increase stress in pigs such as unfamiliar noises and odours, deprivation of food and water, crowding, vibrations and changes in acceleration, and extremes of temperature. However, studies of transportation stress are difficult to interpret due to the cumulative contribution of each factor associated with transport (Stephens and Perry, 1990). Fighting may also occur during transport but this is usually only a problem in a stationary vehicle. Loading and unloading of pigs from transport vehicles appears to be the most stressful aspect and is dependent upon the stock handling skills of the driver (Tarrant, 1989; Stephens and Perry, 1990).

It is difficult to draw definite conclusions about the effect of transport time or distance on muscle glycogen content and ultimate pH. This is possibly due to the many factors involved in the transport process, e.g., loading density, temperature at the time of transportation, genotype of pigs, transport time, the number of stops during transport (particularly if other pigs are loaded at different farms) and the length of time since the last feed; all of which may interact to alter the muscle glycogen levels. Grandin (1980) observed that pigs transported very short distances of less than 30 minutes to the abattoir are often more difficult to move compared to pigs transported for longer distances.

Duration of transport has a variable effect on pork quality. In a study by Martoccia *et al.* (1995), pigs transported 650 km produced darker, redder pork with a higher pH at both 45 minutes and 24 hours compared to animals transported 180 km. Warriss (1987) reported that transport time (from 1 to 4 hours) did not influence ultimate pH. This suggests that pigs do not always express the expected effects of transport on muscle glycogen concentrations and therefore ultimate pH. This may be partially due to the different levels of glycogen found naturally in different muscle types, with white muscle having higher glycogen levels than red muscle.

Processing factors influencing eating quality of pork

Time off feed

The length of time between the last feed and slaughter can influence muscle glycogen concentration (Warriss, 1987). Consequently the Australian pig industry quality program (APIQ) includes a recommendation to remove pigs from feed at least 6 hours and no more than 24 hours prior to slaughter. However, the effects of time off feed have often been confused with the effects of resting time (lairage) without food at the abattoir. During the time off feed there are additional stress factors such as the handling of pigs during loading, transport time as well as the length of the lairage period. It is difficult to assess the direct effect of time off feed on muscle glycogen and subsequent pork quality due to cumulative stresses imposed on pigs due to length of lairage period and transport (Kelley *et al.*, 1980; Grandin, 1980; Weick *et al.*, 1983).

Pre-slaughter handling

In the pig, any form of stress will induce the release of adrenaline that will deplete muscle glycogen. The nature of pre-slaughter handling immediately prior to slaughter can have a major influence on final pork quality (Tarrant, 1989) as pigs have no time to recover from any stress imposed on them (Chandler *et al.*, 1997). Large slaughter facilities operate at high line speeds and as such, the need to handle pigs quickly may not be

matched by the handling techniques. High line speeds and forceful handling of the pigs may lead to increased stress, resulting in poorer meat and eating quality (Warriss, 1987; 1993).

Pigs subjected to lengthy periods without feed and water, prolonged and poor handling and transport, protracted fighting and extreme weather conditions may suffer severe physiological effects. It is generally acknowledged that meat quality can be improved by resting in lairage at the abattoir since pigs that are stressed or fatigued by previous handling or transport may recover to some extent during this period (Martoccia *et al.*, 1995). Generally, resting time is desirable as a means of reducing PSE, while excessive resting time can increase the incidence of dark firm and dry pork (DFD). Skjervheim (1978), as quoted by van der Wal *et al.* (1997), found that pigs slaughtered either on arrival at the abattoir or shortly afterwards had lower pH values and more PSE than pigs held in lairage for longer periods. van der Wal. *et al.* (1997) suggested that in relation to optimal eating quality (as determined by pH and colour measurement), the resting period prior to slaughter for the loin (*M. longissimus lumborum*) should be 3 hours 25 minutes and 4 hours 14 minutes for the topside (*M. semimembranosus*). A resting period of at least 2 hours was recommended by Warriss (1995) to allow pigs sufficient time to recover from previous stresses suffered prior to arrival at the abattoir without there being a significant depletion of muscle glycogen and an increase in skin blemishes.

However, in a Victorian study (Anon., 2000) the effects of lairage period on pork eating quality were variable. Entire male pigs from the same farm were either slaughtered directly upon arrival or following overnight lairage. Pigs in the direct slaughter treatment produced pork with a higher ultimate pH and better colour compared to that from pigs in the overnight lairage treatment. However, no differences in tenderness, assessed by a trained taste panel, were found between pork from the direct slaughter and overnight lairage treatments.

The use of electric goads by stockpersons immediately prior to slaughter has been shown to increase the incidence of PSE pork (D'Souza *et al,*. 1998; D'Souza and Hofmeyr, 2000). Although minimal use of electric goads is recommended, poor facility design at some Australian abattoirs, particularly in raceways leading to the stunning station, necessitates the judicious use of electric goads by trained stockpersons (D'Souza and Hofmeyr, 2000).

Mixing unfamiliar pigs results in fighting as they attempt to establish a new social hierarchy (Guise and Penny, 1989; Warriss, 1996). Fighting is a major cause of DFD as it depletes muscle glycogen and is the principal cause of death in transit and lairage. Other economic losses from fighting include damage to the surface of the carcass (Murray and Jones, 1992; Chandler *et al.*, 1998) and an increase in PSE if fighting takes place immediately pre-slaughter. Fighting can affect skin quality with bruising occurring in extreme cases. Fighting among pigs almost always occurs in lairage as the animals are unfamiliar with each other. This not only applies to pigs from different farms but also among pigs from the same farm from different pens. Showering pigs with water can reduce the effects of fighting (Schutte *et al.*, 1996). This not only reduces the effects of any heat stress suffered during transport and/or in lairage but also tends to wash away their individual body odours and make them more acceptable to each other.

Stunning method

The majority of research into stunning methods has concentrated on aspects of animal welfare and worker safety with little research investigating the effects on overall eating quality. Channon *et al.* (2000), in a study on pork quality comparing the effects of halothane genotype, pre-slaughter handling and stunning method (CO_2 vs electrical stunning), found that although the rate of muscle pH decline was slower in pigs stunned with CO_2, tenderness of pork (measured by WB shear force) was not influenced by stunning method. However, the faster decline in muscle pH post-slaughter of electrically stunned pigs may have contributed to the higher percentage drip loss from the *M. longissimus thoracis* (LT) muscle compared with that from CO_2 stunned pigs. Casteels *et al.* (1995) also reported higher water holding capacity of pork from pigs stunned with CO_2

compared with electrical stunning. Further research may be required to determine the impact that stunning method may have on tenderness, juiciness and overall eating quality of pork.

Chilling rate

The duration for processing a pig carcass from stun to chiller is about 30-45 minutes in most commercial Australian abattoirs, however, this time can vary significantly. While it is acknowledged that the pigs should be processed as quickly as possible, there is little research regarding the effects of length of processing time on pork quality. D'Souza *et al.* (1998) found that a prolonged rate of carcass processing (70 vs 45 minutes) resulted in lower muscle glycogen concentrations in both the LT and *M. biceps femoris* (BF) muscles at 75 minutes and 24 hours post-slaughter, however muscle pH was not affected. Any effects on eating quality due to length of processing time remain unknown as measurements of tenderness (either objective or subjective) were not made. Stoppages on the chain and delays in carcass evisceration can also significantly increase the incidence of PSE pork (Eldridge *et al.*, 1993; O'Shea, 1992). However, other studies have shown that delays in carcass processing had little, if no, influence on pork quality (Honkaavara, 1989).

The majority of studies that have investigated the influence of the rate of pH decline in pork have concentrated on PSE and DFD conditions rather than on tenderness *per se.* The glycolytic rate is the most important post slaughter factor influencing tenderness of pork, while early post slaughter temperature is believed to influence tenderness through its control over the glycolytic rate. Very slow chilling rates accelerate the rate of glycolysis resulting in improved tenderness but can also result in increased drip loss in pork. Rapid chilling (at -20°C for 2-3 hours post-slaughter) can diminish the exudative and pale characteristics of susceptible muscles (Honikel, 1986). However, cold shortening can occur if the muscle temperature falls below about 10°C within 3 hours of slaughter whilst muscle pH remains above 6 (Dransfield and Lockyer, 1985). Cold shortening can result in the production of tough meat. Therefore careful control of chilling must be implemented to maximise pork tenderness whilst minimising the incidence of the PSE condition. Ageing meat for an extended time post-slaughter cannot alleviate the effects of cold shortening. Taylor *et al.* (1995a) found that loin chops from carcasses conventionally chilled at 1°C were more tender than those from rapidly chilled carcasses (-20°C for 2-3 hours followed by chilling at 1°C).

Table 6: Correlations between the rate of muscle pH decline, the rate of muscle temperature decline and sensory and objective measurements of eating quality of the pork loin (*M. longissimus thoracis et lumborum*) (Channon *et al.*, 2001a).

Measurements	Rate of muscle pH decline	Rate of muscle temperature decline
Tenderness[a]	-0.066	0.119
Juiciness[b]	-0.106	0.024
Flavour[c]	-0.100	0.091
Overall liking[c]	-0.086	0.062
WB shear force (kg)	0.059	-0.103
Ultimate pH	0.031	0.031
Muscle lightness[d]	-0.002	0.041
Drip loss (%)	0.113	0.076

a 0 = very tough to 100 = very tender
b 0 = very dry to 100 = very juicy
c 0 = dislike extremely to 100 = like extremely
d 0 = black to 100 = white

Recent studies by Channon *et al.* (2001a) have identified that both the rate of muscle pH and the rate of temperature decline from 40 minutes to 8 hours post-slaughter were very poorly correlated with sensory and objective measurements of the eating quality of pork (Table 6), with no correlations found to be significant. It is suggested that differences in rate of muscle temperature and muscle pH decline from 40 minutes to 8 hours post-slaughter of carcasses were not large enough to contribute to problems in eating quality attributes of pork.

Electrical stimulation

Electrical stimulation of carcasses post-slaughter can significantly reduce cold shortening by accelerating rigor development and therefore improve tenderness and meat colour. Electrical stimulation is most effective in improving tenderness when carcass cooling is fast enough to induce cold shortening. Electrical stimulation prevents cold shortening by causing a more rapid rate of post slaughter metabolism in muscle. This results in a lower pH while muscle temperatures are still high which maximises proteolysis (Dutson and Pearson, 1985). Sorinmade *et al.* (1982) stated that electrical stimulation may cause a physical disruption in muscle as a direct result of the application of electricity.

However, care must be taken with electrical stimulation of pork carcasses as the rapid metabolism induced by electrical stimulation could result in an increased occurrence of PSE (Crenwelge *et al.*, 1984; Warriss *et al.*, 1995). Therefore, electrical stimulation using constant voltage (variable current) electrical stimulation systems is not used in Australian abattoirs due to the risk of increasing the incidence of PSE.

The magnitude of the effects on meat quality varies with the type and method of electrical stimulation. Low voltage electrical stimulation (LVES) is defined as a voltage of 20-90 V delivering a current of less than 1 amp which must be applied less than 10 minutes post-slaughter to be effective. The propagation of current in LVES systems is reliant upon the nervous system in the carcass being active. Electrical stimulation in Australian pig processing plants would most easily be incorporated in the slaughter chain immediately after sticking and prior to entry of carcasses into the scald tank, i.e., at 5-10 minutes post- slaughter. The time that low voltage electrical stimulation is applied after exsanguination is an important factor influencing pH decline and tenderness. Delaying low voltage stimulation can reduce its effectiveness due to the inactivation of the nervous system, resulting in the carcass becoming unresponsive to the stimulation. Furthermore, if stimulation is delayed, muscle temperature may have fallen, reducing the potential magnitude of the change in muscle pH. Glycolysis may have also progressed further, reducing the potential magnitude of change in pH resulting from electrical stimulation.

Previous studies have evaluated the application of electrical stimulation to pigs at 3-5 minutes post-slaughter (Taylor and Martoccia, 1995; Bowker *et al.*, 1999; Rees *et al.*, 1999a; 1999b; Rees, 2000) and at 20 minutes post-slaughter (Dransfield *et al.*, 1991; Warriss *et al.*, 1995; Taylor *et al.*, 1995b; Maribo *et al.*, 1999). The results indicate that electrical stimulation on the incidence of PSE, rate of pH fall post-slaughter, drip loss and colour are inconsistent, whilst tenderness of pork has generally been improved by electrical stimulation. Taylor and Martoccia (1995) reported a 28% improvement in tenderness over non-stimulated pork carcasses when high voltage electrical stimulation was applied at 20 minutes post slaughter. These authors also reported that low voltage electrical stimulation applied at 20 minutes or 5 minutes post slaughter resulted in a 17 and 18% improvement in tenderness, respectively. Electrically stimulated pig carcasses also require less ageing than unstimulated carcasses in order to reach an acceptable level of tenderness (Savell, 1979; Dransfield, 1994; Channon *et al.* 2001b). Maribo *et al.* (1999) reported that although tenderness of the LD was improved following high voltage stimulation, stimulation had a negative influence on the technological quality of BF and SM muscles. Maribo *et al.* (1999) therefore recommended that, in comparison to ageing, electrical stimulation was not an economically attractive practice that the Danish industry could use to improve tenderness of pork.

A possible explanation for the inconsistent effects that conventional LVES has on quality traits of pork may be that although conventional LVES systems deliver constant low voltage but the peak current delivered during stimulation can vary considerably. The level of the peak current delivered during stimulation may be directly related to the rate of glycolysis post slaughter. If excessive, conventional LVES systems could easily trigger the development of PSE, which may then impede any improvement in tenderness from ageing. Therefore, the use of new generation LVES systems that can deliver constant current may provide the Australian pig industry with an opportunity to improve the tenderness of pork without inducing PSE post-slaughter.

Research currently underway at VIAS, Werribee, funded by PRDC, is investigating the use of a new-generation LVES system that delivers constant current. Peak currents were set at a low (50 mA), normal (200 mA) and high (400 mA) level and were applied to pig carcasses at 5 minutes post-slaughter for a duration of 30 seconds. Low voltage electrical stimulation of pig carcasses using 200 mA and 400 mA was effective in significantly improving tenderness (as measured by WB shear force) of the *M. longissimus lumborum*. The rate of pH decline in loin muscles from carcasses in the 200 mA and 400 mA treatments was faster compared to carcasses in both the 50 mA and control (no stimulation) treatment groups (Channon *et al.*, 2001b). Carcasses stimulated with 50 mA for 30 seconds produced pork with a rate of pH decline and average WB shear force similar to carcasses that were not stimulated. These findings also suggest that although the rate of muscle pH decline of the *M. longissimus lumborum* from pigs in the medium and high stimulation groups resulted in higher percentage drip loss and paler meat colour, this did not have an impact on WB shear force values.

Carcass suspension

The conventional method used by Australian pig processors to suspend pig carcasses is by passing a gambrel behind the Achilles tendon. However, if carcasses are hung from a hook placed into the obturator foramen (commonly known as the aitchbone), the *M. longissimus thoracis et lumborum* and the muscles on the outside of the hip, including the *M. semimembranosus*, are stretched when rigor is attained. The stretching of these muscles results in improved tenderness after cooking. Aitchbone hanging can also be used to minimise the effects of rapid chilling on cold shortening. Aitchbone hanging (pelvic suspension) is now commercially practised in the UK as part of the blueprint program developed by the Meat and Livestock Commission to improve tenderness of pork.

Table 7. Effect of hanging method (Achilles or aitchbone) on the sensory attributes of tenderness, juiciness, flavour, odour, overall liking and quality grade of the pork loin (*M. longissimus lumborum*) and topside (*M. semimembranosus*).

	Loin				Topside			
Sensory attribute	Achilles	Aitch-bone	lsd	P	Achilles	Aitch-bone	lsd	P
Tenderness[a]	51.7	58.8	2.92	<0.001	50.0	61.5	2.53	<0.05
Juiciness[b]	58.1	60.2	2.46	0.093	45.5	59.4	2.41	<0.05
Flavour[c]	59.3	62.7	1.76	<0.001	56.2	61.7	1.84	<0.05
Odour[c]	59.9	60.4	1.29	NS[1]	62.8	61.8	1.70	NS
Overall liking[c]	57.2	62.2	2.25	<0.001	52.6	61.4	2.08	<0.05
Quality grade[††]	3.16	3.41	0.11	<0.001	2.93	3.36	0.11	<0.05

a 0 = very tough to 100 = very tender
b 0 = very dry to 100 = very juicy
c 0 = dislike extremely to 100 = like extremely
†† 0 = very poor to 5 = excellent
[1]NS not significant (P>0.05).

Increased tenderness of muscles through aitchbone hanging is associated with longer sarcomeres that result from stretching (Moller and Vestergaard, 1986; Taylor *et al.*, 1995b). Channon *et al.* (2001a) found that the improvement in consumer sensory scores for tenderness were greater in magnitude for the pork topside than the loin when carcasses were hung by the aitchbone (11.5 units vs 7.1 units on a 1-100 scoring scale for the topside and loin, respectively, Table 7). Consumer scores for sensory flavour, overall liking and quality grade of pork loin steaks and topside roasts were also improved by hanging carcasses from the aitchbone. Changing the hanging practices of pig carcasses from the conventional Achilles hanging to aitchbone hanging can therefore improve the consistency of pork eating quality.

The National Pork Producers Council (NPPC) has developed a series of pork quality targets and suggested a WB shear force target of less than 3.2 kg following ageing for 7 days post-slaughter (NPPC, 1998). Channon *et al.* (2001a) found that only pork from aitchbone-hung carcasses aged for 7 days post-slaughter achieved an average WB shear force value of 3.2 kg - pork obtained from Achilles-hung carcasses and aged for either 2 or 7 days post-slaughter in vacuum packaging did not achieve this level.

Aitchbone hanging results in unconventional shapes of muscles, altering their appearance – an important issue for retail butchers. It is possible to rehang pig carcasses from the Achilles tendon after rigor has developed (Warriss, 2000). However, Australian processors have resisted the introduction of aitchbone hanging on a routine basis because of the additional labour required to change the hanging of carcasses from the Achilles tendon to the aitchbone on the slaughter floor. Aitchbone hung carcasses also take up more space in the chiller, thereby reducing chiller capacity.

Ageing of pork

Some of the desirable eating quality characteristics of pork, particularly tenderness, increase with post slaughter storage at 0-5°C. In the case of pork, the improvements in tenderness due to ageing are rapid in the first 1-2 days then continue at a slower pace and plateau at around 6 days post-slaughter (Dransfield *et al.*, 1980-81). The improvements in tenderness seen with ageing are believed to occur because of the degradation of some of the key structural proteins (desmin, titin and nebulin) by endogenous enzymes when meat is aged (Koohmaraie *et al.*, 1995).

As stated by Warriss (2000), conditioning is the term that refers to the natural process of tenderisation that occurs when meat is stored or aged post-rigor. This tenderisation may result from weakening of the myofibrils and changes in the connective tissue components of meat. The changes in the myofibrillar component are generally regarded to be more important as only very small changes in the connective tissue component have been found. During conditioning, the muscle does not become more extensible, so it is not considered that the process of conditioning is associated with the dissociation of actomyosin. Tenderisation is due to the activities of proteolytic enzymes present in the muscle, particularly calpains and cathepsins.

There are differing views on the influence of post mortem ageing on the tenderness of pork following conventional processing. Harrison *et al.* (1970) and Buchter and Zeuthen (1971) observed an increase in tenderness up to six and eight days post mortem, respectively. In contrast, Bennett *et al.* (1973) found that ageing for more than one to two days post-slaughter did not significantly improve tenderness of pork. Feldhusen and Kuhne (1992) also found that the optimum shear force values were attained after two to three days post mortem. Dransfield *et al.* (1980-81) found that, on average, 50% of the tenderisation of pork has been observed to occur in two days (and 80% within 4.9 days) compared to 4.2 days for beef and veal. Rees (2000) also found that 50% of tenderisation of pork loin muscle occurred within 2 days post-slaughter and 80% within 4 d.

As stated by Verbeke *et al.* (1999), little attention is paid in current slaughter practice to prolonged (more than 3-4 days) post-slaughter ageing of pork, in contrast to beef. In Australia, it is common commercial practice for pork to be delivered to retail butchers and supermarkets in carcass form, with very little boxed pork sold at the retail level. This

practice, therefore, currently limits the amount of ageing pork muscles can undergo before being prepared into retail cuts and sold. Due to shelf life restrictions of ageing pork in carcass form, ageing of pork is best conducted following vacuum/modified atmosphere packaging. The positive effects of ageing for 7 days post-slaughter found by Channon *et al.* (2001a) (Table 8) were also confirmed by results of the Victorian Pork Alliance study (Anon, 2000). However, hanging carcasses from the aitchbone and ageing pork for 7 days post-slaughter was not additive in improving eating quality attributes of pork loin steaks (Channon *et al.*, 2001a).

Table 8. Effect of ageing period (2 or 7 days) on the sensory attributes of tenderness, juiciness, flavour, odour, overall liking and quality grade of the pork loin (*M. longissimus lumborum*) and topside (*M. semimembranosus*) (Channon *et al.*, 2001a).

Sensory	Loin				Topside			
attribute	2 days	7 days	lsd	P	2 days	7 days	lsd	P
Tenderness[a]	52.0	58.5	1.70	<0.001	51.8	59.8	2.52	≤0.05
Juiciness[b]	58.8	59.5	1.57	NS[1]	48.0	56.9	2.36	≤0.05
Flavour[c]	59.4	62.5	1.34	<0.001	56.4	61.6	1.57	≤0.05
Odour[c]	60.2	60.2	1.02	NS	62.0	62.6	1.47	NS
Overall liking[c]	57.7	61.7	1.46	<0.001	54.0	60.0	1.92	≤0.05
Quality grade[††]	3.18	3.39	0.068	<0.001	2.98	3.32	0.09	≤0.05

a 0 = very tough to 100 = very tender
b 0 = very dry to 100 = very juicy
c 0 = dislike extremely to 100 = like extremely
†† 0 = very poor to 5 = excellent
[1]NS not significant (P>0.05)

Wood *et al.* (1996) found that additional ageing time for pork from 4 to 10 days led to an increase of 0.4 units for tenderness, using a 1-8 scoring scale, with the same improvement in tenderness also found for pork obtained from aitchbone hung carcasses, over the same period of time. Ageing pork for 10 days post-slaughter increased the taste panel score for tenderness by 1 unit compared with pork aged for only 1 day, whilst pork aged for 10 days also obtained higher flavour intensity and overall liking scores and lower scores for intensity of abnormal flavours. These findings highlight the importance of the early post-slaughter period between 1 and 4 days on tenderness of pork. Wood *et al.* (1996) also found that tenderness and flavour were moderately correlated with overall liking, with correlations of 0.60 and 0.65, respectively.

Channon *et al.* (2001a) reported that, based on a 100 point scale, ageing of pork loins and topsides for 7 days post-slaughter improved sensory tenderness scores by 6.5 units and 8.0 units, respectively, compared to pork aged for only 2 days post-slaughter. Wood *et al.* (1996) found that ageing pork for 10 days post-slaughter had a greater effect than both genotype (Duroc vs Large White) and feed level (*ad libitum* vs. 0.8 *ad libitum*) in improving tenderness. Taylor *et al.* (1995a) also showed that ageing of vacuum packaged pork loin at 1°C from 4 to 7 days, and further for 12 days, improved tenderness, measured both objectively and by using a taste panel.

When meat is aged, a slow increase in water holding capacity occurs (van Laack and Solomon, 1994). This may account for the lower drip loss percentage from the pork loin found by Channon *et al.* (2001a) following 7 days ageing compared with pork aged for 2 days post-slaughter. Channon *et al.* (2001a) found that ageing of pork for 7 days resulted in paler pork colour (lower muscle lightness – L* values) compared with pork aged for 2 days (52.3 vs 50.5, sed 0.283). Anon (2000) found that consumers prefer pork that is pale pink in colour, as it was considered that this colour indicates freshness and tenderness. If pork is too pale or too dark, it was perceived that pork is going off or is old, tough and stringy. It may therefore be postulated that at the retail level consumers may prefer the lighter colour of aged pork.

Enhancing pork quality

Sheard *et al.* (1999) found that the injection of a 5% polyphosphate solution into pork increased tenderness by over 1 scale unit on the 1-8 scoring scale. The size of this effect was considered large, particularly when compared with other factors including breed and feeding level, chilling rate, aitchbone hanging and electrical stimulation (Taylor *et al.* 1995b), ageing period (Wood *et al.* 1996) and cooking temperature (Wood *et al.* 1995). Sheard *et al.* (1999) concluded that processing factors have larger effects on tenderness compared with production factors.

The adoption of techniques to inject (or enhance) the eating quality attributes of fresh pork may provide the Australian pork industry with an alternative means of consistently producing high eating quality fresh pork. In the USA, the widespread adoption and acceptance at the retail level of enhanced pork is regarded as a short term method of improving eating quality attributes of pork (Channon, 2000). The raw material that is used to produce enhanced pork cuts ideally should have a muscle pH of 5.6-5.9, due to improved purge and colour compared to pork with pH <5.4 (Paterson, 2000).

Enhancement, by the application of functional ingredients in the brine solution to fresh pork, provides pork companies with a way to reduce the variation in eating quality and improve overall eating quality in the final product. The total amount of added ingredients in the US range from a 7 to 15% addition to the initial weight of the meat (Channon, 2000). The technology and ingredients used for enhancement have generally been adapted from those developed and used for processed meat products. It is thought that the use of such technologies in the US will not alter unless the US pork industry is able to reliably produce untreated pork that is of consistently high eating quality.

The marketing of enhanced pork, if undertaken in Australia, will require close liaison between the processor and retailer due to the importance of temperature control and product handling to ensure optimal food safety.

Prediction of eating quality

Prediction of overall quality of pork using sensory traits

Channon *et al.* (2001a) found that flavour (r=0.88) and tenderness (r=0.87) were found to be the two important factors influencing consumer perceptions of overall liking for pork loin steaks, followed by juiciness (r=0.67) and odour (r=0.33). Wood *et al.* (1996) found that both tenderness (r=0.60) and flavour (r=0.65) contributed significantly to overall liking. However, Enfält *et al.* (1997), using trained taste panellists rather than consumers found that overall acceptance of pork was related more to tenderness (r=0.81) than to taste intensity (r=0.67), off flavour (r=-0.43) and juiciness (r=0.38).

Previously, objective measurements of pH, fibre optic probe (FOP), firmness (NPPC scores) and colour have been used (Kauffman *et al.*, 1994), together with WB shear force to predict tenderness of pork and separate pork into eating quality classes (Miller *et al.*, 2000). Consumer research in the US identified that pH more closely grouped pork loin and topside chops into categories of eating quality than WB shear force or intramuscular fat content (Miller *et al.*, 2000). In a Japanese consumer study (Miller *et al.*, 2000), pH categories were able to group consumer responses for visual and eating quality characteristics of pork. In contrast, Channon *et al.* (2001a) found that eating quality attributes of pork were best described by WB shear force, hardness and chewiness, with very poor relationships found between sensory attributes and ultimate pH. Miller *et al.* (2000) stated that research that incorporates the combined effect of visual appearance and eating quality is needed to determine whether pH, colour, firmness, tenderness, marbling or a combination of these attributes can be used to separate pork into quality classes.

A consumer preference study conducted by Moeller *et al.* (Ohio State University, USA, unpublished) showed that US consumers were able to differentiate quality characteristics of pork and are willing to pay more for higher quality pork products, particularly in terms of tenderness and ultimate pH. However, a commercial pilot study was not conducted at the retail level to quantify this. It was concluded, however, that

pork quality indicators, particularly tenderness and its interaction with ultimate pH, are important factors in consumer' decisions of what to pay and how much they are willing to pay.

Prediction of sensory tenderness using objective tenderness measurements

Channon *et al.* (2001a) found that the amount of variation in sensory tenderness explained by WB shear force (R^2=35%) was higher than that previously reported by Hovenier *et al.* (1993) (R^2=25%) and Van Oeckel *et al.* (1999) (R^2=19%). These findings, however, indicate that the measurement of WB shear force with which to predict sensory tenderness of pork is a relatively inaccurate method. Van Oeckel *et al.* (1999) stated that the relatively weak relationship between objective and subjective measurements of tenderness may be due to:

- The repeatability of the taste panel.
- The repeatability of the WB shear force measurement.
- The variation in tenderness along the length of the *M. longissimus thoracis et lumborum.* It is known that the anterior end of the pork loin tends to be more tender than the posterior end.
- Differences in cooking methods used for pork loin steaks and WB shear force samples.
- Different core temperatures of grilled and broiled pork (Jonsäll *et al.*, 2001).
- Meat is of a composite (comprised of myofibrillar structure joined together by connective tissue) and anisotropic (has different physical properties according to the direction being considered) nature (Lepetit and Culioli, 1992).

Conclusion

Inconsistencies do exist in the eating quality attributes of Australian pork. Current grades and/or categories being used by the processing industry to describe pork quality, including sex, carcass weight, fatness level and evidence of secondary sexual characteristics are inadequate descriptors of eating quality. The adoption of carcass management practices, including electrical stimulation, aitchbone hanging and ageing of pork have been identified as ways the Australian processing industry might consider to improve the consistency, and reduce variability, of pork eating quality.

Consumer requirements for tender, juicy pork of acceptable flavour increases the necessity to consistently supply pork of high eating quality at both the retail and food service sectors. This may then result in increased demand for fresh pork. Whilst continuing efforts to introduce and implement quality assurance/best practice systems in the production and transport sectors of the Australian pig industry are to be applauded, the implementation of one or more of the carcass management practices at the processing level that improves consistency of eating quality will only further advantage the Australian pork industry.

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Symposium continued on next page

MANAGING THE EATING QUALITY OF PORK – REALIZING BENEFITS ALONG THE VALUE CHAIN

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Abstract

This paper discusses the need for a coordinated, integrated effort to improve pork quality along the entire value chain. The value chain represents all pork industry segments that add value or worth to the product at each step. Ways that each segment can affect the quality of the product are discussed. Consumer quality is defined as those sensory traits that consumers discern as important to the visual expectation or eating experience of the product. These include colour, marbling, taste, juiciness and tenderness. Consumer studies have shown that while consumers like pork in general, they are very discerning about all these characteristics. Some studies have investigated consumers' behavior in comparison to what they say. There have been several programs implemented to measure and improve pork quality and these are discussed. One such program is the extensive U.S. national pork quality audit, which will study pork quality status and effects at the production level, at the packing plant, at the processing plant and at retail. This is the first time a study of this magnitude has been attempted. The paper also discusses standards and targets for fresh pork. Genetics account for a significant portion of the variation in fresh pork quality and improvement of pork quality through genetics is discussed. The paper concludes with some detail on enhancement technologies being used in the US to improve the juiciness, flavour, and tenderness of fresh pork through injection of salt and sodium phosphate solutions. Consumer reactions to the results of this technology are provided. The conclusion is that improvement of pork quality must be driven by the consumer but must be enacted by all segments of the pork value chain working together.

Introduction

Any approach to managing pork quality must be a coordinated, integrated effort. There are so many factors that affect pork quality throughout the chain that to do any less would be largely futile. First, it would be appropriate at this juncture to define the "value chain". Otherwise simply known as the pork chain, the value chain represents all segments taking value from the pork industry from pork production supply networks to the last segment selling a product to the consumer. Therefore, the chain includes suppliers, producers, slaughterers, processors, distributors, retailers, institutions and foodservice, and exporters, each representing links in a chain.

One characteristic of the pork industry worldwide is that the segments, by definition, are very competitive, they withhold information, and they tend to blame each other for problems. In order to improve eating quality of pork, the entire chain needs to become more coordinated with their efforts more integrated for the common good. They also need to be more willing to share information for product improvement and they must share the blame and work together to solve the problems.

Even if pork producers produce the highest quality fresh pork possible, using that raw material, the processor can easily produce a very low quality product. Vice versa, the producer, through poor genetics, nutrition and handling, can produce a very low quality product and regardless how good the processor's quality program is, the consumer will experience a low quality product. Therefore, it is essential that the producer and processor work together to learn all the factors involved in pork quality both in a positive and negative way, and to address these factors at all levels. There is a significant amount of literature available to provide scientific guidance but the amount of that science dwindles as one moves along the chain. Even at early stages of the chain such as the production segment, there is much yet to learn. For example, nutritional effects, both

positive and negative, need to be studied more to understand new opportunities. New genetic technologies demonstrate that the industry has barely touched the surface of this potential.

While the pork chain after the producer and processor can have little impact on improving pork quality, these segments, including further processors, distributors, retailers, foodservice, and export agencies, need to have some understanding of pork quality differences and what can be done to improve them. In this way, they can communicate their needs and their customers' needs back to those who are in a position to make improvements.

The previous authors in this symposium addressed issues related to what each of the production and processing segments can contribute to making these improvements. This paper will attempt to address definitions, specifications, consumer preferences, and some of the programs in place to bring about improvement.

Definition of eating quality

The quality attributes of primary interest in this symposium are those that relate to the eating experience. Processors often regard water holding capacity, drip loss or purge loss as the most critical and costly of all pork quality traits. Except for the effect it has on juiciness, this is not a concern relevant to the eating quality of the product. However, pH of the meat is highly correlated to water holding capacity and it is a concern because of the flavour and tenderness ramifications that pH has on fresh pork. The measure of pH is simply one of acidity with a pH of 7 being neutral. Levels below this are acidic while levels between seven and fourteen are alkaline. When pH levels in pork are out of the acceptable range, whether too high or too low, they cause off-flavours in fresh pork (Prusa, 2000). For definition purposes, pH is not really a quality attribute but rather an indicator or measure of quality. The eating quality traits are simply those traits of concern to consumers of the products and generally include juiciness, tenderness, and flavour. They also include food safety traits and nutritional value of the meat product. Even appearance or colour, which is clearly a sensory trait, is not an eating quality trait. On the other hand colour and marbling are related to the eating quality traits. Pale colour is one component of pale, soft, exudative pork (PSE). This condition produces product which dries excessively with cooking, has poor texture, is often more tough, and always has an off-flavour when compared to normal pork. Marbling is related to tenderness and juiciness.

US consumer preferences for eating quality

The National Pork Producers Council (NPPC) in the US has conducted numerous consumer surveys, focus groups and preference studies over the past two decades. They not only have a plethora of data, but can also track changes in data from year to year or over periods of years. These data show some very interesting results relative to eating quality. The NPPC Kitchen Report (2000) showed that consumers were most interested in fulfilling their health concerns (74%) when they prepare a meal. Secondly, they eat for enjoyment (71%). Fulfillment of the latter criteria relates to the eating quality of the food. If pork is not juicy, flavoursome and tender, the enjoyment will not be there. This same study showed that dietary fat content (67%) and maintaining weight were also major concerns (65%).

Over the past five years, many people have modified their eating habits to eat more fruits and vegetables, less salt and less fat. However, the proportions of those adopting some of these healthier eating habits have declined over the past two years. For example, the proportion of those eating more fruits and vegetables has dropped from 74% to 62%, and those choosing lower fat recipes has dropped from 72% to 54%. Meal planners driven mainly by nutrition are more likely to have decreased their meat intake but increased their consumption of fruits/vegetables. The main reason for serving pork is because families like it (50% response). The next most important reason for serving pork, after family preferences, is taste (24%). Most kids like pork. According to this same study, 92%

of children show a desire for pork with some who say they love pork (21%), like it a lot (34%), or like it somewhat (37%) with only four percent saying they hate it. Over half of consumers identify chops as their children's favourite cut of fresh pork. Bacon is named by a plurality (36%) as their kids' favourite type of processed pork, while ham comes in second.

Sixty-six percent of U.S. consumers say they consider pork great tasting compared to 81% who make this statement about beef and 83% about chicken. Only 60% stated that fish is great tasting. When asked to rate the meats, fish and poultry on the basis of nutritional value, pork and beef tied with only 48% rating these meats to be good or exceptional in nutritional value. This compares to 81% and 85% for chicken and fish, respectively. This represents a great challenge and a great opportunity for the meat industry. While meat has at least the nutritional value of fish and poultry, consumers in the U.S. do not recognize this value (NPPC Tracking Study, 2000).

When asked if a product was considered a healthy alternative, only 60% of foodservice chain operators chose pork compared to 91% and 86% for chicken and fish, respectively. Beef lagged way behind with only 25% thinking that it is a healthy alternative. Only 70% of foodservice operators agreed that pork has a high quality image compared to 88% who agreed that seafood has a high quality image and 72% for beef. The percentage agreeing for processed pork and chicken were 60% and 52%, respectively. When asked if it is a product that foodservice patrons are concerned about food safety, 70% said yes for chicken, 58% for fish and 57% for chicken. Only 48% thought pork was a food safety concern and even less (38%) had this concern for processed pork. Information regarding food safety has had a minor impact on food preparation, though. In the past couple of years, information on food safety has changed the way most people prepare foods, but in most cases the changes have not been great (Technomic, 2000)

To summarize these studies, U.S. consumers eat pork because they or their families think it is great tasting. However, they like the taste of beef and chicken more. They also consider fish and chicken to be healthier and of greater nutritional value than beef or pork and they consider fish to have a higher quality image. On the other hand pork is considered to be safer than chicken, fish or beef. According to this data, pork should capitalize on its perceived good taste and safety while trying to bolster its standing relative to nutrition and health.

Miller *et al.* (2000) looked at the quality traits for pork and variability of these traits in a series of consumer preference studies conducted for the National Pork Producers Council in the US. The studies were conducted in several large metropolitan cities in the US and involved cooking pork of varying classifications based upon three categories for pH, three for tenderness, and three for intramuscular fat. This work was then duplicated in Tokyo, Japan. Investigating the relationship of these quality traits to consumer acceptance for fresh pork, she concluded that the visual and sensory quality characteristics include colour, pH, marbling, firmness, and tenderness. From the consumer studies she conducted, pH was the best indicator of both visual and sensory quality. This was the case with US and Japanese consumers. Consumers from both countries were found to be very discerning for pork quality as defined above. Conclusions from the study were that a system for measuring pork quality and a pricing matrix were needed before great strides can be made in reducing the variability in pork quality and increasing subsequent pork demand.

Agerhem *et al.* (2000) concluded that in Denmark, Norway and Sweden, taste is the single most important attribute for liking pork, followed by juiciness and tenderness irrespective of country. Bennett (1997) concluded that Australian consumers considered pork to be tough, dry and poor in flavour.

It appears that the sensory attributes associated with palatability, tenderness, juiciness and flavour, are the primary consumer considerations for preference and acceptability of fresh pork. In addition, it should be noted that consumers are very discerning about these characteristics in meat.

Recent consumer tracking data show that consumers in the US are less concerned about fat and calories than they were 10 years ago. The NPD Group's National Eating Trends Service (1999) showed that when asked to react to the statement that "a person

should be very cautious when serving a food with fat", 51% of the respondents agreed in 1990 whereas that number went down to only 41% in 1998. Likewise, the number of homemakers agreeing with the statement "I am always conscious of the calories in the meals I serve" reduced from 39% in 1990 to 26% in 1998. When asked how they specifically describe pork, US consumers call it great tasting, proud to serve to guests, can be prepared in a variety of ways, food they get a taste for, nutritional value, and wish restaurants would offer more.

Brewer and McKeith (1999) demonstrated some very interesting findings with their research of consumer perceptions of colour and marbling (Table 9). As purchase intent (defined as their willingness to purchase the product) increased for the lighter-coloured pork (from 1.6 to 4.0 on a 5-point scale), the visual pink colour also increased; however, purchase intent for dark-coloured pork was nearly constant (4.7 on a 5-point scale). Small changes in perceived pink colour (0.5 units) resulted in greater changes in purchase intent of lighter coloured pork than did small colour changes in darker coloured pork. As might be expected, as purchase intent increased, appearance acceptability also increased; again, the change was most dramatic for the lightest pork. Light pork in the "wouldn't buy" category had an appearance acceptability of 1.5; in the "would buy" category, the appearance acceptability was 2.1. The appearance acceptability for medium and darker pork increased by less than 0.2 units as the chops moved from the "wouldn't buy" to the "would buy" category. Again, small changes in overall visual appearance acceptability made greater changes in purchase intent of lighter-coloured pork than in darker-coloured pork. Given that 80% of this consumer group chose the lean or medium marbled chops to take home, and their demonstrated ability to visually discriminate among marbling levels, it seems both overall appearance acceptability and purchase intent are more highly driven by degree of marbling than by perceived colour.

Table 9. Visual "pink colour intensity" of pork chops in various purchase intent categories (Brewer and McKeith, 1999).

Pork colour	Wouldn't buy	Probably wouldn't buy	Might buy	Probably would buy	Would buy
Light pink	1.5^{f}	1.8^{ef}	1.9^{de}	2.0^{d}	2.1^{d}
Medium pink	2.8^{b}	2.6^{c}	2.8^{b}	2.8^{b}	2.7^{bc}
Dark pink	4.7^{a}	4.7^{a}	4.7^{a}	4.7^{a}	4.7^{a}

Colour mean in that category: 1 = very light pink, 5 = very dark pink. ^{a,b,c,d,e,f}Means with different superscript letters are significantly different (P≤0.05).

The presence of visible fat within the lean tissue can send more than one message to consumers: the product is high in fat, and it may be more tender, juicy and flavoursome. In a recent study (Brewer and McKeith, 1999) where consumers chose from a retail case pork chops that they took home for their families to evaluate, 40% chose lean chops while only 20% chose the highly marbled chops (Table 10). Consumers were able to tell the difference in colour, leanness, tenderness, juiciness and flavour, and the more highly marbled chops were more tender, juicy and flavoursome. When they evaluated these same chops at home, the chops were given higher ratings for all attributes, regardless of degree of marbling, than they had when chops cooked by laboratory staff were evaluated. Lean appearance seems to drive purchase intent (when colour is approximately the same), but once the chops have been purchased, the quality of all chop choices is likely to be judged as very high when they are consumed at home. This implies that satisfying the expectations which a consumer has coming into the store may be much more of a factor in stated purchase intent than any of the individual attributes.

Table 10. Marbling effects on sensory characteristics of pork chops prepared at home (Brewer *et al.*, 1999b).

	Marbling level[f]		
Characteristic[a-e]	Low	Medium	High
Juiciness[a]	3.6	3.9	4.0
Tenderness[b]	4.0	4.2	4.3
Flavour intensity[c]	4.3	4.4	4.5
Oily mouthfeel[d]	1.8	2.1	2.2
Purchase intent[e]	4.2	4.1	4.2

a 1 = not at all juicy, 5 = very juicy,
b 1 = not at all tender, 5 = very tender
c 1 = not at all flavourful, 5 = very flavorful
d 1 = not at all oily, 5 = very oily
e 1 = definitely would not buy, 5 = definitely would buy
f Low = 1.1% fat, medium = 2.3%, high = 3.5%.

Measurement and improvement of meat quality

National Pork Quality Audit

For any improvement program to be successful, there must be a clear understanding of where the industry has been and where it is now. This was the basis for conducting a National Pork Quality Audit in the early 1990's. The audit provided a benchmark of where the industry stood in terms of quality in the production segment, the packing and processing segments, the retail segment, and in the foodservice segment. That study concluded that the US pork industry sacrificed $10.10 at the packing level for each of the 88 million market hogs slaughtered in 1992 (Cannon *et al.*, 1996). Even greater economic losses resulting from quality defects were undoubtedly incurred downstream as value-added pork neared the ultimate consumer. According to Cannon *et al.* (1996) the main concerns of the processors about the quality of their fresh pork were as follows:

1. Excessive external fat
2. Incidence of colour/water holding capacity problems
3. Lack of uniformity of live hogs
4. Too high incidence of abscesses in carcasses and cuts
5. Excessive seam fat in butts and hams
6. Excessive amounts of trimming required on carcasses
7. Low overall cutability
8. Inadequate loin muscle size
9. Two-toned colour in fresh hams and loins
10. Excessive amount of purge in boneless, vacuum packaged product.

The purveyors (those who merchandize wholesale pork to the foodservice industry) listed these as their top quality concerns:

1. Excessive external fat
2. Too large loin muscle size
3. Insufficient marbling
4. Inadequate tenderness
5. Too high incidence of injection-site blemishes
6. Too high incidence of bone chips in raw materials
7. Lack of juiciness in cooked products
8. Lack of conformance by packers in meeting cut specifications.

Currently, the US pork industry is embarking on a new National Pork Quality Audit study. Many of these factors that were concerns only 10 years ago when this study was first conducted are changed or improved now. There is interest in conducting the new study to track these changes. In addition, there is curiosity about the costs of quality further down the chain. Therefore, the proposed study will include two new phases including a processing and a retail phase. In the first of these new phases, product of various quality classifications will be shipped to a processor and tracked through the production of hams and bacon to determine the actual costs of these quality defects. For the retail phase, product will be collected from retail stores throughout the US and analyzed for certain quality parameters. These quality factors will be related to price and markdowns in the store to establish a value to the defects at that level. The project should be completed by early 2002.

US Standards

For most of the eating quality traits, measurements are not easily conducted. Tenderness can be measured in the laboratory with a variety of techniques, the most popular of which are Warner Bratzler Shear (WBS) and sensory testing using trained taste panels. However, neither of these lends themselves to use in the field. Furthermore, juiciness and taste are more subjective and can only be determined with taste panels. Therefore, developing standards for these measurements is difficult. In consideration of this, the National Pork Board (NPB) Quality Solutions Team still wanted to establish some targets so the industry had some idea of what to aim for with some of these attributes. Table 11 shows the listing of these targets for the industry.

Table 11. Quality targets for selected pork quality attributes

Attribute	Target	Comment
Colour	3.0 – 5.0	Utilizing NPB[1] 6-point scale
pH	5.6 – 5.9	
Tenderness	<3.2 kg	Utilizing WBS[2] at 7 days
Flavour	Robust pork flavour	No off-flavours
Marbling	2 – 4%	
Drip loss	Not to exceed 2.5%	

[1]NPB, National Pork Board. [2]WBS, Warner Bratzler Shear force.

In addition, the Quality Solutions Committee developed and introduced official colour and marbling standards. While colour and marbling are not eating quality traits, they are related to the eating quality traits. The colour standards are objectively based with each of the six standards shown with a related Minolta L* value. The committee decided against establishing optimum, acceptable or unacceptable standards. They wanted the marketplace to establish these in each particular situation. Many packers, however, have stated that a colour standard range of 3.0 to 4.5 is the range they want.

Figure 1. *Official colour and marbling cards available from NPB.*

The Quality Solutions Committee also established the marbling standards, again with the concept that these are subjective standards tied to an objective measure. The standards represent the percent lipid in the sample shown. A marbling score one would therefore equal one percent in intramuscular lipid. The number of scores theoretically possible is from one to 100 with the latter being total fat. For practical purposes, most U.S. pork will fall into the range of marbling scores one to four.

Pork Quality Research Initiative

"You can't improve what you can't measure" is a quote attributed to Dr. Roger Johnson, Farmland Foods. This quote captures the need to develop a system and instrumentation to measure or predict pork quality in commercial settings on-line in slaughter plants. This quote was the driving force behind the development of the Pork Quality Research Initiative, a targeted effort to develop instrumentation to measure pork quality for commercial application. The intent is to pool resources from the slaughter and breeding segments of the pork industry to fund targeted research for development of prototype instruments to measure quality. Currently, proposals are being reviewed for possible funding. The goal is to have short-term solutions to this problem so the industry can develop measuring schemes and communicate this information back to pork producers. Then, pork producers can make the changes necessary to improve the quality of their stock.

Potential for improvement

Pork quality traits are all of medium to high heritability as shown in Table 12 (Goodwin, 1994). This means that genetic progress to make changes in pork quality can be very fast when appropriate selection pressure is placed upon these traits. However, this selection cannot be made unless the traits are measured and communicated. Some of these traits manifest themselves differently in different breeds. This presents a real challenge to pork producers who must balance several traits in reproduction, performance and carcass composition (lean:fat ratio) with the pork quality traits. Breeds excelling in reproduction and composition are usually not the same breeds that are superior in pork quality. For producers to make the changes necessary to improve the product to the consumer, they must be made aware of how their animals and in particular their seedstock performs with regard to meat quality traits. This message is even more forceful when accompanied by an economic incentive.

Table 12. Heritabilities of selected pork quality traits.

Trait	Measurability	Heritability
Colour	Yes (not at line speed)	0.15-0.50
pH	Yes (maybe at line speed)	0.50
Marbling	Not at line speed	0.05
Tenderness	Not at line speed	0.28
Water-holding capacity	Not at line speed	0.31
Flavour	Not at line speed	0.47
Others	Not at line speed	0.15-0.65

Most of the quality traits are not very highly correlated with performance or carcass composition traits (Table 13; Goodwin, 1998). Backfat and intramuscular fat are positively correlated, but the correlation is not very high. This means that with selection for leanness only, intramuscular fat will be reduced. However, if there were selection pressure placed upon both reducing backfat and increasing intramuscular fat, it would not be very difficult to accomplish because the genetic correlation is relatively low.

However, to enable selection, there must be some means of measuring the intramuscular fat in the live breeding animal.

Table 13. Genetic correlations of selected performance, composition, and quality traits.

Trait	Average daily gain	Backfat
Backfat	0.14	
Colour	-0.07	-0.02
pH	-0.11	0.03
Drip %	0.07	-0.05
Intramuscular fat	0.06	0.30

There are many other factors that affect pork quality in addition to genetics. The previous two papers (D'Souza and Mullan 2001 and Channon 2001) in this symposium covered these. It is important that whenever improvement is planned for any of the pork quality traits, that holistic strategies be designed. The totally integrated approach to quality problem solving should include a focus on all the activities and decisions on the farm, in transport and in the slaughter plant that can cause problems.

Enhancement technologies for quality improvement

The term "Enhanced Pork" evolved from the injection of a solution into fresh pork to enhance the eating characteristics of the final product. The use of injection or the addition of ingredients to meat is an historic practice. Non-meat ingredients are used to improve juiciness and/or tenderness, enhance flavour, improve colour, stabilize colour, increase shelf life, improve safety, or increase water-holding capacity in the final product. Additionally, some ingredients work synergistically with other ingredients to further enhance their functionality. Enhancement of fresh pork provides opportunities to improve the overall quality and to reduce the amount of variation in pork quality. Enhancement is not a method to improve low quality pork, but it is a method being used by the pork industry to improve the overall quality of fresh pork in the retail meat case. The major ingredients used in enhanced pork are water, sodium phosphates, salt, sodium lactate, potassium lactate, sodium diacetate and varying flavouring agents of which lemon juice has been singled out for use in some products (Miller, 2001).

A series of studies conducted at the University of Illinois investigated the use of a level of pump to compare with unpumped control product. The injection solution consisted of salt, sodium phosphate and water and was pumped at ten percent of the weight of the pork sample. The study showed that pork loin chops containing a 10% injection level and then either grilled or fried to internal cooked temperatures of 70 or 80°C had more pork flavour, were juicier, more tender, and had less off-flavours than chops from unpumped loins. Additionally, pumped pork loin chops had similar juiciness ratings regardless of the endpoint temperature that they were cooked; whereas, unpumped pork loin chops were drier as endpoint temperature increased. They also reported that pumped pork loin chops were lighter, redder, less yellow and had lower WB shear force values. These results support the concept that addition of non-meat ingredients provides functional properties that improve tenderness, juiciness, colour and flavour of pork loins.

They also examined the effect of pump level (0, 6, 12 and 18%) when used in pork loins that varied in pH. The purpose of this work was to understand if the addition of non-meat ingredients had greater benefits for meat from specific pH groups. The pork loin chops were evaluated after being cooked to 70 or 80°C. They found that as pump level increased, pump retention, package purge, retail purge, cook loss, salty flavours, and juiciness increased. However, pumping at any level increased tenderness and juiciness. They also reported that as meat pH increased, pump retention increased and package purge, retail purge and cook loss when chops were cooked to 80°C decreased.

These studies indicate that enhancement or injection of non-meat ingredients adds functionality to pork products and that improvement in eating characteristics and colour are found; however, as pump level exceeds 12% increased package and retail purge may be a concern.

Brewer et al. (2000) examined consumer acceptability for package purge, colour, overall appearance acceptability, and purchase intent of vacuum-packaged, pumped pork loin roasts injected with 0, 6, 12 or 18% of a solution of 0.25% sodium tripolyphosphate (STP) and 1% sodium chloride. The results in Table 14 are based on a rating of how willing consumers would be to purchase loin roasts based upon visual cues for colour and texture. The non-injected loin roasts were judged as more desirable on overall appearance acceptability than loin roasts injected at any level. For the higher levels of injection particularly, the significantly poorer consumer acceptability of both the texture and of the amount of liquid in the package contributed to the difference in overall acceptability rating. Based on visual assessment, there were no significant differences in the purchase intent of these loin roasts although consumers appeared to rate the loin roasts injected at levels of 6, 12, and 18% as slightly less acceptable than the non-injected pork loin roasts.

Table 14. Characteristics of pork loins pumped to different levels (least square means).

	Pump level (%)			
Characteristic	0	6	12	18
Purchase intent	3.34	3.18	3.17	3.17
Acceptability of liquid in package	3.64^{a}	3.28^{b}	3.05^{c}	3.01^{c}
Colour acceptability	3.56	3.40	3.4	3.33
Texture appearance acceptability	3.45^{a}	3.23^{ab}	3.12^{b}	3.23^{ab}
Overall appearance acceptability	3.46^{a}	3.22^{b}	3.16^{b}	3.12^{b}

^{a,b,c}Means in the same row with different superscripts differ significantly ($P \leq 0.05$).

The effect of adding 0.25% STP, 0.5% sodium chloride and 2.5% sodium lactate in beef strip loin steak with injection level from 7.5, 10, 12.5 and 15% has been examined (Vote *et al.*, 2000). They reported that when comparing the injected product to the non-injected controls, the injected beef strip loin steaks were juicier, more tender and had more intense cooked beef flavour, especially when steaks were cooked to higher degrees of doneness. In addition, as injection level increased, the steaks tended to be more tender and juicier, but flavour was not affected. Additionally, WB shear force values decreased from 3.39 kg at the 7.5% injection level to 2.60 kg at the 15% injection level, but these differences were not statistically different. The lack of statistical difference for tenderness measurements was most likely due to the difficulty of controlling such fine differences of injection in a laboratory situation. Over time in a production situation, the differences they reported may be important.

Conclusions

Pork quality is a multi-faceted issue that can be affected by several segments along the pork chain. Likewise, the benefits can be realized along the pork chain with most of them being accrued to the consumer in terms of product value. There are many programs in place to attempt to measure, quantify, and improve pork quality for the benefit of the consumer and the entire pork chain. This improvement of fresh pork quality is evolving currently. It will be interesting to note what the future holds for the quality of this pork product. Whatever, the industry is likely to experience great improvements as it puts so much emphasis on this important facet of our product.

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SYMPOSIUM CONCLUSIONS

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During the production and processing of pork there are many risks to the eventual eating experience of the product. Indeed, efforts to reduce production costs and provide leaner and healthier pork products to consumers have sometimes increased these risks. The papers in this symposium described the research that has been done in Australia and elsewhere to understand and address these risks and, in many cases use this information as an opportunity to improve the consumers' pork eating experience.

Table 15. Collation and risk rating* of the factors that might have an impact on pork eating quality along the value chain.

Critical management point	Rating	Issue*
Breed	**	• Duroc known to boost marbling
		• Hal gene known to be linked with PSE
		• Unknown status of RN gene
Sex	***	• Castration reduces risk of taint
		• Castration increases marbling
Age and weight at slaughter	*	• Little effect of weight within current commercial range
Nutrition	**	• Taint from certain ingredients (fish meal/oil)
		• Benefits of Mg/reduced PSE and Vitamin E /lower drip loss and longer shelf life
		• Risks to eating quality of metabolic modifiers
Housing	*	• Risk of skatole taint
On-farm handling	*	• Possible link to stress/PSE
Transport	**	• Stresses of mixing and handling/PSE
Lairage/pre-slaughter handling	**	• Stresses of mixing and handling/PSE
Time off feed	**	• 6 - 24 hours prior to slaughter
Stunning	*	• Low risk if done correctly with either electrical or CO_2 stunning
Stimulation	**	• Low voltage electrical stimulation 5-10 minutes post-slaughter
Carcass processing		
chilling	****	• Effect on PSE
hanging	****	• Benefits of aitchbone hanging/improved tenderness
Product preparation		
ageing	*****	• Benefits of ageing - >2 and up to 7 days /improved tenderness
pumping	*****	• Major impact on eating quality /improved juiciness and tenderness
Consumer preparation	******	• Cook to end point temp between 65 and 71°C

* low risk, ***** high risk/impact on eating quality.

New approaches to managing pork eating quality are best demonstrated by the enhancement or pumping technology that is now widespread practice in the US industry. Yet, as described by Meisinger (2001), this is not a technology to improve low quality pork, but it is a method being used by the pork industry to improve the overall quality of fresh pork in the retail meat case. Considerable management skill and control is still required to provide processors with the pork needed for successful enhancement.

Table 15 attempts to put some perspective to the many factors that affect pork quality throughout the value chain. Most of the critical management points have been discussed during this symposium, but they also extend to the role of the cook.

Although the factors with the greatest risk/impact to eating quality tend to be those further along the value chain, few of these factors are independent. As pointed out by Meisinger (2001), to manage pork eating quality, there must be a coordinated, integrated effort that extends beyond the producer and the processor. Manufacturers, distributors, retailers, foodservice and export agencies need to be involved and, as demonstrated in this symposium, so do meat and consumer scientists.

Symposium References commence on next page

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A REVIEW - THE PREVALENCE AND ERADICATION OF PIG DISEASES IN AUSTRALIA

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Abstract

The Australian pig industry derives a competitive advantage because of its freedom from many major viral diseases of pigs. It also has the opportunity to reduce the impact of a number of other significant bacterial and parasitic diseases. To varying degrees swine dysentery, enzootic pneumonia, mange, pleuropneumonia, leptospirosis and atrophic rhinitis erode profits on Australian pig farms. This review discusses the prevalence of these diseases in Australia, their cost, how they are spread and the technologies available to eradicate them: depopulation, Swiss depopulation, medicated early weaning and herd medication or vaccination. It also discusses the key principles of herd biosecurity so that once diseases are eradicated logical steps can be put in place to prevent their return.

Introduction

The first pig to die in Australia did so on 6 February 1788 after it was killed during a thunderstorm by a falling tree (Clark *et al.*, 1988). The pig was one of 32 taken on board at Cape Town and which arrived with the first fleet in 1788 (Tench, 1789). The long journey would have allowed many infectious diseases to run their course, susceptible pigs to die and any viral pathogens to be eliminated by the time the ships docked, or at least by the time new stock arrived with later shipments. By 1793 there were still only 43 pigs on farms in the new colony. Low stocking density and small herd sizes further minimised any disease threat. However, survival of the humans rather than husbandry of the animals was the major preoccupation and animal disease itself was afforded little apparent attention.

Reports of foot and mouth disease investigations in the 1870s indicate pre-embarkation inspection and a regulatory framework was present for disease control (Victorian Parliament, 1872). In 1908 the first Quarantine Act was passed and in 1923 the first state Stock Diseases Acts were passed.

Bunn *et al.* (1998) describe how, in 1872, a suspected outbreak of foot and mouth disease in cattle and pigs near Werribee was contained and eliminated. In 1903 there was a serious epizootic of classical swine fever (CSF) in Victoria and, in the same year, a similar disease appeared in Queensland, New South Wales, South Australia and Western Australia (Albiston, 1966). Classical swine fever appeared several times through the first half of the 20th century; it was usually associated with garbage and food waste which was fed to the pigs. The last outbreak occurred in 1961 when a low virulence form of the disease was responsible for an increase in the number of carcasses condemned for septicaemia in New South Wales. The disease was eradicated by a slaughter out campaign that was completed late in 1962 (Flynn and Jones, 1964; Keast and Golding, 1964).

Today Australia remains remarkably free of most of the major viral infectious diseases of pigs although many of the infectious bacterial diseases seen throughout the world are present. Despite importations of pigs from South Africa during early settlement and, more recently Ireland through the 1950s, Canada and the UK through the 1980s, and semen until about 1994 from Canada and Norway, the Australian pig herd has escaped infection from many important diseases of pigs. Australia is free of Aujeszky's disease, African swine fever, CSF, transmissible gastroenteritis, foot and mouth disease and the other vesicular diseases of pigs, swine influenza, porcine respiratory coronavirus, porcine epidemic diarrhoea virus, trypanosomiasis, rabies, trichinosis and porcine reproductive and respiratory syndrome (PRRS). It does appear however, that progressive

atrophic rhinitis was introduced with breeding stock in the 1980s. Its distribution was limited to the stud pig sector and its customers; hence the spread of the disease was restricted (Mercy *et al.*, 1986).

Japanese encephalitis virus is present in the Torres Strait Islands (Geering *et al.*, 1995). It is spread by mosquitoes and is detected from time to time on the Cape York peninsula, most recently in 1997-8. It is mentioned here because, although it is not a significant disease of pigs, they are amplifying hosts for this viral agent that causes serious disease in people. In addition, a new disease of pigs, Menangle virus (a paramyxovirus), carried by flying foxes and causing reproductive failure, spread to pigs in NSW in 1994. The clinical syndrome was recognised as differing from that of any known disease, the infectious agent was isolated and the virus eradicated from the herd before it could spread further (Love *et al.*, 2001).

The eradicable diseases of pigs in Australia

The more common bacterial and parasitic pathogens that occur worldwide are present in Australia. A subset of these provides the focus of this paper. The subset (and the diseases they cause) includes *Mycoplasma hyopneumoniae* (enzootic pneumonia), *Actinobacillus pleuropneumoniae* serotypes 1, 3, 5, 7 and 15 (pleuropneumonia), *Brachyspira hyodysenteriae* (swine dysentery), toxigenic *Pasteurella multocida* (progressive atrophic rhinitis), *Sarcoptes scabiei var suis* (mange) and *Leptospira interrogans serovar pomona* (leptospirosis). For this paper these diseases are called the target diseases. The knowledge exists to eradicate them from pig herds (Cutler, 2001). Some of them can be spread by aerosol, others by intermediate animal hosts or contaminated clothing, boots or equipment; all of them can be spread directly from pig to pig (Table 1).

Table 1. Prevalence of diseases of pigs in Australia and their means of spread (Cutler and Dunlop, 2001).

Pathogen	Disease	National herd prevalence	Means of spread
M. hyopneumoniae	Enzootic pneumonia	86.7%	Pig to pig, aerosol (3-5 km)
A. pleuropneumoniae (APP)	Pleuropneumonia	Widespread. Not quantified. Estimate >85%	Pig to pig, aerosol (500 m)
B. hyodysenteriae	Swine dysentery (SD)	25% (estimate only)	Pig to pig, rats, mice, dogs, contaminated boots and clothing, effluent.
Toxigenic *P. multocida*	Progressive atrophic rhinitis (PAR)	Low incidence, not quantified.	Pig to pig
Sarcoptes scabiei	Mange	>80%	Pig to pig
L. pomona	Leptospirosis	<6%	Pig to pig

The prevalence of the target diseases in Australia is summarised in Table 1. The data are drawn from abattoir monitoring studies and other surveys (Meo and Cleary, 1997).

A range of other diseases infects pigs but the technology to eliminate them from pigs on a farm, from the farm environment or to prevent their reintroduction, is limiting. The more significant diseases or infectious agents in this group include enterotoxigenic *Escherichia coli*, coccidiosis, rotavirus (neonatal and post-weaning diarrhoea), *Staphylococcus hyicus* (greasy pig disease), haemagglutinating encephalomyelitis virus, *Haemophilus parasuis* (Glasser's disease), *Streptococcus suis*, *Erysipelothrix rhusiopathiae*, salmonellosis, *Lawsonia intracellularis* (ileitis), *Mycobacterium avium* (TB), *Brachyspira pilosicoli* (spirochaetal diarrhoea) and porcine parvovirus. The internal parasites *Ascaris suum* and *Trichuris suis* complete the list.

Eradication of *B. pilosicoli* has been reported (Fossi *et al.*, 2000) but because the organism has been recovered from people and dogs in addition to being widespread in pigs in Australia (Hampson and Trott, 1995) the success of eradication attempts is doubtful.

Mycoplasma hyopneumoniae

Mycoplasma hyopneumoniae is widespread in the Australian herd. It is also known as enzootic pneumonia, virus pneumonia, and mycoplasma pneumonia. In most Australian herds infection will be complicated by *Actinobacillus pleuropneumoniae*. Described in an early report by Pullar (1948) as being associated with the introduction and mixing of store pigs or adult breeding stock, the disease continues to have a significant impact on Australian herds. Although there remain a small number of herds free of the disease, over 85% of Australian herds must be considered infected. Individual states report similar prevalences. The prevalence of lesions amongst animals at slaughter is influenced by herd size, stocking density, group size, air quality and vaccination status. It ranges from 28.6% in Western Australia to 55.4% in South Australia (Pointon 1995). Prevalence of lesions is higher in late spring and summer than at other times.

The disease is diagnosed on the basis of clinical signs, lesions at slaughter, histopathology, polymerase chain reaction tests and serology. Several groups have established *M. hyopneumoniae* free herds only to find they have become infected with *M. hyopneumoniae* within periods of 1-25 years. Currently three of Australia's major seed stock suppliers maintain herds or breeding herd pyramids free of *M. hyopneumoniae.*

Commercial vaccines against *M. hyopneumoniae,* although first reported in 1990 (Ross, 1999) have only been available in Australia since 1997. They are remarkably effective, significantly reduce the prevalence and severity of lesions and improve growth performance in vaccinated pigs. The introduction of vaccines against *M. hyopneumoniae* reduces the pressure to eradicate the disease and changes the financial equation for eradication measures.

Actinobacillus pleuropneumoniae (APP)

Lesions of pleuropneumonia are not common in slaughtered pigs but APP is widespread and the national herd prevalence is probably well in excess of the 50% suggested by Pointon (1995). The agent has infected major breeding stock suppliers for at least the last twenty years but two of them have developed breeding herd pyramids free of the disease. *Actinobacillus pleuropneumoniae* serovars 1, 7 and 15 are the predominant Australian serovars. Infection largely manifests as pleurisy or a fibrinous pleuropneumonia that are readily apparent at slaughter and confirmed by culture. Subclinical infections do occur and can be confirmed by serology for serovars 1 and 15. The South Australian herd prevalence and the individual animal prevalence range for pleurisy was, according to Pointon *et al.* (1992), 58% and 13% respectively from 1985-7. There has been some upward movement in herd prevalence and average animal prevalence since then. When APP 1 exists in a herd the disease is severe and problems with growth performance and mortality extract a cost which can exceed $100/sow/year (Cutler and Gardner, 1988; Skirrow *et al.*, 1995).

When combined with *M. hyopneumoniae,* APP infection causes serious disease (Skirrow *et al.*, 1995) and imposes an increase of as much as 10 cents/kg in the cost of production through its impact on growth and mortality rates. Vaccination with *M. hyopneumoniae* vaccines appears to have reduced the impact of chronic respiratory disease caused jointly by APP and *M. hyopneumoniae.*

Brachyspira hyodysenteriae

Swine dysentery occurs in about 30% of Australian herds (Hampson and Trott, 1995). Its prevalence is difficult to measure because *B. hyodysenteriae* is difficult to grow and there are no satisfactory serological tests. Diagnosis rests on clinical signs confirmed

by post-mortem, histopathology and culture. Spirochaetal diarrhoea caused by *B. pilosicoli* can look the same and consequently can make diagnosis difficult.

Swine dysentery causes a significant reduction in growth performance and feed efficiency. Fahy (2001) quotes an example where the disease reduced whole herd feed efficiency by 0.58 and increased the cost of production by 15%. In addition, to maintain production continuous use of feed or water medication is required. The disease is possibly the most devastating endemic disease Australian pig producers face. It adds in excess of $100/sow or about 10 cents per kilogram to the cost of production (Cutler and Gardner, 1988); however, Fahy (2001) suggests that the cost is over double this amount.

Toxigenic Pasteurella multocida

Progressive atrophic rhinitis (PAR) is caused by toxigenic *P. multocida* either alone or in association with toxigenic *Bordetella bronchiseptica.* It is differentiated from nonprogressive atrophic rhinitis (NPAR) which is associated with toxigenic *B. bronchiseptica.* Both diseases are associated with hypoplasia of the nasal turbinate bones accompanied by facial distortion. Nasal bleeding is rare in NPAR but characteristic of PAR (de Jong, 1999). Toxigenic *B. bronchiseptica* is widespread in pigs and causes minor or insignificant growth depression. Toxigenic *P. multocida* however, is of global significance and is accompanied by poor growth in fattening pigs. The disease was introduced into Australia in the 1980s with breeding stock from Canada (Mercy *et al.,* 1986). It entered a small number of herds whose owners were active in the show circuit and the disease spread quickly through this group and their customers. Fortunately it has failed to develop into the threat to Australian production that has happened abroad. The disease is not believed to be present in the herds of the five major breeding stock suppliers. Pointon *et al.* (1992), drawing on 1986-9 data, estimated that the herd prevalence of PAR infection in Western Australia was about 5%.

Sarcoptes scabiei

The parasitic mite, *S. scabiei* var. suis, causes sarcoptic mange. It is a common infestation on pig farms. It appears to spread more slowly than other diseases and many herds that have succumbed to respiratory disease or swine dysentery remain free of mange. The disease has the potential to extract a significant impact on production. Cutler and Gardner (1988) attributed a production cost of about $30-60/sow/year if mange was uncontrolled but most herds adequately control the disease for about $5.00-10.00/sow/year with treatments to the sow herd, weaned pigs and occasional treatments to the growing herd. The ivermectin group of parasiticides has provided the opportunity to eradicate the disease (Reddin, 2001). Pointon *et al.* (1992) estimated that about 93% of South Australian herds were infested with a prevalence within the herd of 66%. These numbers probably overstate the infestation rate because the diagnosis at slaughter checks is based on lesions of papular dermatitis-like lesions (specificity 79%) and these are easily confused with other conditions. Pointon (1995) suggests a 20% prevalence of papular dermatitis is not inconsistent with freedom from mange. Definitive diagnosis rests on the demonstration of *S. scabiei* in skin scrapings but recently ELISA tests (Zalunardo *et al.,* 2000; Deckert *et al.,* 2000) have been reported to provide a useful diagnostic aid for herd freedom. Unfortunately, field experience with false positive reactions in negative herds suggests some caution is appropriate (Cutler, unpublished).

Leptospira pomona

A range of leptospires has been isolated from Australian pigs and there is serological evidence that Australian pigs are also infected with *L. interrogans bratislava.* A study of pigs slaughtered in Victoria between 1986-89 found the following leptospiral microscopic agglutination test titres greater than 256 and above: bratislava 11%, hurstbridge 7%, pomona 4% and tarrassovi 0.2%. Earlier studies found higher prevalences of pomona but lower prevalences of tarrassovi (Chappell *et al., 1998*).

Most of the focus has been on pomona, probably because it is has been the best studied. It causes reproductive failure but it is also a zoonotic disease. Its prevalence seems to be decreasing in both pigs and people. It is a major recognised cause of visible nephritis in kidneys but some caution is warranted because septicaemias and some other diseases can cause the same lesion of a focal interstitial nephritis, so there could be a tendency to over diagnose it. Nonetheless, Chappell *et al.* (1998) demonstrated leptospires in 28% of 368 kidneys with lesions. Pointon *et al.* (1987) found 11% of all pigs monitored had nephritis. These pigs were drawn from 96 South Australian herds. Lesions were evident in more than 50% of the pigs in 19 of these herds. Pointon *et al.* (1992) reported a herd prevalence for nephritis of 65% with an animal prevalence of 29%. Chappell *et al.* (1998) cite a lesion prevalence of 4% and a herd nephritis prevalence in Victoria of 59%. In a further study Chappell *et al.*(1998) found 40 of 94 pigs with nephritic kidneys positive for leptospires. The samples were drawn from 58 herds. Thirty herds were positive for leptospires but only one herd (five samples) was positive for pomona, indicating that other leptospires were probably involved and that the apparent prevalence of pomona was decreasing.

How diseases are spread

The following case studies from the author's experience and published studies further describe how the target diseases can be spread.

Pig to pig: Mycoplasma hyopneumoniae, atrophic rhinitis and swine dysentery

While *M. hyopneumoniae* is widespread in the Australian herd there remain significant numbers of herds that have been able to remain, through good luck or good management, *M. hyopneumoniae* free. In the late 1990s an uninfected seed stock herd (A) became infected with the disease. The herd was situated in a remote location and the precise origin of the infection remains unknown. However, the disease spread quickly to those farms that purchased breeding stock and introduced them directly into their farms. During the five weeks it took for clinical disease to be diagnosed in herd A the disease was transferred to eight susceptible herds that received breeding stock from herd A in this period. Within a period of 4-12 weeks after the introduction of infected breeding stock clinical pneumonia was evident in the susceptible herds. Some herds which held new pigs in an isolation or quarantine facility escaped infection but at least one herd which did use an isolation facility was unable to prevent the introduction of *M. hyopneumoniae* because the disease went undetected in isolation.

In the 1980s when seedstock producers imported breeding stock from Canada several stud producers elected to introduce their imported breeding stock directly into their herds. The breeding stock had been penned closely together during their flight from Canada and spent further time together in quarantine. Although the breeding stock themselves were clinically healthy their progeny developed clinical progressive atrophic rhinitis. Pigs from those herds that were exhibited at stud shows quickly spread the disease to in-contact pigs and progressive atrophic rhinitis quickly became established in the stud pig circuit. Those seedstock producers who elected to introduce their genes by semen or variations of medicated early weaning programs avoided this problem.

A herd (B) supplying breeding stock experienced diarrhoea in grower and finisher pigs. Within days a herd that had always been closed but had taken its very first load of new breeding stock from herd B experienced a similar diarrhoea. Swine dysentery was diagnosed in both herds on post-mortem. The *Brachyspira hyodysenteriae* cultured was shown to be pathogenic in laboratory challenge trials. Swine dysentery clearly spread from the first herd to the second but the origin of infection for the first herd was never identified. The herd had tight controls on visitors and staff movements.

Aerosol and rats: Mycoplasma hyopneumoniae, Actinobacillus pleuropneumoniae and swine dysentery

In 1989 a large farm (C) embarked on an ambitious project to depopulate its herd and repopulate it with pigs free of *M. hyopneumoniae*, APP and SD. When repopulation commenced about 400 sows from the original herd remained in buildings about 500 metres from the repopulated unit. The new sows were free of these diseases and their source herds remained free, yet progressively the repopulated herd became infected over the next 12 weeks with *M. hyopneumoniae*, APP and SD. The first two were believed to be spread by aerosols from the neighbouring sow herd. Swine dysentery was believed to be spread by rats that moved back to the new farm from the 400 sows when it was restocked and pig feed once more became available for the rodent population.

Contaminated truck: Mange

A large NSW herd (D) imported boars and sows from a parent nucleus breeding herd in Victoria. Both herds were originally free of mange but over time, while the Victorian herd remained free, the NSW herd became infected. The origin of the infection was believed to lie with the trucks used to ship the pigs to the NSW herd. The trucks were used at other times to ship pigs from other farms to abattoirs and most likely carried sarcoptic mites in hair and tissue debris on the floor of the transport vehicle.

Wildlife carriers

In NSW a herd (E) experienced an episode of severely deformed and mummified pigs. The malformations suggested the disease as "different" and ultimately a paramyxovirus, Menangle virus, was identified. The source of the infection was traced to a flying fox colony located close to the farm (Love *et al.*, 2001).

Feral pigs

Feral pigs present a disease risk for many farms. Australia has between 3.5 and 23.5 million feral pigs, depending on seasonal factors; they occupy 38% of the continent (AFFA, 2001). In addition to the endemic disease risk, they represent a worrying potential reservoir for exotic diseases that may be introduced and would create problems of diagnosis and control. Further, their importance increases as more pigs are raised in outdoor systems. The author has direct experience with entrance of feral pigs into outdoor herds on two occasions on the same farm over a three-year period.

Most Australian farms have ignored the feral pig risk. There have been feral boar incursions on too many large Australian pig farms that ought to have had better controls in place. Fortunately, in most cases the health status of the herds were inferior or equivalent to that of the feral pigs although in one instance feral pigs were probably responsible for infecting a large Queensland commercial herd with *M. hyopneumoniae*. In addition, feral pigs have been implicated in the introduction of *Brucella suis* into both indoor and outdoor herds in Queensland (Webster *et al.*, 1982).

Biosecurity

Before any farm manager embarks on a disease eradication program there must be a protocol in place to prevent later incursions of the disease. The key elements of a biosecurity program are drawn from Cutler and Dunlop (2001) and include:

1. Isolation from other farms.
2. A ringlock or similar mesh fence one metre high and locked gates to keep feral pigs out.
3. A closed herd or single source supply of breeding stock from a herd of higher or comparable health status.

4. A load out area which is clearly defined as off-farm.
5. An off-farm isolation or quarantine facility.
6. A single controlled entrance for staff and visitors that clearly separates "clean" farm areas from "dirty" non-farm areas and an area to change into farm clothes and boots that is clearly separated from the non-farm area.
7. Training programs for staff about disease control matters.

These elements recognize that most diseases are spread from pig to pig. While there are some other ways diseases can be spread, in most cases they can be covered by prevention protocols. All it takes is one breach of security to ruin a herd's health status. For large farms this loss could be forever because the practicalities of disease eradication mean that it becomes increasingly difficult as herd size increases. Not only is the total cost higher but the logistics of replacement gilt supply are prohibitive. As a consequence large farms usually employ techniques such as age segregated rearing to control disease.

Most farms don't have an isolation facility for new breeding stock. As a consequence herds are denied any real protection against diseases which could be introduced with breeding stock. Even if mange, *M. hyopneumoniae* and APP 15 are not an issue for most farms (because they are already infected) SD and APP 1 certainly are. *Mycoplasma hyopneumoniae*, APP, SD, mange and PAR have all been spread to customer herds from seed stock producers in Australia. A similar story exists abroad for Aujeszky's disease and PRRS, just to name two. The spread of leptospirosis is insufficiently documented but a similar story probably exists. Any sort of basic quarantine facility and a simple protocol will protect a herd against mange, APP and SD introduced with imported breeding stock, but few herds take this precaution. For herds free of *M. hyopneumoniae* isolation facilities provide a measure of insurance and protection, although some recent episodes of *M. hyopneumoniae* infection were not stopped by this measure because the disease was not immediately identified in the source herd. To allow for extended periods before disease is detected in source herds an eight-week isolation period is recommended. This period of isolation can be combined with serology for diseases such as APP and *M. hyopneumoniae* but the logistics of testing and the uncertainty of interpretation of results (at least for *M. hyopneumoniae*) make it too complex for even sophisticated management, so the tendency is to rely on clinical signs and slaughter checks of the source herd.

Producers often seem curiously willing to change their breeding stock suppliers for little logical reason and contravene the most fundamental principle of disease control – single source supply of replacement breeding stock.

Most farms have some sort of control for visitors. Despite common perceptions, people are rarely true carriers of pig pathogens under circumstances that would permit transmission back to pigs (Amass and Clark, 1999). Foot and mouth disease virus has been recovered from the nose of people working with FMD infected animals after 28 hours but not after 48 hours; this is probably the origin of the 48 hour rule that applies on many farms (Sellers *et al.*, 1971). In unusual cases FMD can be transmitted to people, who will be infectious for animals. Porcine reproductive and respiratory virus has been recovered from the hands of people after continuous exposure to viraemic pigs and PRRS RNA was demonstrated in fingernail rinses and nasal washings 5 and 48 hours after exposure, but the virus was not transmitted to sentinel pigs (Amass *et al.*, 2000). Wentworth *et al.* (1997) recorded transmission of swine influenza virus to human caretakers despite the use of biosafety containment practices (coveralls, boots, goggles, gloves, hairnets and dust masks).

Veterinarians have been linked to the spread of viral diseases through contaminated equipment and syringes and it is clear that some infectious agents will survive in faeces and mucus on boots and clothing. Hence clean equipment and a change of boots and clothing provides the necessary layer of protection for any diseases that may be carried by people. This, combined with clearly demarcated "clean" and "dirty" areas, is all that is required. Some farms insist on extended periods away from pigs for essential visitors and for staff who come into contact with other pigs or after training sessions where they meet people from other pig farms. There is no basis in fact for these recommendations. Indeed,

they have failed to protect herds against disease incursions and probably hinder production rather than help. Shower-in facilities appear to provide no additional protection (Goodwin, 1985). Because of the consequences of disease introduction and the added security provided, a pig free period of 12 hours or overnight and a shower-in policy are not unreasonable imposts for visitors to some high health status herds.

Footbaths have been shown by Amass et al. (2000) to be practically useless in eliminating bacterial contamination. For them to provide any protection at all boots must be free of organic matter and spend in excess of five minutes in most disinfectant solutions. Only Vircon S®, a peroxygen compound, can be used as a disinfectant in a walk through footbath with any sort of efficacy (Amass *et al.*, 2001). For most farms it will be enough for the farm boots to be clean. Most disinfectants provide little or no practical benefit beyond that and for many farms clean boots will be a significant improvement.

Domestic animals present few risks as far as the target diseases are concerned. *Brachyspira hyodysenteriae* can be recovered from dogs (Harris *et al.*, 1999) but they only present a risk if they travel to different farms or their "own" farm undergoes a SD eradication program. In parallel with this concept, in Denmark farm dogs have been implicated in the reinfection of farms with salmonellae after depopulation (Nielsen *et al.*, 1998). Birds have been implicated in the spread of transmissible gastroenteritis (Saif and Wesley, 1999) but are unimportant in an Australian pig disease transmission context.

Vehicles are only a risk if they are carrying pigs or if they have not been cleaned before they arrive on farm to collect pigs for shipment for sale or slaughter.

In other parts of the world PRRS, Aujeszky's disease, classical swine fever, African swine fever, swine influenza, transmissible gastroenteritis and foot and mouth disease demand additional levels of biosecurity but Australia can take advantage of its health status in this regard.

Staff training programs are important elements of biosecurity and some suggest that creating some biosecurity hurdles that staff must endure reinforces awareness of biosecurity.

The cost of disease

Disease burdens place farms under severe financial pressure when prices are low and small changes in performance and cost of production can make farms unprofitable. The increases in cost of production associated with minor changes in performance are presented in Tables 2 and 3.

Table 2. Ready reckoner for calculating the impact of changes in mortality rate on profit (Cutler, 2001).

Mortality rate increase	Reduction in profit per sow/year ($)	Extra cost (¢/kg) of meat (DWT) produced*
1% in sow mortality rate	3.30	0.2
1% in pre-weaning mortality rate	19.00	1.0
1% in post weaning mortality rate (4–8 weeks)	18.00	1.0
1% in mortality rate (9–15 weeks)	24.00	2.0
1% in mortality rate (16–24 weeks)	30.00	2.0
1% in mortality rate (4–24 weeks)	30.00	2.0

*Assumes 1440 kg dressed weight (DWT) pork sold per sow per year. Numbers rounded.

The simulations are drawn from Auspig models and cash costs of production (COP) of $1.66/kg (dressed weight) including feed costs of about $230 per tonne (raw materials) and where the price received for pork ranges from $1.97 to $2.50. In this scenario the profit per pig (dressed weight) ranges from $21.86 to $38.16. To this COP must be added allowances for return on capital of about 20 cents per kilogram. Impose disease on this system and the profit changes substantially. Hence it is easy to see how small decreases in production performance add significantly to the COP and can drive it up to approach

or exceed $1.90/kg, even on the best farms. During 1998 the average price of pigs rose above $1.90/kg dressed weight (DWT) for only about 18 weeks of the year (Meo and Cleary, 2000).

Table 3. Ready reckoner for calculating the impact of changes in growth rate on profit (Cutler, 2001).

Reduction of 1 kg liveweight at:	Reduction in weight (%)	Reduction in profit /sow/year ($)	Increase in *COP ¢/kg
Weaning	14.0	86	6
8 weeks	5.3	47	3
15 weeks	2.0	24	2
23 weeks	1.1	19	1

*Cost of production (cents per kg dressed weight).

Disease eradication strategies

The disease eradication options available to producers include depopulation, Swiss depopulation, medicated early weaning (MEW) and medication and vaccination programs against specific diseases.

Depopulation

Depopulation involves the total depopulation of the herd and repopulation with high health status breeding stock. The technique is described by Hitchens (2001) and is usually associated with a thorough hygiene and rodent control program. Failures have occurred where farms have destocked because of SD and repopulated, only to break down with SD within a 6-12 month period because the depopulation program failed to eliminate the rodent population.

Conventional wisdom holds that herds need to be free of pigs for about six weeks before they are repopulated if SD is to be eradicated. This period just allows more time for rodent control and hygiene programs to be implemented. For mange, a down time of about four days is appropriate to allow for any off-host *Sarcoptes scabiei* to die. For the other diseases, 24 hours is sufficient because *M. hyopneumoniae* and APP do not survive off the host for any significant period of time. In practice, the logistics of the cleaning procedure and the associated maintenance require six weeks downtime; anything shorter is usually wishful thinking.

Table 4[1]. Depopulation and repopulation to reduce cost of production (Hitchens, 2001).

		Dirty herd	Clean Herd	Clean Herd
Sow herd size		150	150	190
Grower feed cost per kg $		1.05	0.78	0.78
Sow feed cost per kg $		0.19	0.19	0.19
Other costs per kg:	Labour $	0.23	0.23	0.18
	Breeding Stock $	0.11	0.11	0.11
	Freight and Levy $	0.09	0.09	0.09
	Miscellaneous $	0.21	0.21	0.16
Total cost of production	$/kg DWT	1.88	1.61	1.51

[1]Assumptions for Table 4:

- 150 sows expanding to 190 sows selling 20 pigs/sow/year at 93 kgs liveweight.
- Grower herd feed:gain = 2.47 for dirty herd, 2.08 for clean herd.
- Average feed cost $280/tonne, in-feed medication costs in dirty herd, $40/tonne.

The total cost of a depopulation program depends on the targeted diseases and the price of pork and feed but a net cost of $400/sow can be taken as a guide. This cost is recovered within 12-18 months through a combination of superior performance and reduced medication costs (Table 4). Hitchens (2001) found that the superior performance of the repopulated herd enabled him to increase throughput and, as a consequence, herd size and output. Cost of production fell as the herd costs were distributed over the increased output.

Some herds undertake a depopulation only to fail months or years later through lax biosecurity or chance introduction of respiratory disease. However, many herds have enjoyed substantial periods free of the target diseases. The Victorian Institute of Animal Science herd at Werribee remains free of *M. hyopneumoniae*, SD, and mange after over 30 years of production. A large NSW herd (F) survived about 15 years free of the target diseases before it became infected with *M. hyopneumoniae* in 1990. Another large herd (G) in Southern NSW enjoyed 24 years of production free of this disease.

Swiss depopulation

Swiss depopulation targets the elimination of pathogens by medicating the sow herd and depopulating the growing herd. It relies on the lower level of pathogen excretion from sows combined with high levels of maternal immunity which are passed on to progeny. Treatment either eliminates infection or suppresses it to the point where it does not spread. The technique, described in detail by Frey (2001) for *M. hyopneumoniae*, has been applied to APP (Cutler, 2001) and with minor variation to Menangle virus (Love, 2001) and could be used for other diseases where it was important for the herd's genetic base to be retained. Smith and Mortimer (2000) and Baekbo (1999) claimed success with the eradication of *M. hyopneumoniae* and APP using this technique although Baekbo (personal communication) was less confident of success with APP.

The technique is particularly appropriate for outdoor sows when they are moved to a new site and for weaner producers. The greatest limiting factor is the availability of housing for depopulated weaned and growing pigs. Swiss depopulation involves removal of weaned pigs and any other pig less than nine months of age off-site, medication of the sow herd for 2-4 weeks depending on the disease, and then normal production is resumed. The herd is closely watched and sampled for the presence or emergence of disease. Early programs halted farrowing for two weeks while the medication program was implemented but later protocols have been shown to be successful without this step (Mortimer, Elanco, UK, personal communication).

Medicated early weaning (MEW), snatch farrowing and isowean

These techniques provide an opportunity to produce pigs free of disease for relocation to another site.

"Snatch" farrowing is the colloquial term given to the practice of removing piglets from their dams immediately after birth (Ross and Cutler, 1992). This procedure was applied in the late 1980s on the then Commercial Pig Company farm at Huntly, Victoria, to produce high health status breeding stock as part of a program to depopulate and repopulate the 3000 sow Huntly herd with pigs free from *M. hyopneumoniae*, SD and APP. The herd was already free of mange.

The protocol involved inducing the farrowing in a dedicated facility of selected sows that had been medicated with antibiotics, immediately removing the newborn piglets to positively pressured humidicribs and fostering them to synchronised high health status sows on a new site about 6.5 kilometres away. It was applied at a time before MEW procedures were widely accepted and was perceived to be a lower risk procedure than MEW. It also solved the problem of the expense and complexity of alternative protocols that were based on caesarean delivery. The "snatch" technique successfully produced 5000 pigs that were used to repopulate the main herd. Snatch farrowing worked but survival of the fostered neonates (72%) was lower than expected and obtaining a reliable supply of high health status foster sows proved difficult.

Medicated early weaning resolves both these problems. First reported by Alexander *et al.* (1980) the procedure involved heavy medication of sows before farrowing (at an off-site facility) and until weaning, when, at about five days of age, the piglets were moved to a separate location. The suckers were also medicated during this period. Medication suppressed any infections that the sows carried, reduced or prevented their excretion and prevented spread to and infection of neonates. In addition, during this time the neonates were naturally protected by the dams' passive colostral immunity. Further risk reduction of disease transmission was provided by using mature sows as the donor dams rather than gilts, which could have been expected to be shedding more pathogens.

Alexander *et al.* (1980) targeted *M. hyopneumoniae* when designing the MEW protocol but foreshadowed that it could be applied to other infectious agents. The technique has been proved effective for atrophic rhinitis and APP among others and has been applied throughout the world, especially to establish high health status breeding herds for seedstock producers. The protocol has been successively modified to the point where parity one sows are no longer excluded; piglets are weaned as late as 10-14 days of age and the whole procedure carried out on farm. Weaned pigs are of course still removed to a separate site.

Medicated early weaning protocols are described by Higgins (2001) and have been used in Australia to secure herds free from *M. hyopneumoniae* and APP. Their success lies in diligent application of the protocols, conscientious dosing of neonates and sows, and limited numbers. For example, MEW successfully eliminated APP15 from a 250-sow herd (I) but failed to eliminate it from a 1200 sow herd (H) using the same MEW protocol. While no clinical disease was ever apparent, evidence of APP 15 infection was detected serologically.

Medicated early weaning does not eliminate several common pathogens or diseases. They include, among others: *E. coli*, erysipelas, *Lawsonia intracellularis*, *Haemophilus parasuis*, *Streptococcus suis* and coccidiosis, even though on one Queensland farm (J) the last was especially targeted during an MEW procedure.

The North American industry observed the success of MEW pigs and their tremendous performance improvement and sought ways to exploit the procedure (Harris, 1988). Starting with the Pig Improvement Company in the USA, the MEW protocol was modified. First of all the sows were no longer moved off-site so the piglets were taken straight out of the farrowing house. Different medication and vaccination strategies were applied and pigs were weaned at different ages. Gradually, and empirically, it became clear that it was possible, even without treating sows and suckers, to wean pigs to an isolated or off-site nursery where their performance exceeded earlier benchmarks. Harris (2000) called the concept Isowean. The procedure didn't necessarily eliminate disease but the effect on performance was still evident. Where disease elimination was necessary MEW protocols were still required.

Harris *et al.* (1992) used the MEW/Isowean concept to reduce the cost of depopulating breeding herds to eradicate Aujeszky's disease. They found that even though the sow herd might be infected with Aujeszky's disease they could contain it to one site and produce pigs free of the disease on the weaner and finisher sites. This was known as a "three-site" farm and the concept of multisite and multisource farms based on all-in all-out production by room or building or site grew. The system was also helped by the all-in all-out pig flow that allowed each room or building to be thoroughly cleaned between each batch of pigs. The nature of pig flow through the system also facilitates medication approaches to disease eradication. Harris (2000) described combining the Isowean concept, also known as segregated early weaning (SEW) or age segregated weaning, with a farm production system based on separate sites for breeders and farrowing sows, weaners and grower-finishers. These multisite production systems do not necessarily eliminate or eradicate disease but they do permit better performance in pigs produced by sows that carry disease.

Disease eradication by medication or vaccination

Eradication of sarcoptic mange provides the best example of a disease that can be eliminated by medication. Swine dysentery is another disease that has also been successfully eliminated.

Eradication of sarcoptic mange

The eradication of mange is described by Reddin (2001) and draws from the experience of Vesseur *et al.* (1998), Mohr (2000), Rambags *et al.* (2000), Smets *et al.* (1999) and Cargill *et al.* (2000) who describe the simultaneous use of ivermectin or doramectin by injection or in-feed treatments to all pigs in the herd to eliminate the parasite. Vesseur *et al.* (1998) used an eradication program based on ivermectin (two treatments by subcutaneous injections 14 days apart and an additional injection for all pigs born during the first week of the program). Based on this approach the Dutch have established a mange eradication and certification program. Nearly 500 farms have been certified. No certified farms have become infected with the disease but 6% of those undergoing certification failed to eradicate mange. The pay back period for the eradication program is about six months. Even if eradication is not successful it provides a period of 18-24 months before treatment has to be considered again.

It has been recognised since 1983 that ivermectin (Ivomec®) could be used to eliminate the scabiei parasite and over the years eradication programs using this parasiticide have become widely accepted. Other products, doramectin (Dectomax®) and a long-acting ivermectin (Virbamec®) are similarly efficacious. Eradication is made easier by the availability of a form of ivermectin that can be added to pig feed (Mohr, 2000.)

In early mange eradication programs, spraying the external environment to kill any mites temporarily living off the pig was included as a key element but recent experience has shown this step to be unnecessary. An example of a mange eradication program is drawn from Reddin (2001). Central to the success of this protocol is thorough treatment and accurate dosage of each and every pig on the farm. Reddin (2000) describes using injectable Ivomec® (1ml/33 kg live weight) by injection to treat every pig on the farm twice at an interval of 14-28 days. However, a single treatment with injectable Ivomec® followed by Ivomec® feed premix in the diets is also successful (Mohr, 2000). The longer lasting miticides provide the opportunity to treat the breeding herd just once; the residual activity of the products providing a long enough period to kill any *S. scabiei* immature mites that might hatch from eggs laid earlier and which themselves are resistant to treatment.

Eradication of swine dysentery

Swine dysentery places such huge financial burdens on infected farms that the substantial costs of the medication program are usually recovered inside a year. The principle of the disease eradication strategy is based on a period of medication at a level that is known to eliminate the pathogen from sows and growing pigs. Additional safety is then provided by a level of medication that is known to suppress excretion of the pathogen for the period any treated growing pigs remain on the farm. Selection of an antibiotic that is lethal at normal concentrations to resident *B. hyodysenteriae* populations is important.

The program is based on the idea that infected asymptomatic sows pass *B. hyodysenteriae* to their progeny via faeces and then the infection is maintained or spread amongst the growing pigs. Piglets born to treated sows are assumed to be free of the pathogen and this is tested when all medication is removed from the diets after the last "treated" pig has left the farm. If the disease is going to emerge experience has shown that it will do so in about six months although the Pig Health Control Association guidelines in the UK nominated two years as the test period.

Muirhead (1987) described how swine dysentery was eradicated from six herds after 11 attempts and he has now sufficiently refined the process to predict an 85% chance

of success. Fahy (2001) describes a range of medication options based on tiamulin, lincomycin or dimetridazole. In one treatment schedule lincomycin is fed for six weeks to dry sows at the rate of 300 g/tonne, followed by inclusion in lactation diets at 200 g/tonne, and in weaner, grower and finisher diets it is fed at the rate of 150 g/tonne. Thereafter, for the next 18 weeks, all age groups receive 44 g/tonne of lincomycin. The dose rates demonstrate the key principle of allowing for less than *ad libitum* intake in dry sows and lactating sows. Using dimetridazole can considerably reduce the cost but some markets do not accept pigs treated with this antibiotic. Tiamulin is an equally suitable drug but it is still more expensive than dimetridazole. The ultimate selection of treatment depends on antibiotic resistance patterns.

Eradication of leptospirosis

Eradication of *L. interrogans serovar pomona* from herds has been based on a program that combines hygiene, medication to suppress excretion of the pathogen and vaccination over a 6-12 month period. Serology is used to monitor the herd's changing immune status over the eradication period. In Victoria and South Australia the disease was eradicated from herds by using the following program (Chappel and Cutler, 2001):

1. Immediately the diagnosis is made medicate feed with oxytetracycline or chlortetracycline at 800 g/tonne under veterinary supervision for 10 days to suppress the leptospires in the short term and so reduce the level of exposure to farm and abattoir workers as well as the pigs.
2. Follow up the vaccination and treatment programs with a regular hygiene program.
3. Vaccinate gilts at selection and again four weeks later.
4. Vaccinate sows in late pregnancy (three weeks pre-term) in conjunction with other vaccination programs.
5. Vaccinate growers twice, at least four weeks apart, depending on the distribution of infection in the herd. In most cases vaccination at about four weeks and again as the pigs leave the weaner house will be effective.
6. Continue the vaccination, with good hygiene, for twelve months.

Conclusion

The Australian pig industry derives a competitive advantage from its health status. Freedom from the major infectious diseases facilitates access to export markets. Freedom from a range of other serious diseases such as Aujeszky's disease, TGE, PRRS and swine influenza makes production less complex and, compared to our competitors lowers the cost of production.

There is an opportunity to further exploit this advantage. The technology is available to eradicate mange and the methodology is proven. The cost benefits are substantial. Given the relatively small size of the Australian herd it should be possible to eradicate mange from those 20% of herds that produce 80% of the pigs.

Eradication of the other diseases at a national or regional level is harder. Respiratory disease eradication relies on isolated farms for a start but in some areas of Australia, the density of pig farms precludes eradication.

Disease is a major determinant of production success and profit. When prices are low a high health status provides producers with an increased chance of trading profitably during adverse economic circumstances.

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ERADICATION OF MYCOPLASMA PNEUMONIA: FIRST REPORTED "SWISS DEPOPULATION" IN AUSTRALIA

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Swiss depopulation requires removal of all animals less than 10 months of age from the herd, followed by a two-week period in which there are no farrowings. During this time all stock are medicated for a period of 14 days to eradicate *Mycoplasma hyopneumoniae* from the herd. Animals born after this time will be free of the organism, and medication for *M. hyopneumoniae* can be discontinued. The aims of this paper are to demonstrate the economic benefits of the program and its simplicity. How modifications can be adapted to reduce the time without cash flow, and to show an alternative to the long term use of antibiotics.

The program was carried out in a commercial 100 sow piggery located in South-East Queensland. Initially, herd management was changed from weekly to monthly batch farrowing (over a period of 10 days). In this way, there was no need to stop farrowing or sell the young progeny for a period of a fortnight as is commonly done overseas. To accommodate production and to correct previous scour problems, an insulated weaner shed with a capacity for 220 pigs was built.

The program started on the 10/1/2000 by inducing all sows to farrow and weaning all piglets on the 31/1/2000. All stock less than 10 months of age were moved to a leased piggery about 15 km distant from the main piggery by 25/1/2000. All buildings were pressure cleaned and disinfected as pigs were moved out to the other piggery. All remaining stock was treated for a period of three weeks using Lincomycin (Lincomix 44 premix™, Pharmacia & Upjohn) at 5 mg/kg body weight starting on the 11/1/2000. The inclusion rate was 220 ppm for the lactation sow diet and 440 ppm for the dry sow diet. The next batch of sows started farrowing on the 9/2/2000. The first batch of pigs was sold in the second week of July/2000. Means were compared using Pearson's Chi-square.

Table 1. Grower herd performance before and after mycoplasma pneumonia eradication.

	1998	1999	2000	2001
Pneumonia prevalence (%)	72.1[b]	65.75[b]	0[a]	0[a]
Average lung score (%)	9.51[c]	5.67[b]	0[a]	0[a]
Average daily gain (g/d)	585[d]	610[c]	700[b]	743[a]
Days to market	179[c]	172[b]	150[a]	141[a]
Cost of medication for control of enzootic pneumonia/yr ($)	7,412	6,844	1,725	0
Cost/sow/year for control of enzootic pneumonia ($)	87.2	80 .0	20.0	0.0

[a,b,c,d]Means in a row with different superscripts are significantly different, P≤0.05.

Three abattoir inspections were done post eradication, viz., June and December 2000 (sera collected on both occasions for *M. hyopneumoniae* ELISA serology) and in May 2001. All lungs inspected were grossly free of *M. hyopneumoniae* pneumonia lesions. The sera were negative in the ELISA test. Results indicate that there has been a significant improvement in days to market and average daily gain. Many studies have attained success in eradicating Mycoplasma pneumonia using tiamulin (Baekbo *et al.*, 1994; Frey and Lysaght, 1998). There is only one report however, where Lincomycin was used at the same dosage (5 mg/kg) but in a smaller herd (Zimmerman and Weiskopf, 1996).

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UROGENITAL TRACT INFECTION IN BREEDING HERDS

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Urogenital tract infection (UGTI) has been identified as a major cause of reproductive failure and sow mortalities in Australian breeding herds (Paterson *et al.*, 1997).

In order to investigate the role of UGTI in reproductive failure, urogenital tracts were collected at slaughter from 117 culled sows from 24 commercial herds, and examined for the presence or absence of bacteria and inflammatory changes. The urogenital tracts collected were from unmated sows slaughtered after the last weaning; sows and gilts slaughtered and diagnosed not in pig between one and 11 weeks from the last recorded mating; sows and gilts slaughtered and diagnosed not in pig 11-15 weeks after the last mating; and unmated gilts that had not cycled. The urogenital tracts were cultured for bacteria and examined for evidence of inflammation. The definition used for infection in the study was the presence of inflammatory cells associated with the presence of bacteria in tissue.

A mixture of bacteria was isolated from the majority of urogenital tracts examined. Common isolates included *Escherichia coli* (44 tracts with inflammatory changes/63 without inflammatory changes), *Staphylococcus aureus* (16/21), *Enterococcus spp.* (13/32), *Streptococcus suis* (11/17), *Streptococcus dysgalactiae* (8/23), *Bacillus spp.* (6/11), *Streptococcus* group G (6/4), *Aeromonas hydrophila* (6/9) *Proteus spp.* (4/5) and *Streptococcus zooepidemicus* (3/0). The majority of these isolates was sensitive to Ampicillin, but all were resistant to Tetracycline. A similar range of bacteria was isolated from the prepuce of boars from the same herds. Data was analysed using ANOVA (*Statistix*®)

The prevalence of UGTI in sows culled between one and 11 weeks post-mating was 22% higher than in sows culled pre-mating (P=0.05), and 14% higher than in sows examined 11-15 weeks post-mating (Table 1). No inflammation was observed in urogenital tracts collected from unmated gilts. The percentage of UGTI in Parity 0 sows was 36% compared with 12% in Parity 1 sows, 46% in Parity 2-4 sows and 48% for older parities.

Table 1: Distribution of urogenital tract infection (UGTI) by sow group classification.

	Unmated gilts	Unmated sows	1 to 11 weeks post-mating	11 to 15 weeks post-mating
UGTI present	0	13	22	11
UGTI absent	11	26	18	16
% UGTI present	0	33	55	41

Most bacteria isolated from urogenital tracts were environmental contaminants and their role in infection remains unclear. Although they were isolated more frequently from tracts without inflammatory changes, their presence in association with inflammation cannot be ignored. The absence of bacteria and inflammatory changes in unmated gilts and the higher prevalence of UGTI in sows culled up to 11 weeks post-mating, as well as the presence of bacteria in the prepuce of boars, support an infectious role for these organisms. However, if their role is that of an opportunistic pathogen, further investigation is required to determine the conditions under which they are capable of initiating an inflammatory response. Failing that, the cause of the inflammatory response needs to be elucidated.

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OPTIMUM DESIGN OF GENOME SCANS TO DETECT QUANTITATIVE TRAIT LOCI IN COMMERCIAL PIG POPULATIONS

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If genetic markers could be found linked to quantitative trait loci (QTL) affecting economic traits in pigs, these markers could be used to increase the accuracy of selection, using marker assisted selection (MAS). Markers in linkage with QTL can be found by a genome scan (markers are placed at regular intervals along the genome) in commercial pig populations. Genome scans are expensive, so it is important the genome scan design (number of boars and progeny per boar) maximises the proportion of total genetic variance explained by QTL detected, as this parameter largely determines the advantage of MAS over selection without marker information (Lande and Thompson, 1990). The aim was to determine the genome scan design which maximised the proportion of total genetic variance explained by QTL detected in the genome scan.

A population of pigs with markers and QTL segregating was simulated. A pig had a genome of 18 chromosomes. Each chromosome was 100 centi-morgans long and had four QTL and five marker loci. The distribution of QTL effects in the large population was similar to that estimated by Hayes and Goddard (2001). Heritability of the trait was 0.25. One, two, five or 10 boars with the largest phenotypes were selected from the population and a total of 500, 1000 or 2000 progeny were bred from the boars. A variance component method was used to detect QTL (Goddard 1992), with the significance threshold $P \leq 0.05$ at each marker bracket. The true proportion of variance explained by detected QTL in the original population was determined for each design (Figure 1).

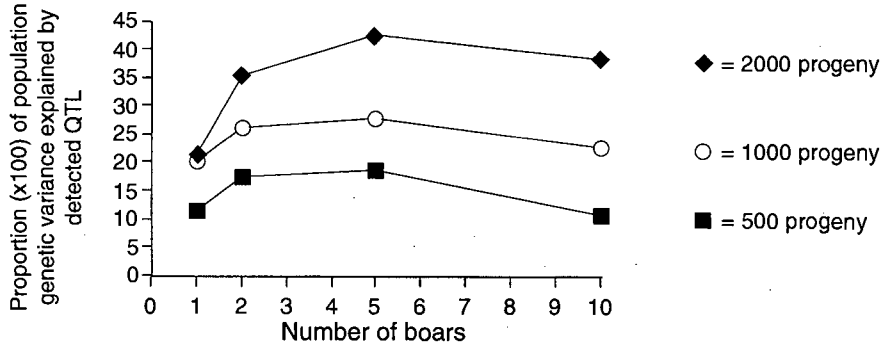

Figure 1. *Proportion of genetic variance explained by detected QTL in genome scans with one, two, five or 10 boars and 500, 1000 or 2000 total progeny allocated to the mapping experiment.*

Increasing the numbers of boars increased the chance one or more boars was heterozygous for a QTL segregating in the population. However, for a given total number of progeny for the mapping experiment, increasing the number of boars decreased the progeny per boar, decreasing the chance that the QTL effect is statistically significant. Using five boars balanced these two phenomena to maximise proportion of variance explained by detected QTL, regardless of total number of progeny in the experiment. If possible, five boars should be used to breed the resource population for future QTL mapping experiments, if the aim of these experiments is to detect QTL for MAS.

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GENETIC GAIN FROM MARKER ASSISTED SELECTION IN A COMMERCIAL PIG ENTERPRISE

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If genetic markers can be found linked to quantitative trait loci (QTL) affecting economic traits in pigs, these markers could be used to increase the accuracy of selection, using Marker Assisted Selection (MAS). In this paper the increased genetic gain from using linked markers in the nucleus of a pig enterprise is evaluated.

A small nucleus population of 20 sows was simulated. Each pig had 18 chromosomes. A chromosome was 100 centi-morgans long and had 4 QTL and 5 marker loci. Quantitative trait loci affected four traits, an index of growth and backfat (growth index, GI), feed conversion ratio (FCR), number born alive (NBA) and meat quality index (MQI). The distribution of effects of the QTL on these traits was such that there were many QTL with small effects and few with large effect (Hayes and Goddard 2001). Pigs were selected on an index of their genetic merit, where

$$Index = \$5.6\,GI - \$4.6FCR + \$2.7NBA + \$1.7MQI.$$

For each trait, the couple of QTL with the largest effects on that trait were traced by markers, and each nucleus piglet was genotyped for markers linked to these QTL prior to selection. Marked QTL explained 29%, 22%, 13%, and 28% of the total genetic variance for GI, FCR, NBA and MQI respectively. Phenotypic measurements were recorded on all pigs prior to selection for GI, male pigs prior to selection for FCR, selected females for NBA, and male relatives of selected boars for MQI. Selection decisions were made without (non-MAS) or with (MAS) information on markers linked to QTL.

Table 1: Average genetic merit of the nucleus ($ returns per slaughter pig) for seven generations of either non-marker assisted selection or marker assisted selection (MAS). Genetic merit was 0 in generation 0. Results are averages from 100 replicates.

Generation	Non-MAS	MAS
1	4.14	4.31
3	12.25	12.53
5	17.37	18.06
7	20.76	21.96

Extra gain from using MAS over the seven generations was 4 to 5% for each generation. Using markers increased the accuracy of selection for all traits. The largest increases in accuracy were for NBA, MQI and FCR. For these traits either there was no phenotypic information for selection candidates prior to selection, or phenotypes were measured only in one sex. Since pig enterprises turn off a large number of slaughter pigs each generation, returns from a $1 increase in returns per slaughter pig with MAS could outweigh costs of genotyping nucleus piglets.

However, MAS as described in this study is difficult to implement in commercial herds, as markers and QTL were not closely linked, and linkage phase between QTL and markers had to be established within every family. If markers could be found in linkage disequilibrium with QTL, so marker-QTL allele associations persist across the whole population, MAS could greatly accelerate rates of genetic gain (Meuwissen *et al.*, 2001).

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RANDOM REGRESSION MODELS IN PIG BREEDING

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Phenotypes of animals change with age. The changes with age differ among animals and are partly caused by genetic factors (Atchley *et al.*, 1997). Interest is in genetic parameters that describe the changes with age. These genetic parameters can give an insight as to whether and how genetic changes in these traits can be achieved. Usually genetic parameters that describe changes with age are obtained using a random regression model. In a random regression model the genetic animal effect and the non-genetic animal effect are modelled as a function of age. A number of studies have been performed to quantify the genetic parameters for traits that change with age (Kirkpatrick *et al.*, 1994; van der Werf *et al.*, 1998; Meyer, 2000). The objective was to investigate the impact of different measurement strategies on response to selection in growing pigs.

Phenotypes of animals were simulated with the following correlation and variance structure:

$$\rho_{i,j} = \frac{(99 - |i-j|)^2}{99^2} \; ; \; \sigma_i^2 = 10 + \tfrac{1}{2} i - 0.0025 i^2 \; ;$$

where i = 1...100, j = 1...100, $\rho_{i,j}$ is the genetic correlation between days i and j, and σ^2_i is the total variance at day i. Heritability had a constant value of 0.33 over the 100 days period. Animals were measured over a 100-day period, with a 10-day interval between measurements. Selection was on estimated breeding value for growth at the end of the growth-period, i.e., from day 81 through day 100. Animals were selected on estimated breeding value, the top animals were used to produce the next generation. This was done for three generations of selection, with 12 sires and four dams per generation; each sire-dam combination had four offspring. After a new generation was created a random regression model was used to estimate breeding values. Fitting the random regression model resulted in five breeding values for each animal, because there were five random coefficients in the random regression model. The five breeding values were used to calculate a breeding value at any time in the 100 days period. After calculating the breeding value pattern, a breeding value for late growth (LG) was calculated. Five measuring strategies were applied, all strategies started out with four full sibs per sire-dam combination. Strategy (1): all animals were measured till day 100; (2): two full sibs were removed after day 75; (3): two full sibs were removed after day 50; (4): all full sibs were removed after day 75 and (5): two full sibs were removed after day 50 and the remaining two full sibs after day 75.

After three generations of selection strategy 1 showed the highest response to selection on LG, applying strategy 2 and 3 resulted in respectively 89% and 78% of the response of strategy 1. The strategies with no measurements after day 75 showed a lower response to selection for LG, strategy 4 and 5 resulted in respectively 41% and 36% of the response of strategy 1.

When estimating breeding values as a function of age it is recommended to have measurements during the whole age-period. It is not necessary to have measurements for all animals during the whole age-period when selecting on growth in the final part of the age-trajectory. The optimal distribution of measurements over the whole age-trajectory depends on the trait of interest. In this study, emphasis was on live weight gain during the final part and measurements during that period turned out to be crucial. The assumed correlation structure is realistic to a certain extent, in reality the correlation will not drop to zero. Future research will focus on different traits for selection, e.g., early growth, more realistic correlation structure and reliability of the estimated breeding value patterns.

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ECONOMIC VALUES FOR THE AUSTRALIAN PIG INDUSTRY

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Genetic improvement of livestock has to consider a number of traits and is often based on an economic index. The economic index is the sum of the estimated breeding values for traits in the breeding objective weighted by their economic values. The economic value of a trait is the change in profit per unit change in the trait. For example, the economic value of growth rate reflects the lower on-farm costs resulting from reaching a target slaughter weight in fewer days. Economic values of traits depend on management and payment systems, and should be derived for the system of interest. The aim of this study was the estimation of economic values for a typical Australian situation.

A bioeconomic model, based on that of de Vries (1989), was used to estimate economic values for a range of traits. A base set of production and economic variables, taken from Meo and Cleary (1999) and current PIGBLUP default values (Crump, 2001), were used as inputs to obtain a baseline profit value. To obtain the economic value of a given trait, the level of that trait was modified by a given amount (see Table 1) and the bioeconomic model re-run. The economic value was the change in profit from the baseline profit value.

Table 1 contains economic values for a range of pig production traits expressed on per slaughter pig and per farrowing bases. Differences between economic values on a per slaughter pig and per farrowing basis reflect litter size and offspring mortality rates. Price per kg of carcase weight varied non-linearly with carcase backfat depth (BF), resulting in an economic value of BF dependent upon the average BF of the herd. A quadratic equation was used to convert the payment grid to a continuous curve, rather than discrete steps. The economic value of food conversion ratio reflects food costs. The economic value of number born alive in the first parity is around half of that in subsequent parities, the repeated observations for the latter trait increasing the returns associated with it.

Table 1. Economic values of pig production traits in Australian dollars.

Trait	Increment	per slaughter pig	per farrowing
Average daily gain	10 g/day	0.49	3.97
Carcase backfat[1]	-1 mm	-2.05	-16.55
Feed conversion ratio	-0.1 kg/kg	-2.11	-17.04
Number born alive	1 piglet	3.56	31.72
Number born alive, parity=1	1 piglet	1.22	10.19
Number born alive, parity>1	1 piglet	2.49	21.53
Dressing percentage	1 %	1.39	11.25

[1]At a mean carcase backfat of 18 mm.

The method used allows rapid calculation of economic values and adaptation to incorporate more breeding objective traits is straightforward. Calculation and use of economic values based on this method will be included in the next PIGBLUP release.

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EPIDEMIOLOGY OF LAWSONIA INTRACELLULARIS IN THREE AUSTRALIAN PIG FARMS

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Serological surveys performed in the UK and US suggest that most pigs are exposed to *Lawsonia intracellularis*. Management factors such as recent co-mingling of pigs and changes in medication have frequently preceded outbreaks of proliferative enteropathy. This study aimed to determine when pigs become infected with *L. intracellularis* on farm and to identify risk factors associated with infection.

Sera were collected from 10% of weaners (7-9 weeks old), weaner/growers (10-14 weeks), growers (17-19 weeks) and finisher pigs (23-25 weeks) from three farrow to finish units, and tested for IgG antibodies to *L. intracellularis* using an indirect fluorescent antibody test (IFAT). Pigs experimentally infected with *L. intracellularis* became seropositive 21 to 28 days after exposure (Collins *et al.*, 1999). Factors considered important in the transmission of *L. intracellularis* infection, including the mixing of animals and the cleaning and disinfection of pens were noted.

Pig farm No. 1 was a continuous production unit weaning 450 pigs/week. Diarrhoea, of unknown cause, was observed in 50% of weaner pig batches, and in 10-20% of weaner/grower pig batches, which were medicated with 12.5 mg oxytetracycline (OTC) /kg bodyweight (BW) in-feed. Grower and finisher pigs were medicated with 2.5 mg/kg BW of tylosin in-feed. None of the weaner pigs developed serum IgG antibodies against *L. intracellularis*, however, 50% of weaner/growers, 85% of growers and 25% of finisher pigs were seropositive to *L. intracellularis*. The presence of seropositive weaner/grower pigs was surprising given the level of in-feed medication. In experimental infection studies, pigs medicated with 5.0 mg/kg BW of OTC in-feed were susceptible to infection, while infection was prevented in pigs medicated with 15 mg/kg BW OTC (Vu *et al.*, 2001). The frequent exposure of the pigs to *L. intracellularis*, due to poor cleaning and mixing of pigs may mean that the medication was insufficient to prevent infection.

In pig farm No. 2 (all-in-all-out production of 120 weaners/week), diarrhoea was observed rarely in weaner-grower and grower pigs. Weaner, weaner/grower and grower pigs were pulse medicated in water with 12.5 mg/kg BW OTC, one week in four. Finisher pigs were not medicated. No seropositive pigs were detected in any production phase, which could be due to the medication or to the lack of exposure to *L. intracellularis*. The removal of faeces and infrequent mixing of pigs would reduce the potential for transmission of infection.

Pig farm No. 3 weaned 350 pigs/week, in an all-in-all-out system, with a few weaners in every batch developing diarrhoea due to *Escherichia coli*. Weaner pigs were medicated in-feed with 20 mg/kg BW OTC and 2.5 mg/kg BW olaquindox. In-feed medication with 2.5 mg/kg BW olaquindox was continuously supplied to pigs until 3 weeks before slaughter when pigs were pulse medicated one week in four with 2.5 mg/kg BW tylosin in-feed. No serum IgG antibodies against *L. intracellularis* were detected in the weaner, weaner/grower, grower or finisher pigs, but 75% of pre-slaughter pigs (27 weeks) were seropositive. The removal of olaquindox from feed and the frequent mixing of pigs probably precipitated *L. intracellularis* infection. Olaquindox at 2.5 mg/kg BW prevents infection in most pigs inoculated with *L. intracellularis* (Vu *et al.*, 2001).

This study determined when pigs became infected with *L. intracellularis*, and identified the mixing of pigs, poor cleaning and changes in medication as risk factors associated with infection.

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EFFECT OF ANTIBIOTIC MEDICATION ON DEVELOPMENT OF IMMUNITY TO LAWSONIA INTRACELLULARIS IN PIGS

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Porcine proliferative enteropathy (PPE) caused by *Lawsonia intracellularis* is associated with reduced growth rate and diarrhoea in young pigs and may also cause bloody diarrhoea and sudden death in adult pigs. Pigs that recover naturally from the infection are immune to re-infection (Collins *et al.* 1999). A variety of antibiotics have been tested to control and prevent PPE. Two experimental studies were conducted to determine the effects of different levels of antimicrobials on infection and development of immunity to re-infection.

In the first study, five groups of five 3-week old Large White x Landrace pigs were housed separately and dosed orally with 2.5 mg, 5 mg tylosin (T2.5, T5), 2.5 mg and 5 mg oxytetracycline (OTC2.5, OTC5) per kg body weight (BW) or no medication (NM). All pigs were inoculated orally with 6.25×10^8 *L.intracellularis*. Faeces were collected every 2-3 days for polymerase chain reaction (PCR) detection of *L. intracellularis* DNA. Blood was collected weekly for an indirect immunofluorescent antibody test (IFAT) against *L. intracellularis*. Pigs were re-inoculated with bacteria from the same source after faecal shedding ceased and medication was removed. In the second study, 15 mg, 30 mg of oxytetracycline (OTC15, OTC30), 2.5 mg and 5mg of olaquindox (Olaq2.5, Olaq5) /kg BW were tested in a protocol similar to that described in the first study.

Faecal shedding of *L. intracellularis* from day 7 to day 28 post inoculation (pi) was confirmed by PCR in all pigs in the NM groups and from all pigs fed with T2.5, OTC2.5, and OTC5 diets (Table 1). Only a proportion of pigs from the T5 (2/5) and Olaq2.5 (1/4) groups shed *L. intracellularis*. Faecal shedding was not detected in pigs from Olaq5 or OTC15 or OTC30 groups. All pigs that shed *L. intracellularis*, except 1 in T2.5 group, developed IgG antibodies as detected by the IFAT. All pigs that did not shed were negative in the IFAT. After re-inoculation, all pigs which had not shed *L. intracellularis* following the first inoculation became infected.

Table 1. Faecal shedding and antibody response in pigs inoculated orally with 6.25 x 10^8 *L. intracellularis* and treated with antibiotics or not treated (positive samples/total).

Treatment	Day 0		After 1st inoculation		After 2nd inoculation	
(mg/kg BW)	PCR[1]	IFAT[2]	PCR 7-28 d	IFAT 21-35 d	PCR 7-28 d	IFAT 7-28 d
Non-medicated	0/12	0/12	12/12	12/12	0/4	
Tylosin (2.5)	0/5	0/5	5/5	4/5	0/5	4/5
Tylosin (5)	0/5	0/5	2/5	2/5	3/5	5/5
Oxytetracycline (2.5)	0/5	0/5	5/5	5/5		
Oxytetracycline (5)	0/5	0/5	4/4	4/4		
Oxytetracycline (15)	0/4	0/4	0/4	0/4	3/3	3/3
Oxytetracycline (30)	0/4	0/4	0/4	0/4	3/3	3/3
Olaquindox (2.5)	0/4	0/4	1/4	0/4	2/2	2/2
Olaquindox (5)	0/4	0/4	0/4	0/4	3/3	3/3

[1]PCR, Polymerase chain reaction. [2]IFAT, Indirect fluorescent antibody test.

Oral medication with 2.5 mg, 5 mg of oxytetracycline and 2.5 mg tylosin per kg/BW did not prevent pigs from becoming infected with *L. intracellularis* and 5 mg tylosin and 2.5 mg olaquindox prevented infection in some pigs. Oxytetracycline at 15 mg, 30 mg and olaquindox at 5mg/kg BW prevented infection and development of immunity and these pigs were susceptible to re-infection. Some antibiotics are highly effective in preventing *L. intracellularis* infection, however, they may maintain the susceptibility of pigs to infection and postpone the onset of disease.

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COMPARISON OF CIRCULATING IMMUNOGLOBULIN AND SPECIFIC ANTIBODY CONCENTRATIONS IN PIGLETS FED COLOSTRUM FROM DIFFERENT SOURCES

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The epitheliochorial placenta of the pregnant sow prevents transfer of antibodies and large antigenic material between sow and piglet (Klobasa and Butler, 1987) leaving the neonatal pig agammaglobulinaemic at birth. Passive transfer of maternal antibodies to piglets occurs entirely through the ingestion of colostrum, which is produced from approximately 21 days before farrowing. Immunoglobulin G (IgG) is the main immunoglobulin found in colostrum. This experiment compared concentrations of IgG and K88 pilus antibodies in the blood of piglets that were suckled naturally or were fed either a commercial colostrum substitute (COM) or a colostrum substitute derived from cows immunised with an *Escherichia coli* vaccine containing K88 pilus (HYP).

Piglets to be treated were removed from their sow prior to sucking and placed in a crib. These piglets were fed by tube directly into the stomach 20 ml/h for 7 hours and then returned to the sow of origin. The treatments included 10 piglets/group fed either the HYP or COM colostrum and for comparison, 15 piglets that were naturally suckled. At 24-36 h of age, blood was collected from each pig. The concentrations of bovine and porcine IgG were determined using radial immunodiffusion kits (Bethyl Laboratories©,Texas, USA). Total serum IgG concentration was the sum of bovine IgG, derived from cow colostrum, and porcine IgG derived from the sow. The K88 pilus antibody concentrations were determined by enzyme linked immunosorbant assay using either anti-pig IgG or anti-bovine IgG conjugates. Total IgG and K88 pilus antibody concentrations were analysed using analysis of variance. Bovine IgG concentrations were analysed using the Mann-Whitney U test.

Piglets receiving colostrum from immunised cows (HYP) had significantly higher antibody concentrations to the K88 antigen than those piglets fed the commercial (COM) product ($P<0.001$) (Table 1). All piglets fed HYP colostrum had higher levels of bovine IgG than piglets fed COM ($P<0.001$). Piglets that had been suckled naturally, had significantly higher total IgG concentrations than the animals fed HYP or COM colostrum ($P=0.002$).

Table 1. Concentration of K88 antibodies, bovine IgG and total IgG in the serum of piglets naturally suckled or fed either immunised cow colostrum (HYP) or a commercial colostrum substitute (COM).

Colostrum source	Naturally suckled	COM	HYP	l.s.d$_{5\%}$
Mean K88 antibody concentration (optical density values)	1.011*	0.828^{b}	1.596^{a}	0.231
Mean bovine IgG (mg/dl)	NA[1]	104^{b}	775^{a}	
$\log_e$(total IgG concentration mg/dl)	7.76^{c}	6.10^{d}	6.87^{d}	0.84

*Not included in analysis. [1]NA, not applicable. $^{a,b;c,d}$Comparable means in a row having different superscripts differ significantly $^{a,b}P<0.001$ and $^{c,d}P=0.002$.

Feeding piglets colostrum from immunised cows provided higher concentrations of IgG (bovine) and K88 pilus antibodies than the commercial colostrum substitute. Although total IgG concentration was lower than that attained from naturally derived sow colostrum, protection for colostrum-deprived piglets may be improved by supplementary feeding of colostrum from cows immunised against pig pathogens.

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LEG CONFORMATION AND HERD LAMENESS

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Lameness has been identified as a major cause of unplanned culling and euthanasia of sows in Australia (Paterson *et al.*, 1997). Over 70% of sows culled for lameness (Paterson *et al.*, 1997) were lame in one or both back legs, and more than 70% of these animals had no visible external lesions. This suggests that factors other than injury (such as bad flooring) are responsible for lameness.

The causes of lameness are usually categorised as infectious and non-infectious. The non-infectious causes include a range of degenerative conditions, but the role of conformation in the development of non-infectious lameness also needs to be considered. A study in Norway found that the prevalence of severe osteochondrosis decreased from 5.2% in 1970 to 0.6% in 1995 following emphasis on conformation at gilt selection (Svendsen *et al*, 1988). However, the heritability of leg weakness traits appears to vary among breeds (Paterson *et al*, 1997).

A comparison was made among the conformation of sows in five herds that used a conformation scoring system for gilts similar to the Danish protocol (Paterson *et al*, 1997), and six herds with no formal selection protocol. None of the herds had flooring defects and all animals were housed in stalls from mating to farrowing. Each herd was examined following feeding with all sows standing, and the time at which each sow sat recorded. The first 20 sows to sit were examined for conformation and gait using the Danish protocol and defects recorded. In the protocol used, a conformation score of "1" indicated that the conformation of the feature (joint, toe or gait) was correct and a score of "2" indicated a defect. Hence a leg with good conformation scored "3", whereas a score of "6" indicated that defects were found in the hock/knee and pastern joints, and the toes. Sows were also examined for toe lesions and the number of times weight was shifted from one leg to the other (pietinement) during three successive one-minute periods were recorded. Data was analysed using ANOVA (*Statistix*®).

Herds using a formal protocol to examine conformation when selecting gilts for breeding had significantly lower hind leg and gait conformation and pietinement scores ($P<0.01$), but not foreleg or toe lesion scores ($P>0.05$), when compared with control herds (Table 1). The time taken for 50% of the sow herd to sit was significantly lower ($P<0.01$) in herds that did not use a formal method to evaluate conformation at selection (Table 1).

Table 1. The mean ± SE of leg and gait conformation and pietinement scores for the first 20 sows to sit in herds with and without a conformation selection protocol for gilts, and the time taken for 50% of the sow herd to sit

Protocol used		Foreleg scores	Hind leg scores	Gait score	Pietinement scores/min	Sitting time
Yes	Mean ± SE	3.49 ± 0.04	3.75 ± 0.04[a]	1.42 ± 0.05[a]	2.90 ± 0.4[a]	85 ± 8.9[a]
	Range	3.40-3.60	3.65-3.90	1.35-1.60	1.55-3.85	70-120
No	Mean ± SE	3.63 ± 0.59	4.47 ± 0.24[b]	1.82 ± 0.08[b]	5.94 ± 0.70[b]	60 ± 6.5[b]
	Range	3.45-3.80	3.60-5.15	1.45-2.00	3.35-8.65	40-85

[a,b]Means in columns with different superscripts were significantly different ($P<0.01$).

The fact that in herds using a formal protocol for scoring conformation at selection, pietinement scores were lower and the time taken for 50% of sows to sit was greater, indicates that these herds had fewer lame animals than the other herds. In similar studies (Cargill *et al.*, 2001), it was reported that 50% of sows in lame herds sat within 70 minutes, compared with greater than 70 minutes for a similar group of sound herds.

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FOOD INTAKE OF LACTATING LARGE WHITE SOWS SELECTED FOR GROWTH RATE ON RESTRICTED FEEDING

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Low appetite can be a severe problem in sow populations, especially in primiparous sows under tropical climates because it is accompanied by large reductions of body weight and body fat during lactation. This may result in prolonged intervals from weaning to oestrus and to conception, and possibly reduced ovulation rate in subsequent breeding periods (Rydhmer, 2000). A reduction in feed intake during lactation may also be associated with a decreased piglet weight, leading to increased pre-weaning mortality and reduced post-natal growth of piglets. Experimental results indicated that selection objectives putting high emphasis on efficiency rather than rate of lean growth on *ad libitum* feeding resulted in a decline in voluntary food intake, which may impair post-weaning sow productivity and growth of piglets (Kerr and Cameron, 1996). Currently the genetics of food intake of sows during lactation is not fully understood and it is difficult to draw firm conclusions as to how this trait can be incorporated into future breeding programs. The current paper tests the hypothesis that voluntary food intakes of lactating sows of lines selected for high and low growth rate on restricted feeding remain unchanged.

Approximately one week before the expected farrowing date Large White sows were moved to the farrowing/weaner building where they were farrowed in batches of 24 (12 sows per line). Lactating sows were fed *ad libitum* on 14 MJ DE and 0.55 g/MJ lysine diet. Voluntary feed intakes were measured from 7 to 35 days after farrowing. A few piglets were cross-fostered among sows of the same line prior to 7 days of age.

Selection line means for daily food intake of sows during lactation were obtained from REML analysis of 913 sow records using linear mixed models procedures (GenStat, 1995) fitting batches, parities and selection lines as fixed effects and animal as a random effect, with the number of sucking piglets per litter as a covariate. Daily food intakes of lactating sows were 6.09 (kg/d) in the high and 6.22 (kg/d) in the low lines. This difference was not statistically significant (standard error of difference 0.09).

After four years of divergent selection for growth rate in the same lines, lower feed intake in the high than in the low growth line was apparent in growing stock (McPhee et al., 1999), but this study shows there was no significant difference ($P>0.05$) between the lines in daily feed intakes of lactating sows. This indicated that the reduction of feed intake in growers was not carried over to lactating sows. It is concluded that selection for rate of growth on restricted feeding would have no effect on lactation feed intakes of sows. This is consistent with an absence of line difference in litter sizes at birth and at weaning as reported by McPhee et al. (1999).

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SELECTION FOR GROWTH RATE IN LARGE WHITE PIGS ON RESTRICTED FEEDING: CORRELATED RESPONSES IN PH24

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High incidences of pale, soft and exudative (PSE) (16 – 51%), and dark, firm and dry (DFD) (15 – 44%) meat conditions were recorded in Australian abattoirs (Channon *et al.*, 2000). In general, both PSE and DFD defects are strongly related to muscle pH. The measurement of pH24 (pH at 24h post-mortem) is commonly used to monitor changes in PSE and DFD meat in selection lines. In an earlier study, after four generations of selection for high growth rate and low backfat, McPhee and Trout (1995) found that the selected lines had higher pH24 values than the control. It was hypothesised that strong selection for efficient lean growth had raised metabolic rate associated with an increased rate of protein deposition. This increased the rate of depletion of glycogen reserves during prolonged pre-slaughter fasting and transport, and reduced the amount available for conversion to lactic acid at slaughter causing a movement toward the DFD end of the meat quality spectrum. In the present study, the hypothesis that selection for post-weaning daily gain alone on restricted feeding will increase both lean growth and content without changes in pH24 is examined.

Details of the development of the two lines, one selected for high and one for low post-weaning gain on restricted feeding were described by Nguyen *et al.* (1999). Large White pigs in this study were fed either on a restricted scale (80% *ad libitum*) or *ad libitum* for 6 weeks starting at 50 kg live weight. At finish, pigs travelled an 8 hour journey from their farm in Central Queensland to an abattoir in Brisbane where they were held in lairage overnight without food but with water. Measurements of pH24 using the WP80 TPS meter (Brisbane Qld) were taken at the P2 site on carcasses stored in a chiller at -5°C.

Data was subjected to REML analysis with batch, sex, and feeding regime and line and their interaction fitted as fixed effects and animal as the random effect (Genstat 5, 1997). The high and low selection line means for pH24 were 5.99 and 6.06 on restricted feeding and 6.03 and 6.04 on *ad libitum*. Differences were not significant between either the selection lines or feeding regimes (average standard error of difference 0.05).

The high average pH24 of the present study indicated that the same stressful pre-slaughter conditions prevailed as in the previous study by McPhee and Trout (1995). However, this time, no genetic relationship between lean growth and pH24 was apparent as there was no difference between the high and low growth lines despite their differences in lean growth rate (McPhee *et al.*, 2001). It is suggested that an increase in metabolic rate due to increased lean deposition rate in the high relative to the low line may have been compensated by a reduction in metabolic heat production from another source such as physical activity associated with feeding (De Haer *et al.*, 1992). Evidence for such a reduction is the reduced residual food intake in the high line (Nguyen *et al.*, 2001).

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GENETIC CORRELATIONS BETWEEN MORTALITY RATE AND OTHER LITTER TRAITS OF THE SOW

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Litter mortality rate until weaning should be low in order to have a high number of piglets weaned. This trait has been analysed in two recent studies (Hermesch *et al.*, 2001; Knol, 2001). Genetic correlations of litter mortality with average piglet weight at birth and within litter variation of birth weight differ between these two studies, which may be partly due to different trait definitions for litter mortality. Knol (2001) defined litter mortality as the percentage of a litter that died before weaning (MORT%). In contrast, Hermesch *et al.* (2001) analysed the number of piglets that died per litter (NDIED). This study presents genetic correlations between MORT% and litter traits of the sow.

Individual piglet weights and piglet mortality were recorded for 2297 litters of 1767 sows from three maternal lines. This information was used to derive a number of litter traits, which have been described by Hermesch *et al.* (2001) along with the data structure. Fixed effects for MORT% were farrowing week, line and parity of the sow. The number of piglets fostered on and litter size were fitted as linear covariables. Variance components were estimated with the ASREML program (Gilmour *et al.*, 1999).

Heritabilities (h^2) for MORT% were low for models with (0.03 ± 0.02) and without (0.04 ± 0.03) adjustment for litter size. Mortality rate (unadjusted) had moderate to strong genetic correlations with the other litter traits analysed (Table 1). Adjusting MORT% for number of piglets born in total (NBT) only reduced the genetic correlation with NBT.

Table 1. Genetic (r_g), and phenotypic (r_p) correlations (standard errors) between litter mortality (unadjusted and adjusted for litter size) and number born in total (NBT), average piglet weight at birth (AWTB) and within litter variation (CVNBT).

Trait		NBT	(SE)	AWTB	(SE)	CVNBT	(SE)
MORT%[1]	r_g	0.63	(0.30)	-0.42	(0.23)	0.28	(0.28)
(unadjusted)	r_p	0.27	(0.02)	-0.35	(0.02)	0.31	(0.02)
MORT%	r_g	0.41	(0.40)	-0.46	(0.24)	0.28	(0.26)
(adjusted)	r_p	0.05	(0.03)	-0.30	(0.02)	0.35	(0.02)

[1]MORT%, The percentage of a litter that died before weaning.

Hermesch *et al.* (2001) found a genetic correlation of 0.05 between NDIED and coefficient of variation of piglet birth weight within a litter (CVNBT). The higher genetic correlation between MORT% and CVNBT is not significantly different from zero. Genetic correlations between NDIED and the average piglet weight at birth (AWTB) (Hermesch *et al.*, 2001) and MORT% and AWTB were similar, supporting the inclusion of AWTB in breeding programs to aid selection for lower litter mortality rate. It is concluded that the trait definition of litter mortality does not significantly affect estimates of genetic correlations with further litter traits.

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A SYMPOSIUM - PIG AI IN AUSTRALIA – OPPORTUNITIES AND LIMITATIONS

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Introduction

The use of artificial insemination (AI) in the pig industry, particularly in the developed world, has increased dramatically in the last decade (Table 1). This has been a result of a combination of factors. The benefits of AI to the commercial pig producer include the efficient and rapid spread of genes from boars of high genetic merit, reduction in genetic lag, less overuse of boars for natural matings, decreased risk of disease importation into the breeding unit, greater worker safety, and reduced breeding costs due to lower boar and labour requirements (Flowers and Alhusen, 1992).

Table 1. Changes in AI use in selected countries (Reed, 1982; Weitze, 2000).

Country	Estimated total number of sows (millions) in 1998	AI usage (%) 1982	AI usage (%) 1998
China	38.0	<1	25
USA	6.5	<1	55
Spain	2.4	3	85
France	1.4	3	55
The Netherlands	1.3	-	85
Canada	1.2	-	50
Denmark	1.1	34	42
Belgium	0.8	2	90
UK	0.7	3	30
Australia	0.3	-	15
Sweden	0.2	4	70
Ireland	0.1	-	60
Norway	0.1	49	90

Despite its apparent advantages the uptake of AI in Australia has been relatively slow. There seems little doubt that this has been partly due to concerns about fertility and fecundity in artificially inseminated versus naturally mated sows. However, recent data clearly show that AI will not result in adverse effects on either farrowing rate or litter size if semen quality is high, oestrus detection is good and the technical skill of the inseminator is high (Flowers and Alhusen, 1992). Nevertheless, Australian pig producers still appear to be reluctant to adopt AI, with the majority still using full natural service. Where a move has been made towards AI, many producers have only got as far as combination mating (first service via natural mating and second service via AI) suggesting that they still have reservations about the efficacy of AI.

Clearly the Australian pig industry needs to review the reasons why it is failing to wholeheartedly adopt a technology that most of the rest of the world has obviously recognized to be beneficial. The prime concerns would appear to be fourfold:

- Semen quality may be sub-optimum as a result of inadequate transport arrangements for the transfer of semen from collection centre to piggery. Failures or inadequacies at this stage can result in the use of relatively old semen (>72 hours) and/or semen which has undergone major temperature fluctuations in transit (particularly in the summer months).

- Use of off-farm semen (i.e., semen that has been collected from boars located elsewhere) increases the risk of disease transfer into the breeding herd.
- The timing of insemination(s) may be less accurate as a result of less boar presence at oestrus detection.
- The quality of the insemination may be sub-optimal as a result of inadequate management procedures, including poor insemination technique.

The papers presented in this symposium address these issues and provide an up-to-date review of the rationale for using AI and the technical requirements necessary to maximize the subsequent performance of the artificially inseminated gilt or sow.

Symposium continued on next page

PRODUCTION OF FERTILE INSEMINATION DOSES

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Abstract

The fertility of each insemination dose is a function of the inherent properties of semen produced by the boar and the manner in which it is manipulated prior to insemination. Inherent properties of semen include various physical and biochemical characteristics of semen that influence the ability of spermatozoa to penetrate ova. These are commonly referred to as measures of semen quality. Manipulation of semen include the number of spermatozoa inseminated, the type of extender in which the semen is stored, and addition of various compounds during the extension process. There is a significant amount of variation among individual boars in terms of the farrowing rate and litter size that result when the same number of spermatozoa are inseminated. A portion, but not all of this variation can be explained by differences in semen quality. As a result, increasing the number of spermatozoa inseminated is an effective strategy for increasing fertility for some boars. Unfortunately, at the present time no one measure of semen quality appears adequate for determining the number of spermatozoa for optimal fertility for individual boars. The type of extender used affects the fertility of insemination doses. Typically, long-term extenders tend to yield better fertility results than short-term extenders as the interval between collection and insemination increases. In addition, there are unique interactions between individual boars and semen extenders, whereby increased fertility of stored semen can be achieved simply by using a different extender. The physiological basis for these interactions is poorly understood. Finally, the addition of various compounds to semen, which in theory should promote various aspects of fertilisation, has produced equivocal results in terms of improving fertility. Generally, in most cases when this strategy is successful, semen additives appear to be correcting another deficiency in the breeding process.

Introduction

The fertility of an insemination dose is a function of the inherent properties of semen produced by the boar and the manner in which it is manipulated prior to insemination. Numbers of spermatozoa and their ability to fertilize eggs are two of the most important of these inherent properties related to semen fertility. After collection, it is generally agreed that spermatozoa begin to die over time. The rate at which death occurs is reduced by several factors. These include the type and amount of semen extender that is used for extension, and the storage conditions prior to insemination. Consequently, the basic underlying premise for the production of fertile insemination doses is to begin with an ejaculate of high fertility and then attempt to maintain its fertility level after extension and during storage. There are a several factors that influence this process. The objective of this review is to provide an overview of some of these factors and discuss possible ways in which they can be manipulated to insure that the fertility of insemination doses is optimized.

Boar fertility patterns

For most males, the relationship between fertility and semen characteristics is believed to resemble an increasing, non-linear curve that eventually reaches a plateau (Salisbury and Vandermark, 1961). This relationship is often referred to as a fertility curve or pattern. For most fertility curves, there is a range of values over which fertility increases when either sperm numbers or semen quality increase. The magnitude of this improvement decreases until a plateau is reached, after which, additional increases in either the number or quality of sperm cells does not affect male fertility. The

physiological basis for this pattern of male fertility is based on the belief that a finite number of competent spermatozoa must be present in the oviduct to successfully fertilize ova (Hunter, 1990???). Improvements in fertility occur until this threshold level is reached, after which, no increase is observed because the number of sperm required to optimize fertilization has been achieved.

A recent study examined the fertility patterns of boars in a commercial boar stud (Flowers, 2001). Results from this study are based on 40 to 45 ejaculates per boar from 200 crossbred boars that were produced and used to breed sows over a period of one year. In general, two basic fertility curves or patterns were observed (Figure 1). One pattern was similar to the classical pattern described previously, which initially increased and eventually reached a plateau. In contrast, the second fertility pattern appeared to be linear over the range of insemination numbers that were tested (1 to 9 billion total spermatozoa). Furthermore, within each basic pattern, there were distinct differences among boars. For boars with fertility patterns that reached a plateau, individual variations occurred in the insemination dose at which the plateau occurred and the litter size or farrowing rate that resulted. Similarly, the slope of the response line differed among boars with a linear fertility pattern. These data are summarized in Table 2.

Table 2. Characterisation of fertility patterns of boars on a commercial swine operation[a].

Fertility pattern	Characteristics	Frequency of pattern	Range in reproductive levels at peak fertility[b]
Plateau	Plateau, 1 to 3 billion sperm	5/200	9 to 11 pigs born alive 78 to 90% farrowing rate
Plateau	Plateau, 3 to 5 billion sperm	78/200	9 to 12 pigs born alive 75 to 92% farrowing rate
Plateau	Plateau, >5 billion sperm	50/200	8 to 12 pigs born alive 81 to 89% farrowing rate
Linear	Slope, ≤1 billion sperm	18/200	9 to 11 pigs born alive 78 to 90% farrowing rate
Linear	Slope, >1 billion sperm	14/200	7 to 12 pigs born alive 75 to 92% farrowing rate
Others	No consistent pattern	35/200	8 to 12 pigs born alive 80 to 90 % farrowing rate

[a]Adapted with permission from Flowers (2001). [b]Values represent variation in the highest litter size and farrowing rate for each boar within each fertility pattern

Variations observed among the fertility patterns of boars in this study demonstrate that the number of spermatozoa inseminated is an important factor that affects boar fertility, and thus the production of fertile insemination doses. In this particular population of boars, the majority of the boars exhibited a fertility pattern with a plateau that occurred between 3 and 5 billion spermatozoa. It has been estimated that about 90% of the insemination doses used commercially within the swine industry fall within this range (Flowers, 1996a). As a result, in terms of spermatozoa per insemination dose, current industry practices probably have optimized the production of fertile insemination doses for a large number of boars. However, there appear to be a significant number of boars whose average fertility occurred at insemination doses outside the normal range that is used. Thus, it is reasonable to speculate that development of practical and cost effective methods for determining the optimal number of spermatozoa in an insemination dose could result in improved reproductive performance for some boars. This is an important point to recognize because the number of spermatozoa inseminated can be manipulated very easily during the production of insemination doses.

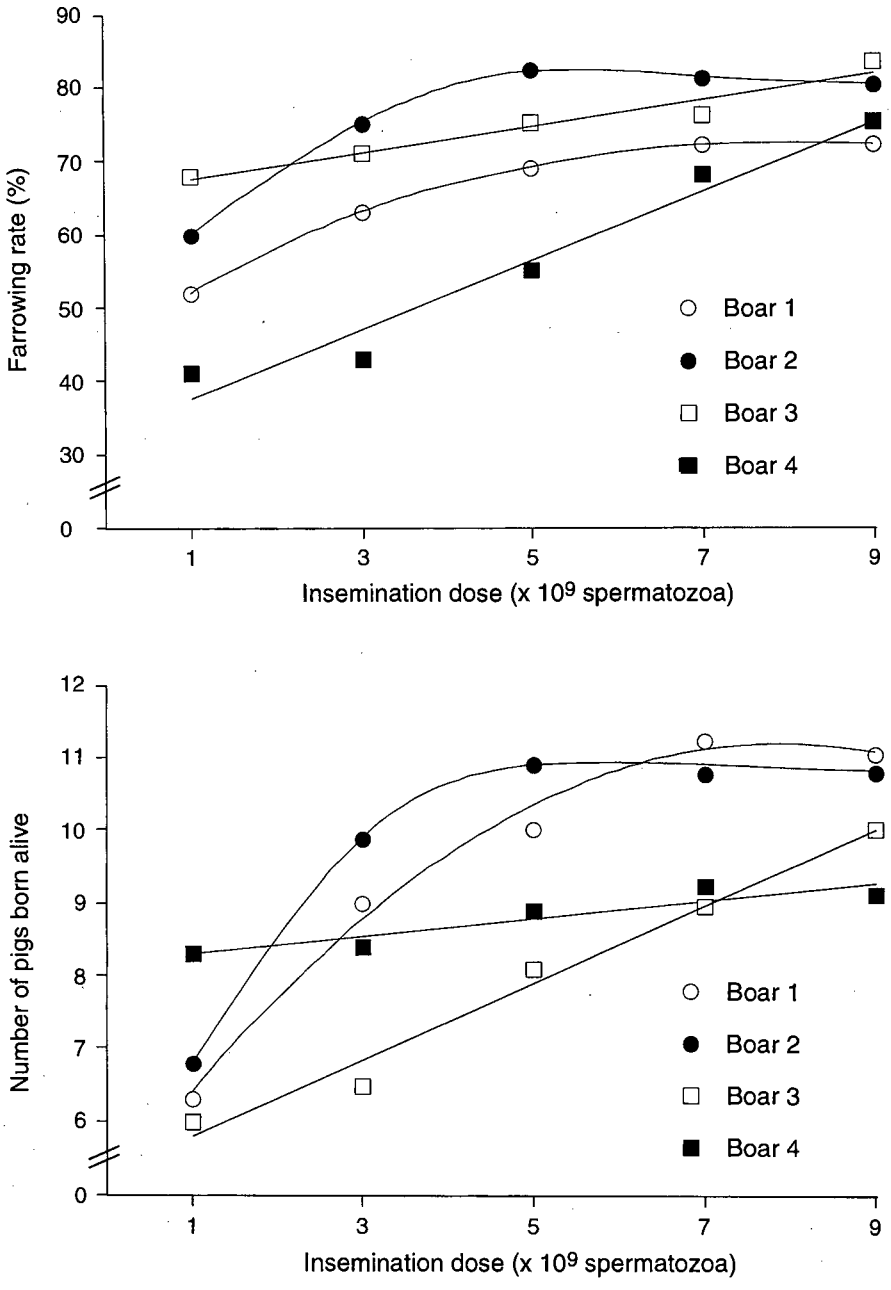

Figure 1. *Fertility patterns for farrowing rate and number of pigs born alive for different boars (with permission from Flowers, 2001).*

Semen Quality

In addition to the number of spermatozoa that are deposited into the cervix, other factors associated with spermatozoa are important in determining the fertility of an insemination dose. Evidence for this is provided by the observation that farrowing rates and litter sizes were quite different among boars in terms of the level at which their fertility pattern reached a plateau (Table 2). From a physiological perspective, this can be interpreted as being indicative of differences among boars in terms of the ability of their spermatozoa to successfully fertilize eggs. In other words, even though the same numbers of spermatozoa were in the insemination dose, inherent differences in their quality affected their fertility. These traits are part of total semen quality.

Selected examples of different tests that have been used to assess semen quality are summarized in Table 3 along with a brief description of the rationale for each one. What is difficult to determine, at the present time, is which of these tests represent shifts along an individual fertility curve compared with those that explain differences among boars in terms of the level at which their fertility reaches a plateau. Both types of assessments for semen quality have practical implications. Shifts along a given fertility curve allow for optimization of the fertility of insemination doses for individual boars. In other words, it may be possible to use these tests to adjust the numbers of sperm cells such that insemination doses of a given level of fertility are produced consistently. Other tests, which are related to differences in farrowing rates and litter sizes at the fertility pattern's plateau, would allow for the identification of boars that consistently produce inseminations of superior fertility.

For example, estimation of the percentage of motile spermatozoa is a semen quality measure that is commonly used throughout the swine industry. Previous studies have shown that the percentage of motile spermatozoa is probably not related to differences in fertility among boars (Flowers, 1997). This statement is based upon the observation that farrowing rates and litter sizes are different among individual animals whose semen possesses the same percentage of motile spermatozoa.

However, current studies (Flowers, 2001) indicate that the percentage of motile spermatozoa can be used to adjust insemination numbers and improve the fertility of individual insemination doses for some boars. In these studies, insemination doses of 3, 5, 7, and 9 billion spermatozoa with 40, 60 or 80% motile cells, were created by mixing fresh ejaculates with those that were aged for 2 days. For boars whose farrowing rate normally reached a plateau between 3 and 5 billion spermatozoa (with 80% motility), increasing the total number of sperm cells in the insemination doses was marginally effective in compensating for the reduced motility, and only when the percentage of motile spermatozoa was 40%. Whether this strategy is effective when motility is less than 40% is not known, because ejaculates with less motility were not studied. In contrast, this same practice produced consistent improvements in farrowing rates for boars with a linear fertility pattern regardless of the motility of the insemination dose.

The physiological basis for these observed differences among boars is not clear. However, it could be related to the total number of spermatozoa that actually enter the oviduct. If more spermatozoa from the boar with the linear fertility pattern entered the oviduct compared with that of his counterpart whose pattern exhibited a plateau, then it is conceivable that increasing the number of total spermatozoa inseminated would increase the total number of motile or competent spermatozoa within the oviduct. This, in theory, should result in an improvement in fertility because of the increased number of spermatozoa capable of fertilizing eggs in the oviduct. In contrast, once the maximum number of spermatozoa at the site of fertilization has been achieved, then further increases in insemination numbers would not be expected to improve fertility, because the total number of competent spermatozoa entering the oviduct would not change. Obviously, this explanation is speculative and requires scientific validation. However, in the interim, given the fact that previous studies (Baker *et al.*, 1968) have reported that there is a positive relationship between the number of spermatozoa entering the oviduct and the number inseminated, adjusting insemination doses for motility differences seems to be a reasonable practice.

Table 3. Summary of selected tests used to estimate semen quality in boars[a].

Semen quality test	Rationale	References
Computer-assisted motility analyses	Number and characteristics of motile sperm using computer-assisted semen analysis (CASA) are correlated with fertility	Holt and Medrano (1997)
Macroscopic morphology	Proportion of sperm with visual morphological defects is inversely related to ability to fertilize eggs in vitro	Xu *et al.* (1998)
Hypoosmotic swelling test	Under hypoosmotic conditions sperm heads with damaged membranes increase in size (swell). Proportion of these in an ejaculate is inversely related to fertility	Vazquez *et al.* (1997)
Fluorescent stains	Some fluorescent dyes (Hoechst 33258) enter if membranes are damaged and stain only dead cells. Others (SYBR-14) enter cells with a membrane potential and stain only live cells	Johnson *et al.* (1996)
Hemizona binding assay	Oocytes are bisected and the number of sperm from different boars that bind to each half is correlated with their fertility	Fazeli *et al.* (1995)
Sperm plasma membrane proteins	Proportion of 3 proteins in plasma membrane is correlated with fertility	Ash *et al.* (1994)
Sperm chromatin structure	Under acidic conditions and stained with metachromatic dyes, normal DNA emits a green colour, while damaged DNA emits a red colour. Ratio of green to red sperm is correlated with boar fertility	Evenson *et al.* (1994)

[a]With permission from Flowers, 2001.

Sperm Production

Assuming a standardized dilution rate, the total number of spermatozoa in an ejaculate is directly proportional to the number of insemination doses produced. As the total number of sperm cells in an ejaculate increases, so does the number of insemination doses. In general, factors that affect sperm numbers can be divided into two general categories: (a) those that have a detrimental effect; and (b) those that have a stimulatory influence. Factors that fit into the first category can be thought of as the removal of conditions that hamper the normal occurrence of spermatogenesis, whereas those in the latter category are basically attempts to enhance its efficiency. Table 4 summarizes several of the most common of these factors including the specific manner in which they are thought to influence spermatogenesis.

One factor that is not included in Table 4, but is thought to negatively affect semen output in boars is an inconsistent collection pattern. On most systems, boars are collected on a regular schedule of once per week or three times over a two-week period. However, it is often necessary to collect more frequently during certain times of the year in order to obtain sufficient quantities of semen to make enough insemination doses to meet daily breeding demands. This is especially true in regions that have long periods of elevated ambient temperatures along with high relative humidity. These changes in collection frequency tend to be randomly applied to boars and lack consistency from week to week. Anecdotal reports from the field indicate that there is a population of boars that do not respond positively to these random changes in collection frequency.

Table 4. Summary of selected conditions that affect spermatogenesis in boars

Condition	Description	References
Chronic nutritional restriction	Protein and energy reductions between 15 and 67% for 6 to 8 weeks decreased sperm production	Kemp and Verstegen (1991)
Acute heat stress	Exposure to temperatures ≥ 30°C for 72 hours decreased sperm production	Stone (1982) McNitt and First (1970)
Chronic heat stress	Exposure to temperatures between 26 to 29 °C for 5 to 6 weeks decreased sperm production	Flowers (1997)
Selection for increased testes size	High positive correlation exists between testes size and sperm production. Selection for increased testes size increased sperm per ejaculate	Rathje *et al.* (1995) Huang and Johnson (1996)
Hormone stimulation	Administration of FSH and growth hormone between 8 and 40 days of age increased number of sperm in sertoli cells	Swanlund *et al.* (1995)
Photoperiod	Reversing natural photoperiod stimulated sperm production	Claus and Weiler (1995)

In order to examine this observation in more detail, an experiment was conducted in which 40 boars were collected once per week for three months (Flowers, 1998a). After this standardization period, 20 boars were collected on a random schedule over a second, three-month period. Boars in this group were not collected more than three times per week or less than once in a 3 week period. The schedule for the remainder of the boars was maintained at one collection per week. Spermatozoa numbers and quality were maintained at a constant level in 18 of 20 boars whose collection schedule was not altered. In one boar, these parameters increased (20%) and in another they actually decreased slightly (15%) during the same time period. In contrast, of the 20 boars exposed to a random collection schedule, semen quantity and quality remained unchanged in only eight boars; increased in three boars; and decreased in nine boars. In four of these nine boars, semen quality of ejaculates failed to return to normal values during a 60-day period after the random collection protocol was terminated.

These data indicate that most boars become accustomed to a given collection regimen and that once acclimatized to this schedule, changing the collection frequency in a random fashion may have a negative impact on spermatozoa production in some boars. Certain physiological mechanisms involved with the control of the quantity and quality of spermatozoa ejaculated in response to changes in collection frequency are not known. However, it is reasonable to speculate that it may simply be a redistribution of spermatozoa release from the epididymides since estimates of daily spermatozoa production did not change over time in similar studies (Flowers, 1998a). In practice, most commercial operations let the daily or weekly breeding demands dictate the collection regimen applied to boars. For example, if there is an increase in the number of sows that need to be bred or spermatozoa numbers per ejaculate decrease for some reason, then more boars are collected to compensate. Although this practice may be part of the reality of operating a boar stud, the long term effect of a constantly changing collection regimen, probably is not conducive for maximizing spermatozoa output. Simply increasing the collection frequency of some of the boars in the stud for extended periods of time during which increased semen demands are anticipated may prove to be a more physiologically sound approach. At least in this situation, boars are not exposed to a random collection regimen, which could negatively affect spermatozoa production.

Semen extenders

As mentioned previously, once collected, spermatozoa have a finite life span in that they begin to undergo metabolic and chemical changes that ultimately lead to their death. In essence, a good semen extender simply reduces the rate at which these changes take place. They accomplish this by providing a source of nutrients for sperm cell metabolism; neutralizing metabolic wastes produced by spermatozoa; and stabilizing sperm membranes, especially those in the acrosomal region (Weitze, 1991). In general, commercially available semen extenders are classified as short-term, medium-term, and long-term. However, a more informative description would be 3-day, 5-day, and 7-day extenders, based on the length of time that they maintain sperm viability. For the most part the energy sources and electrolytes that are used in semen extenders tend to be similar. However, the buffering systems, which remove metabolic wastes, and the compounds that are added to stabilize sperm membranes are the components that differ and are likely the primary reason why sperm cells live longer in some extenders versus others.

While it is important to test semen extenders in attempts to identify the ones that produce superior farrowing rates and litter sizes, conducting such an evaluation in a truly objective manner is very difficult. In order to be scientifically accurate, a single ejaculate should be partitioned and an equal portion extended with the extenders to be evaluated. In addition, an equal number of these insemination doses should be used for breeding sows on at least two different farms. Finally, breeding technicians and semen age at the time of insemination should also be balanced across extender types at each location. These steps are necessary to insure that the true effect of the extender is evaluated and the results are not confounded with other factors known to influence fertility. Even if these precautions are taken and a superior extender is identified, then there is no guarantee that the conditions under which this effect occurred will remain constant in a herd over a lengthy period of time. In fact, data from field observations indicate that the advantage of one extender over another may change over time (Table 5).

Table 5. Effect of changing semen extenders on fertility in a commercial herd[a].

Time period	Semen extender[b]	Farrowing rate (%)	Litter Size
Jan., 1998 - June, 1998	Extender A	86 ± 2^{x}	11.7 ± 0.3^{x}
	Extender B	83 ± 3^{x}	11.5 ± 0.2^{x}
	Extender C	75 ± 3^{y}	10.5 ± 0.4^{y}
June, 1998 - Dec., 1998	Extender A	80 ± 3^{x}	11.1 ± 0.3^{x}
	Extender B	88 ± 2^{y}	11.5 ± 0.3^{x}
	Extender C	78 ± 3^{x}	10.9 ± 0.3^{x}
Jan., 1999 - June, 1999	Extender A	82 ± 3^{x}	11.3 ± 0.3^{x}
	Extender B	85 ± 2^{x}	11.4 ± 0.2^{x}
	Extender C	82 ± 3^{x}	11.1 ± 0.3^{x}

[a]Means ± SE are based on about 1000 matings for each extender during each time period. [b]Semen extenders were coded to remove potential biases during the study. [x,y]Means with different superscripts in a column within the same time period differ ($P \leq 0.05$).

From a management perspective, the most practical guide for the selection of an extender probably should be the average age of the semen at the time the majority of sows are bred within a herd. For example, if the majority of sows on a farm are bred with semen that is 2 days old, then, on the average, the influence of the semen extender of fertility would probably be minimal compared to other factors. In contrast, if the age of semen was 4 days, then it is reasonable to speculate that fertility would be better if 5-day or 7-day extenders were used compared with the use of their 3-day counterparts.

When determining the average age of semen at the time of insemination, it is important to remember to include the age of the insemination doses that are used for the second and third inseminations, when appropriate. A common mistake is to use only the first insemination. This causes problems since, currently, there is no accurate way to know from which insemination fertilization results. For example, if the semen dose used for the first insemination is 2 days old, then the age of the doses used for subsequent matings, if they came from the same batch, would be between 3 and 4 days old, depending on the breeding regimen. In this situation, if a 3-day extender was used and only the first mating was used to calculate semen age, then one could come to the conclusion that the extender was matched correctly with the average age of semen at insemination. However, in reality the second and third inseminations, which probably are involved in the fertilization process of a significant number of females, are actually performed with aged semen based on the extender. If this occurred on a regular basis, then fertility of these insemination doses would likely be suboptimal.

Semen extender additives

In addition to spermatozoa, it has been suggested that other compounds in semen influence physiological events such as ovulation, gamete transport, activation of uterine cytokine system and, possibly fertilization (Claus, 1990; Waberski, 1997). As a result, the question of whether enrichment of extended semen with these compounds has a positive effect on the fertility of insemination doses is worthy of discussion. From a practical perspective, it seems reasonable to speculate that this practice would be beneficial, especially in light of the observation that the concentrations of these compounds would be diluted significantly when insemination doses are produced.

In general, studies attempting to address this question have produced equivocal results (Table 6). In the studies that observed significant improvements in fertility, the reproductive performance of the control treatment (no added compounds) was low. Consequently, it is tempting to speculate that the observed effectiveness of these compounds was due to their ability to correct a deficiency inherent in the production or administration of insemination doses. At least in one instance with the administration of oxytocin, this speculation was true (Flowers, 1996b). In this particular situation, a 3-day semen extender was used and positive effects of oxytocin were only observed when semen older than 72 hours was used or when inexperienced breeding technicians performed the matings. In summary, at the present time it seems that there are a variety of compounds normally present in semen that can influence physiological events associated with mating. However, their influence on the production of live pigs is variable and tends to be positive predominantly in situations where other conditions associated with AI are suboptimal.

Table 6. Summary of selected studies adding different compounds to insemination doses[a].

Additive	Effect	References
Leucocytes	Increase in litter size	Skjervold *et al.* (1979)
	No effect on litter size	Van der Lende *et al.* (1986)
Oestrogens	Increase in farrowing rate and litter size	Claus *et al.* (1989)
	No effect on farrowing rate and litter size	Kirkwood & Thacker (1991)
Oxytocin	Increase in litter size	Odehnal *et al.* (1990)
	Increase in farrowing rate	Paig *et al.* (1992)
	No effect on farrowing rate and litter size	Krajnak (1990)
Prostaglandins	Increase in farrowing rate	Niwa *et al.* (1982)
Relaxin	No effect on farrowing rate and litter size	Peacock *et al.* (1994)

[a]Adapted with permission from Flowers (1998b).

Conclusions

It is clear that there are animal and management factors that influence the production of fertile insemination doses. From the boar's perspective, the number and quality of spermatozoa in the insemination dose influence the fertility of insemination doses. The relationship between these traits and reproductive performance is unique for boars and is referred to as a fertility curve or pattern. On an individual basis, the fertility on insemination doses for most boars occurs when insemination doses contain between 3 and 5 billion spermatozoa. However, when comparing different boars, there are distinct differences in the reproductive performance achieved with these insemination doses. As a result, development of fertility tests to identify these differences proactively will undoubtedly enhance the production of fertile insemination doses. From a management perspective, environmental conditions under which boars are housed and the choice of semen extender used to produce the insemination doses are important considerations. In terms of environmental conditions under which boars are housed, it seems elimination or prevention of detrimental factors such as suboptimal nutritional and temperature regimens have a large impact. In addition, the selection of the semen extender to use should be based on the average age of semen at the time of the insemination. Finally, addition of compounds to extended semen is a practice that is likely to produce equivocal results. Perhaps the best guide to use when making this decision is the average farrowing rate and litter size of the herd in question. If fertility in the herd is generally considered to be good, then enrichment of extended semen likely will not yield consistent improvements. In contrast, if it is considered suboptimal, then this strategy may prove to be effective.

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ESTIMATING THE OPTIMUM TIMING OF INSEMINATION IN PIGS

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Abstract

Successful AI requires that oestrus detection is conducted effectively and oestrous gilts and sows are inseminated at the correct time(s). Undoubtedly, optimum oestrus detection requires that females are tested by a breeding technician, using the back pressure test (BPT), in the presence of one or more mature boars. Determining when to inseminate these oestrous females is more difficult. Theoretically, quality fresh semen needs to be deposited in the female reproductive tract approximately 16-20 hours prior to ovulation in order to ensure that an adequate supply of viable, fertile sperm is present to fertilize shed ova when they reach the oviducts. In practice, achieving this synchrony is difficult because (1) the actual time of onset of behavioural oestrus is not known, and (2) the timing of ovulation varies with duration of oestrus. To minimise these problems it is suggested that all females be checked for oestrus twice-daily and that the timing of the first insemination be varied according to whether the female is a gilt or a sow and, in the case of weaned sows, whether or not the weaning-to-oestrus interval is <6 days. Finally, it is recommended that all females receive a second insemination 24 hours after the first, except where the female is no longer clearly exhibiting an immobilization response when checked for oestrus using the BPT in the presence of a boar.

Introduction

Fertilization only occurs when both fertile spermatozoa and fertile oocytes are simultaneously present at the site of fertilization in the oviduct (usually the narrowest part of the ampulla region of the ampullary-isthmic junction). The task for pig breeding staff is to estimate when to introduce semen into the female tract (either by AI or natural mating) in order to meet this requirement. This estimate will be based on a knowledge of when behavioural oestrus began and the temporal relationships between the onset of behavioural oestrus and ovulation.

Optimum insemination time relative to ovulation

Ovulation does not result in all oocytes being shed at the same time but rather is spread out over a period which normally lasts for 2-5 hours (Soede *et al.*, 1992; Soede *et al.*, 1997). Once shed, oocytes have a short lifespan as measured by their ability to be fertilized and develop into normal embryos (see Table 7). In contrast, spermatozoa appear to maintain their fertility while in the female tract for approximately 24 hours (Soede *et al.*, 1995a, Table 8). These data strongly suggest that optimal fertility and fecundity are likely to be obtained when insemination occurs during the 16-20 hours prior to ovulation.

Time of ovulation within the behavioural oestrus period

The problem with applying the above information is that breeding staff on-farm do not have any means of identifying in advance when ovulation will occur. Therefore, it is usual to estimate the time of ovulation on the basis of when oestrus is first detected.

Table 7. The effects of oocyte age at fertilization on fertilization rate and litter size (Hunter, 1988).

Estimated age of oocyte (h)	Fertilization rate (%)	Litter size[a]
0	90.8	12.0
4	92.1	11.7
8	94.6	8.7
12	70.3	6.8
16	48.3	4.8
20	50.9	5.0

[a]Estimated at day 25 post-mating.

Recent reports clearly suggest that ovulation generally occurs approximately two-thirds of the way through behavioural oestrus (Table 9). This relationship, while subject to variation, does provide a relatively useful indicator of when ovulation will occur if (1) the time of onset of the behavioural oestrus is known with any degree of accuracy, and (2) the duration of the behavioural oestrous period is known in advance. However, in most practical situations this information will obviously not be available. Hence, there is a need to use other methods to estimate when behavioural oestrus begins and to predict the duration of an oestrous period.

Table 8. The effects of the interval between insemination and ovulation on fertilization rate and embryo viability (Soede *et al.*, 1995a).

Interval between insemination and ovulation (h)		Sows with >90% fertilization (%)	Normal embryos (%)
Insemination	48 - 40	17	29
pre-ovulation	40 - 32	14	37
	32 - 24	47	47
	24 - 16	79	79
	16 - 8	83	94
	8 - 0	86	93
Insemination	0 - 8	54	75
post-ovulation	8 - 16	53	62

Estimating the start of behavioural oestrus

Changes occurring at oestrus

Oestrus in the female pig is characterized by changes in both the vulva (size and colour) and the behaviour of the gilt or sow. In addition, changes occur in vaginal mucus in terms of conductivity, pH, fluidity and colour. The fact that vulval reddening and swelling occur during pro-oestrus, while useful as a signal of approaching oestrus, is of little use as a means of identifying the period of behavioural oestrus or the time of ovulation (Sterning *et al.*, 1994). Similarly, the use of changes in vaginal mucus to identify the optimal time of ovulation has met with little success (Harbison *et al.*, 1987; Ko *et al.*, 1989; Stokof *et al.*, 1996). Behavioural changes in female pigs during pro-oestrus and oestrus can include reduced appetite, increased locomotor activity and mounting behaviour (Soede and Kemp, 1997). Most female activity at this time is directed towards the boar (i.e., proceptive behaviour), culminating in the display of receptive behaviour (the 'standing response') in the presence of a boar during oestrus (Signoret, 1970).

Table 9. The relationship between duration of oestrus and the interval between onset of oestrus and ovulation (Steverink, 1999).

Reference	Mean oestrus duration (h)	Mean interval from onset of oestrus to ovulation (h)	Timing of ovulation relative to total duration of oestrus (%)
Weitze *et al.* (1994)	60	45	71
Mburu *et al.* (1995)	56	37	68
Soede *et al.* (1995a)	50	35	72
Soede *et al.* (1995b)	60	41	67
Nissen *et al.* (1997)	60	-	71

Quality of oestrus detection

The display of sexual receptivity is not an all-or-nothing response, but reflects the degree of stimulation being provided (Soede and Kemp, 1997). Hence, more stimuli originating from the boar (particularly olfactory and tactile stimuli) are required to elicit a 'standing response' early and late in the oestrous period than are necessary in mid-oestrus. This information has been used to divide the oestrous period into three phases – an initial period when a 'standing response' can only be invoked when a boar is present, a period in mid-oestrus when a 'standing response' can be invoked by a stockperson performing the Back-Pressure-Test (BPT) in the absence of a boar, and a final period late in oestrus when, again, a 'standing response' can only be invoked when a boar is present (Willemse and Boender, 1966; Hemsworth *et al.*, 1984; de Jonge *et al.*, 1994). While the use of this classification of oestrous sow behaviour may help to better define the optimum insemination time, research data in fact indicate that the duration of the middle inseminator phase can vary from 0 to 65 hours (Willemse and Boender, 1966; Soede *et al.*, 1996).

In practice a high quality oestrus detection regimen requires that the stockperson performs the BPT in the presence of one or more boars, and that while each female is being tested she is in head-to-head contact with a boar (Hemsworth *et al.*, 1984). Additionally, the housing of the females may affect the success of oestrus detection with gilts (but not weaned sows). Gilts that are housed in contact with boars apparently habituate to boar-originating stimuli and thus become more difficult to detect in oestrus (Hughes and Hemsworth, 1994).

Frequency of oestrus detection

Optimal insemination times must be estimated on the basis of (1) observed changes in female behaviour, and (2) average intervals between onset of behavioural oestrus, ovulation and peak fertility. To further refine this practical approach it is necessary to maximize the accuracy with which the onset of oestrus is detected and to understand those factors that are likely to alter duration of the oestrous period. It is obvious that increasing the frequency with which oestrus detection is performed will provide better information on the timing of onset of oestrus and will reduce the variation in the interval between onset of oestrus and time of ovulation (Almeida *et al.*, 2000). However, practical oestrus detection rarely uses anything but once-daily or twice-daily regimens. When using a once-daily regimen, the actual time of onset of oestrus relative to when a female is first detected in oestrus can be anything within the range -24 to 0 hours. This range theoretically declines to -12 to 0 hours if twice-daily oestrus detection is used. In reality this difference can be much less given that most practical twice-daily oestrous detection regimens are actually applied in the morning (usually 0700-0900) and afternoon (usually 1500-1700). Nevertheless, there can be no doubt that a twice-daily oestrous detection regimen is more useful than a once-daily regimen in identifying sows that are very early in the oestrous period and thus unlikely to require immediate mating (see below).

It should be noted that most gilts and sows will only exhibit an immobilization response for a short period of time when provided with boar contact during oestrus detection. After about 10 minutes many oestrous females become refractory to boar stimuli (Table 10).

Table 10. The proportion of oestrous gilts in standing oestrus at various stages after initial boar exposure (Levis and Hemsworth, 1995a,b).

Time of day when oestrus detection performed	Minutes after initiation of oestrus detection					
	0	5	10	11	16	21
AM-Day 1	100%	100%	100%	92.3%	84.6%	84.4%
PM-Day 1	100%	93.3%	93.3%	93.3%	86.7%	66.7%
AM-Day 2	100%	94.1%	88.2%	82.4%	76.5%	70.6%
PM-Day 2	100%	94.1%	76.5%	70.6%	64.7%	64.7%

Predicting the duration of behavioural oestrus

Because the onset of oestrus can, at best, only be estimated to within 12 hours under a twice daily detection regimen, any practical system for optimally timing insemination(s) must rely heavily on an average figure for the duration of the oestrous period. This then allows the breeding technician to reasonably gauge when ovulation will occur in most females. For example, if the mean duration of the oestrous period for sows is 60 hours, ovulation will occur at approximately 40 hours. Further, it may be calculated that maximum fertility will result from inseminations occurring in the 'time window' from 20 to 40 hours after the onset of oestrus (i.e., 20-0 hours before ovulation). Where twice-daily oestrous detection is practised this would indicate that insemination should occur between 0 and 36 hours after oestrus was first observed.

While this system may seem to offer a practical solution to the problem, it does rely on most sows having an oestrous period whose duration is near to the mean. In practice much variation exists in oestrus duration (Soede and Kemp, 1997). Therefore, for this information to have value in practical insemination an understanding of those conditions that influence the duration of oestrus is needed.

Sow parity

It is clear that the duration of oestrus in most gilts is shorter than it is in sows (Table 11). However, data comparing oestrus duration between sows of parities 1-2 and older are contradictory (Weitze *et al.*, 1994; Steverink *et al.*, 1997).

Table 11. The effects of sow parity on duration of oestrus (Steverink, 1999).

Type of female	No. females	Mean duration of oestrus (h)	SEM
Gilt	2180	41.2	1.0
Sow	11246	50.1	1.1

Weaning to oestrus interval

There is clear evidence that the duration of oestrus reduces as the weaning to oestrus interval increases (Rojkittikhun *et al.*, 1992; Weitze *et al.*, 1994; Kemp and Soede, 1996, Table 12). Furthermore, because this effect appears to translate into reduced reproductive performance in those sows returning to oestrus after >5-6 days post-weaning (Table 13), it is suggested that many of these animals are being mated or inseminated too late relative to the time of ovulation to maximize fertility and fecundity.

Table 12. The relationship between the length of the weaning to oestrus interval (WOI) and the interval from onset of oestrus to ovulation (Kemp and Soede, 1996).

Onset of oestrus to ovulation (h)	% of sows			
	WOI = 3days	WOI = 4days	WOI = 5days	WOI = 6days
0-24	8	5	16	45
24-32	13	19	36	27
32-40	27	34	25	18
>40	52	42	23	9

Table 13. Effects of length of the weaning-to-oestrus interval (WOI) on subsequent farrowing rate and litter size (born alive) in sows.

Source of data	No. sows	WOI (d)	Farrowing rate (%)	Litter size
Dewey *et al.* (1994)	18,629	<6	-	11.4
		6-12	-	10.6
Vesseur *et al.* (1994)	3,520	<6	82	11.8
		6-12	74	11.2
Wilson (1994)	23,439	<7	84	10.5
		7-12	66	9.3
Koketsu *et al.* (1997)	7,632	<6	87	-
		6-12	81	-

Lactation length

There is no doubt that, in most sows, reducing lactation length to less than 16-21 days is associated with an extension of the weaning to oestrus interval and a reduction in conception rate, farrowing rate and subsequent litter size (Varley, 1982; Tubbs and Dyer, 1996; Flowers, 1998c). What is not clear is whether the change in conception and farrowing rates in early-weaned sows is a consequence of a longer weaning to oestrus interval (see above) or whether a short lactation per se alters either the duration of oestrus, temporal relationships between events occurring at oestrus or some other unidentified factor.

Season

While there are few research data on the relationship between season and oestrus duration there is a suggestion that oestrus duration may increase in the summer months (Soede and Kemp, 1997). Furthermore, there may be a change in the relationship between the pre-ovulatory LH surge, and thus presumably the timing of ovulation, and the onset of behavioural oestrus in the summer months (Paterson and Pett, 1987).

Stress

There is a wealth of evidence to indicate that chronic stress exerts an adverse effect on many aspects of female pig reproduction including oestrous expression (Varley and Stedman, 1994). Tethering of sows has been reported to significantly reduce oestrous duration compared with sows individually housed in pens with a generous space allowance of 6 m^2 (Soede *et al.*, 1997). Furthermore, low space allowances (probably <1.5 – 2.0 m^2/pig) appear to reduce the duration of oestrus, presumably through a reduction in the intensity of oestrus expression (Hemsworth *et al.*, 1986b). Interestingly, where weaned sows are group-housed there is evidence to suggest that the lowest ranked sows have the shortest oestrous periods (Pedersen *et al.*, 1993).

Boar contact

Varying the intensity of boar stimulation appears to modify the duration of oestrus in sows. In particular, performing oestrous detection in a Detection-Mating Area extends the apparent duration of oestrus (Table 14). It is likely that this effect is a result of better oestrous detection rather than an actual effect on oestrous duration per se.

Table 14. The effect of the intensity of boar contact on the duration of oestrus in sows.

	Oestrous duration (h)		
Reference	BPT[1] only	BPT + Boar presence	BPT in DMA[2]
Jongman *et al.* (1996)	-	53	62
Langendijk *et al.* (2000)	24	45	52

[1]BPT = Back Pressure Test. [2]Detection-Mating Area.

Effects of insemination late in oestrus

There is a growing body of research evidence to suggest that insemination late in the oestrous period, and particularly after ovulation has occurred, is unlikely to be of value in terms of raising reproductive output. Indeed, even if the sow is exhibiting a strong 'standing response' there is a considerable risk that such late inseminations will actually reduce both farrowing rate and litter size (Bischof *et al.*, 1994; Rozeboom *et al.*, 1997, 1998, 1999).

Conclusions

There is no doubt that a 'peak fertility and fecundity period' exists during oestrus at which time insemination will yield maximum reproductive performance in sows. This period appears to last from approximately 24 hours prior to ovulation up to the point of ovulation (Table 15). Further, because spermatozoa maintain their optimum fertility while in the female tract for approximately 24 hours and oocytes for approximately 8 hours, the aim of an insemination regimen must be to place one semen dose in the female tract during this 20-hour 'peak fertility and fecundity period'.

Table 15. The effect of insemination at various times relative to ovulation on subsequent sow performance (Nissen *et al.*, 1997).

Insemination time relative to ovulation (h)	Farrowing rate (%)	Litter size
-36 to –24	68	11.8
-24 to 0	92	13.2
0 to +12	76	12.3

In practice the problem remains that the time when ovulation will occur cannot be accurately predicted. Hence, insemination regimens are developed which are based on average figures for the duration of oestrus. Now that those factors that vary oestrous duration are better understood, it is possible to refine these regimens (Table 16). Such refinements are still based on average figures for duration of oestrus but they do take into account key factors that affect the timing of ovulation. What is clear is that the timing of insemination is improved if a twice-daily oestrus detection regimen is used in comparison with a once-daily detection system.

Table 16. Suggested insemination regimens for three major classes of female pigs.

Oestrous detection frequency	Female type	First insemination	Second insemination
Twice-daily	Gilt	At 1st detection	+24 hours
	Sow: WOI[1] <6d	12 hours after 1st detection	+24 hours
	Sow: WOI 6d+	At 1st detection	+24 hours
Once-daily	Gilt	At 1st detection	+24 hours
	Weaned sow	At 1st detection	+24 hours

[1]WOI = Weaning to oestrus interval.

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EFFECTS OF THE INSEMINATOR AND INSEMINATION TYPE ON EFFICACY OF AI

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Abstract

The overall fertility of the swine herd is the product of at least three factors: male fertility, female fertility, and the expertise of the breeding technicians. In the swine industry, the relative contributions of sows and boars to herd fertility have been studied extensively over the years. In contrast, less attention has been placed on the influence of the inseminator. There are significant differences among inseminators in terms of the farrowing rates and litter sizes that result from the sows that they breed. The manner in which inseminators interact with sows during breeding and the precision with which they perform the technical skills associated with the insemination process are two logical explanations for the presence of these differences among individuals. In addition, there appears to be an inverse relationship between the number of sows that inseminators are required to breed consecutively and herd fertility. Consequently, use of strategies that minimise the occurrence of this situation reduces observed variations in the performance of breeding technicians. In theory, another way to minimise the impact of the inseminator on herd fertility is to make the insemination process less dependent on the skills of the technician. For example, detection of oestrus is a vital part of artificial insemination and involves an interpretation of sow behaviour by the inseminator. Techniques such as induced ovulation followed by timed inseminations and deep uterine insemination are still in the developmental stages, but hold promise for further reducing the impact of the inseminator on herd fertility.

Introduction

In the beef and dairy industries, it is generally accepted that the overall fertility of a herd is the product of three factors: male fertility, female fertility, and the expertise of the breeding technicians. In the swine industry, the contribution of sows and boars towards the reproductive success of a herd has been recognized for a number of years. In contrast, the impact of breeding technicians on farrowing rates and litter sizes has received considerably less attention until recently. Moreover, recent advances in insemination catheters and elucidation of breeding physiology have the potential to accentuate the importance of the stockperson in the breeding process. The primary objective of this presentation is to provide a quantitative assessment of the impact that AI technicians have on reproductive performance on swine farms. In addition, recent advancements in the development of insemination catheters and strategies for hormonally enhancing the insemination process will also be discussed.

Effect of Breeding Technicians

In general, the technical competence of breeding technicians is thought to be positively related to herd fertility on swine operations - as the skill level increases, so does farrowing rates and the number of pigs born alive. However, documentation of this relationship in an experimental setting has been elusive. In a survey of US swine farms experiencing suboptimal reproductive performance, it was reported that the main problem in 30% of the cases was associated with the skill level of the breeding technician (Flowers, 1995). It is important to recognize that this study was retrospective in nature. Thus, although tempting, it is probably not accurate to use its findings as evidence for a cause and effect relationship between the expertise of breeding personnel and reproductive performance. Instead, all that can really be concluded is that there appears to be an association between the breeding skills of the technicians and herd fertility.

In order to establish a cause and effect relationship between breeding technicians and fertility, several aspects of the experimental design need to be carefully considered. The most important of these is that matings administered by each technician should occur over similar time periods and in the same production environment. In addition, other variables that cannot be controlled *a priori* need to be randomized across all breeding personnel involved in the study in order to prevent confounding. The results from a study designed with these characteristics are presented in Tables 17, 18, and 19 (Flowers, 1998c). In this particular study, technicians were assigned to breed an equal number of sows via AI over a 13-week period. Mating assignments were made such that sow parity, lactation length, weaning-to-oestrus intervals and semen characteristics were equally distributed across breeding technicians. In addition, similar breeding regimens, which consisted of one mating each day of oestrus, were used by each technician. Sows were managed as a group after breeding by personnel not involved with breeding. As a result, differences observed among technicians, or change over time for the same technician, were primarily the result of either their technical expertise with AI, or the manner in which they interacted with the sows during mating.

Table 17. Influence of AI technician on farrowing rates and litter size (Flowers, 1998c).

Technician	N[a]	Farrowing rate (%)	Number born alive	Total pigs produced
1	230	91.3 ± 5.1	11.5 ± 0.3	2413[x]
2	230	89.6 ± 4.2	11.4 ± 0.4	2346[x]
3	230	86.1 ± 3.9	11.7 ± 0.4	2310[x]
4	228	84.6 ± 5.2	11.2 ± 0.3	2153[y]
5	230	80.0 ± 4.3	10.2 ± 0.3	1870[y]
6	229	75.1 ± 4.6	8.0 ± 0.3	1377[z]

[a]Number of sows bred. [x,y,z]Totals with different superscripts differ significantly (P≤0.05).

Table 18. Changes over time in farrowing rate (%) for selected AI technicians (Flowers, 1998c)

Month	Technician 2	Technician 4	Technician 5
November	91.2 ± 4.4	93.7 ± 3.2[x]	76.5 ± 4.5[x]
December	89.7 ± 4.3	89.1 ± 4.1[x,y]	81.4 ± 4.2[x,y]
January	92.7 ± 4.4	84.7 ± 3.4[y,z]	89.9 ± 4.7[y]
February	91.3 ± 5.1	80.2 ± 4.2[z]	87.3 ± 4.4[y]

[x,y,z]Means within the same column with different superscripts differ significantly (P≤0.05).

Table 19. Changes over time in number of pigs born alive for selected AI technicians (Flowers, 1998c)

Month	Technician 2	Technician 4	Technician 5
November	11.8 ± 0.3[x]	11.0 ± 0.4[x]	10.8 ± 0.4[x]
December	11.3 ± 0.3[x,y]	11.4 ± 0.3[x]	10.4 ± 0.3[x]
January	10.9 ± 0.3[y]	11.3 ± 0.3[x]	10.5 ± 0.3[x]
February	11.6 ± 0.3[x]	11.1 ± 0.2[x]	9.1 ± 0.4[y]

[x,y]Means within the same column with different superscripts differ significantly (P≤0.05).

These data illustrate three important aspects concerning the impact of technicians on reproductive performance of sows bred artificially. Firstly, the individual that administers the artificial mating has a significant influence on farrowing rate, number of pigs born alive, and the total number of pigs produced. The differences between the best and worst technicians in terms of farrowing rate and litter size were 16% and 3.5 pigs,

respectively. This translated into a difference of about 1000 pigs born over the 13-week period. If this trend continued through an entire year, then a difference of about 4000 pigs would be expected. Secondly, seemingly small deviations in mean farrowing rates and number of pigs born alive that are not different statistically can result in large, significant differences in the total number of pigs born over time. This is evident when the data from technicians 2 and 4 are examined. Technician 2 had a 5% and 0.2 pig advantage over technician 4 in farrowing rate and litter size, respectively. These differences were not statistically significant. However, at the end of the study there were about 200 more pigs born to sows that were bred by technician 2 compared with technician 4. Finally, reproductive performance of sows bred by the same technician is more likely to change than to stay constant over time. This is evident by the significant time by treatment interaction observed for technicians 2, 4, and 5 (Tables 18 and 19). What is more interesting is that changes in farrowing rate did not necessarily mimic or follow changes in number of pigs born alive. These changes over time cannot be explained by environmental or animal factors that influenced the entire herd as farrowing rates and litter size increased for some individuals, while for others they decreased over the same time period.

The purpose of this study was to quantify the impact that breeding technicians have on herd fertility and not to determine reasons for differences among individuals. Consequently, retrospective analyses of differences in personality traits, gender, age, or experience among technicians is of little value. However, it is reasonable to speculate that either the skill with which the technicians inseminated the sows or the demeanour that they displayed towards the females during breeding contributed to the observed fertility differences. Evidence for the latter has been provided by Hemsworth *et al.* (1989). In a series of studies, it was shown that negative correlations exist between the level of fear of humans by sows, as measured by approach behaviour, and reproductive performance on commercial swine operations. Furthermore, inconsistent and rough handling of pigs causes corticosteroid concentrations to increase (Hemsworth *et al.*, 1986a). This, in turn, may provide a physiological explanation for how the demeanour of technicians towards sows during breeding might affect fertility.

One interpretation for the observation that changes in farrowing rate exhibited a different pattern from those for litter size is that different breeding skills are involved for each of these aspects of fertility. Otherwise, one would expect changes in farrowing rate to mirror those in litter size and vice versa. Although no definitive evidence exists, it is tempting to speculate that detection of oestrus is a skill that may be aligned with farrowing rate, whereas placement of the insemination catheter and deposition of semen may be linked to number of pigs born alive. The rationale for this statement is as follows. Errors in detection of oestrus lead to missed insemination opportunities. As a result, the probability that sows do not receive at least one mating during the 24-hour period prior to ovulation increases and the number of sows becoming pregnant, i.e., farrowing rate, decreases (Kemp and Soede, 1996). However, in the females that were bred such that pregnancy did occur, the number of pigs born alive should be close to normal. In contrast, from a physiological perspective, high farrowing rates coupled with low litter sizes usually result from the lack of sufficient numbers of spermatozoa in the oviduct during fertilization or embryonic loss after the first two weeks of gestation. It has been suggested that poor catheter placement and semen deposition increase the amount of spermatozoa lost due to retrograde flow during breeding (Steverink *et al.*, 1998) and decrease spermatozoa transport from the cervix to the oviduct (Flowers, 1996b). Consequently, if the reductions in spermatozoa numbers are not severe enough to prevent pregnancy from occurring, then farrowing rates would be normal, but numbers of pigs born alive would be reduced.

Hormonal enhancement of the insemination process

Many of the physiological aspects associated with insemination are under the control of hormones, which are secreted either spontaneously or are induced by the sows interaction with breeding technicians (Waberski, 1997). Two of the most important of

these aspects are the occurrence of ovulation, which is under the control of cyclical alterations in FSH, LH and oestradiol, and spermatozoa transport, which is stimulated by a variety of hormones including oxytocin and prostaglandins. As a result, it is reasonable to assume that enhancement of these normal processes with exogenous administration of key hormones at the correct time during breeding may have a positive impact on fertility.

Oxytocin and Fertility

A series of studies were conducted to examine the influence of oxytocin on spermatozoa transport and, thus fertility of sows bred artificially (Flowers, 1996b). The rationale for this approach was that oxytocin would enhance sperm transport during insemination and help minimize or correct any human errors associated with fertility and, thus improve both farrowing rates and number of pigs born alive. In the first study, sows were injected with 10 i.u. of oxytocin in 1 ml of saline just prior to each insemination. Oxytocin was injected into the vulva with a 1.3 cm, 26 gauge needle attached to a 1 ml syringe. In this particular study, a long-term semen extender was used. Results from this study are shown in Tables 20 and 21. Administration of oxytocin during breeding had a positive effect of fertility in two situations: (1) when semen was more than 72 hours old when used; and (2) when the experience of the breeding technician was limited. For the purpose of this study, an inexperienced technician was arbitrarily classified as one who had bred less than 20 sows artificially at the beginning of the study. Based on these observations, the routine use of oxytocin in AI breeding programmes probably is not a prudent management practice. In essence, if attention is given to semen age at insemination and training of inseminators, then use of oxytocin would not be expected to have a significant impact on fertility. Nevertheless, there are some situations in which aged semen may have to be used for breeding. These could occur if specific matings between sows and boars were needed and for some reason semen delivery did not coincide with the oestrous activity of sows. Under these circumstances, administration of oxytocin during breeding might prove to be beneficial.

Table 20. Effect of oxytocin and semen age on performance of sows bred artificially.

Treatment	N[a]	Farrowing rate (%)	Number born alive
Semen, ≥ 72 hours old	112	68.2 ± 6.3^{x}	9.4 ± 0.3^{x}
Semen, ≥ 72 hours old + oxytocin	110	85.3 ± 6.1^{y}	10.5 ± 0.3^{y}
Semen, < 72 hours old	232	89.3 ± 5.3^{y}	10.8 ± 0.4^{y}
Semen, < 72 hours old + oxytocin	236	90.2 ± 4.7^{y}	10.7 ± 0.3^{y}

[a]Number of sows bred. [x,y]Means with different superscripts in the same column differ significantly (P≤0.05).

Table 21. Effect of oxytocin on performance of sows bred artificially by experienced and inexperienced technicians.

Treatment	N[a]	Farrowing rate (%)	Number born alive
Inexperienced	150	77.2 ± 4.3^{x}	9.4 ± 0.3^{x}
Inexperienced + oxytocin	146	89.3 ± 4.1^{y}	10.4 ± 0.3^{y}
Experienced	197	87.4 ± 4.3^{y}	10.7 ± 0.3^{y}
Experienced + oxytocin	198	91.2 ± 4.7^{y}	10.9 ± 0.3^{y}

[a]Number of sows bred. [x,y]Means with different superscripts in the same column differ significantly (P≤0.05).

From a physiological perspective, oxytocin does enhance sperm transport during breeding, which results in an increase in numbers of oviductal and, thus, supernumerary spermatozoa during fertilization. However, what is interesting is that this effect is only observed when insemination numbers are suboptimal. This statement is supported by

results from previous studies (Flowers, 1996b). In this study, sows were assigned to receive either oxytocin or saline as a prebreeding treatment and inseminated with either 1 or 3 billion spermatozoa in a factorial arrangement of treatments. After breeding, oviducts were flushed and the number of spermatozoa in the oviduct and attached to ova were determined. Sows receiving oxytocin and only 1 billion spermatozoa had higher and similar numbers of spermatozoa in their oviducts compared with their counterparts given saline or bred with 3 billion spermatozoa, respectively. In contrast, there was no effect of oxytocin on sperm numbers or fertilization rate for sows receiving 3 billion spermatozoa. When these results are considered in conjunction with the data presented in Tables 20 and 21, then the physiology underlying the improvement of fertility in sows bred by inexperienced technicians seems reasonable. In this situation, it is likely that catheter placement or deposition of semen was such that fewer spermatozoa actually entered the uterus during breeding by inexperienced than experienced technicians. Consequently, oxytocin's enhancement of spermatozoa transport probably compensated for this deficiency in breeding technique. What is not clear from a physiological perspective is how oxytocin during breeding improved the fertility of aged semen, unless aged semen is transported less efficiently than fresh semen. At the present time, there is no evidence that this occurs (Flowers, 1996b). Consequently, interactions among the use of oxytocin during breeding, aged semen, and sow fertility require further investigation.

Gonadotropins, induced ovulation, and fertility

Most AI breeding regimens for sows involve multiple inseminations during oestrus. This is due to the fact that the interval from the onset of oestrus to ovulation is extremely variable within and among herds (Flowers and Esbenshade, 1993). Because of this, mistakes in detection of oestrus and semen deposition probably occur at a higher frequency in swine than in other species, such as cattle, in which only one insemination is necessary to achieve acceptable fertility. One approach that has been used over the years in attempts to circumvent the need for multiple matings in swine is to use gonadotropins to control the timing of ovulation in conjunction with a single insemination. This is commonly referred to as a timed insemination program.

A number of different strategies have been used over the years to control ovulation with varying degrees of success (Webel and Day, 1980; Esbenshade *et al.*, 1990). There are three basic characteristics that are common to the most successful of these programmes: (1) follicular development is suppressed for at least two weeks; (2) at the end of this period of inhibition, development of a new group of follicles is stimulated by administration of either pregnant mare serum gonadotrophin (PMSG) or gonadotrophin releasing hormone (GnRH)-like compounds; and (3) ovulation is induced with human chorionic gonadotrophin (hCG) 3 to 4 days later. In most of these systems (Webel and Day, 1980; Esbenshade *et al.*, 1990), a single insemination 24 hours after hCG without detection of oestrus produced fertility comparable to conventional breeding programs in which sows were bred once on each day of oestrus.

At the present time, variation in government regulations of pharmaceuticals approved for use in swine makes development of a universal timed insemination program difficult. For example, in the US, a product called PG600® (Intervet, Boxmeer, The Netherlands) can be used to induce follicular growth in weaned sows, but there are no compounds currently approved for suppression of follicular growth or induction of ovulation. Because lactation serves as a natural suppressor of the final stages of follicular growth in swine (Britt *et al.*, 1985), one could argue that the only portion of a timed insemination that is lacking is an approved pharmaceutical for the induction of ovulation.

When timed insemination programs have been tested under field conditions, the results have shown some potential (Table 22). One such protocol that was tested recently involved an injection of PG600® on the day of weaning (days 18 - 22 post farrowing) followed by an injection of hCG (Chorulon®, Intervet, Boxmeer, The Netherlands) 88 hours later. Sows were inseminated 24 hours after hCG with 3 billion spermatozoa. The control treatment consisted of sows that were weaned over the same time period, but received no hormonal stimulation and were bred once each day of detected oestrus.

Table 22. Reproductive performance of sows bred with timed inseminations.

Treatment	Number bred/ number weaned[a]	Weaning-to-oestrus interval (days)[b]	Farrowing rate (%)	Number born alive
Farm A				
Control	118/124	4.2 ± 0.4	84.3 ± 6.1[x]	11.3 ± 0.4[x]
Timed matings	120/120	---	80.9 ± 5.3[x]	11.2 ± 0.3[x]
Farm B				
Control	94/126	6.1 ± 0.6	82.5 ± 4.3[x]	10.9 ± 0.3[x]
Timed matings	125/125	---	67.3 ± 6.1[y]	9.7 ± 0.4[y]

[a]All sows in timed matings treatment received gonadotropins at weaning. [b]Oestrus was not determined in timed matings treatment. [x,y]Means within each Farm in the same column with different superscripts differ significantly ($P \leq 0.05$)

There were herd-specific responses to this induction regimen. In one herd, farrowing rates and number of pigs born alive were similar between the timed insemination and control treatments. In contrast, in the second herd, fertility was significantly lower in the induced sows compared with the females that ovulated naturally. There were, at least, two differences between the herds that may have contributed to the observed variation to the same induction protocol. These included the normal weaning to oestrus intervals and the proportion of sows that exhibited oestrus after weaning (control treatment). The protocol used for induction of ovulation and administration of timed inseminations in this study seemed to fit the normal rebreeding characteristics of herd A. In essence, in this herd, administration of Chorulon® at 84 hours (4.5 days) after PG600 (and weaning) probably coincided temporally or slightly preceded the time period over which ovulation would naturally occur in these animals. In addition, the majority of the sows in the control treatment did exhibit oestrus after weaning. This is evident in that the weaning-oestrus interval in the control treatment was 4.2 days and 95% of the weaned sows exhibited oestrus.

In contrast, in herd B, mean values in the control treatment for weaning-to-oestrus interval and the percentage of weaned sows exhibiting oestrus were 6.1 days and 75%, respectively. In this herd, the timed insemination protocol may have resulted in a situation in which sows were induced to ovulate and bred sooner than they were physiologically able. In addition, it also resulted in the insemination of a fairly large proportion of sows that may not have normally returned to oestrus after weaning. Both these situations would be consistent with reduced farrowing rates and number of pigs born alive. Whether or not the effectiveness of timed insemination protocols is dependent on the normal patterns of oestrous activity in herds after weaning is not known. However, if it is, then the pattern of oestrous activity provides herd persons with an opportunity to modify protocols to fit their own unique situation.

Mechanical enhancement of the insemination process

Compared with cattle, AI in swine is inefficient. This is primarily due to the fact that considerably more spermatozoa must be used in swine because semen deposition occurs in the cervix and not in the uterus as is the case with cattle. Consequently, practical techniques for intrauterine insemination in swine hold potential for significantly improving the efficiency of swine AI. Recently, there have been reports of the development of insemination procedures that allow for intrauterine insemination of swine (B.N. Day, personnel communication). This technique uses a flexible fiberoptic endoscope (Karlz Storz, Germany) and a conventional AI spirette with a spiral tip. The spirette is inserted through the vagina into the cervix. The endoscope is inserted through the spirette and manipulated such that it is inserted into one uterine horn. It has been reported that insemination doses as low as 50×10^6 spermatozoa have produced acceptable fertility results in sows induced to ovulate with PMSG and hCG. These results

are certainly encouraging and if they can be reproduced consistently on commercial operations, then it is conceivable that the number of sows bred from a single ejaculate could increase from around 15 (3 to 4 billion spermatozoa per dose) to over 900 (50 million per dose).

Conclusions

Breeding technicians have a major impact on the fertility of herds using AI. Unfortunately, at the present time, it is not clear which technical and behavioural traits that technicians possess are responsible for observed differences in farrowing rates and litter size. However, until these are identified, a reasonable management practice is to monitor the subsequent fertility of sows bred by each technician. This practice provides important information that can be used to identify causes of suboptimal fertility on farms using AI. Administration of exogenous hormones during breeding, such as oxytocin, is a management practice that is likely to have variable effects on commercial operations. In situations where it is effective, it likely is correcting a deficiency that is inherent in the standard breeding regimens. Finally, development of timed insemination programs and intrauterine insemination techniques are currently underway and progress is being made. Use of these two management tools has potential for increasing the efficiency of the inseminator and the insemination process.

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BIOSECURITY IN AI CENTRES IN AUSTRALIA — SHOULD WE BE CONCERNED?

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Abstract

The use of artificial insemination (AI) of sows in Australia has increased over the last 10 years. Although AI is often used in order to reduce the risk of introducing disease into herds, experience from Europe and North America has shown that unless biosecurity is strictly implemented, AI studs can be a serious source of disease and can amplify the spread of disease. Classical examples are the spread of Porcine Reproductive and Respiratory Syndrome (PRRS) in North America, and Classical Swine Fever in The Netherlands due to the difficulty of early detection of infected boars. Biosecurity in many Australian AI studs is not up to the standard generally required in Europe and North America. The recent deregulation of artificial breeding centres together with privatisation in Australia and the lack of any standard code of biosecurity specifically designed for pigs should be of great concern to the entire industry. Biosecurity recommendations for boar AI studs in Europe and North America are discussed with particular reference to location, staff and visitor access, disease monitoring and quarantine and isolation requirements. The importance of high standards of hygiene during collection and processing boar semen to ensure semen quality assurance is also discussed.

Introduction

The use of artificial insemination (AI) of sows in the Australian pig industry has increased greatly over the last 10 years. However, the actual number of sows artificially inseminated at least once during oestrus is probably somewhere between 15% and 25%. A much larger number of sows is inseminated in herds of 50 sows or more, often in combination with a natural mating on the first day of oestrus. Although AI has been traditionally considered a method of introducing genetic material into farms with a low risk of introducing diseases, it does have the potential of transmitting specific disease rapidly to a large number of herds if boars in AI centres become infected (Molitor and Shin, 1995; Bouma *et al.*, 2000).

Table 23. The strengths and weaknesses to be considered in relation to the increased use of AI, and the importance of biosecurity in boar AI centres.

UPSIDE	DOWNSIDE
• Large increase in the use of AI over the last 10 years — increasing genetic gains. • Increase in the number of AI centres in Australia — greater genetic pool in boars. • Increase in the number of doses/ejaculate/boar — efficient boar usage. • Wide spread dispersal of semen throughout the country. • Rapid turnover of boars to increase genetic progress.	• Deregulation of AI centres by most State governments. • With privatisation of AI centres there is the risk of inadequate self-regulation. • Existing health standards and codes of practice for artificial breeding centres lack details and specificity for pigs. • No accountable national biosecurity. • Rapid turnover of boars increases risk of pathogen introduction to AI centres. • Ever increasing risk of an exotic disease entering Australia. • AI can amplify the spread of a disease.

The issue of biosecurity in AI centres is of major importance in both Europe and North America. However because of the relative high health status of the Australian national pig herd, a degree of complacency exists in Australia. This is evident in the serious lack of either government or self-regulation regarding standards of biosecurity, or the existence of a National code of biosecurity specifically designed for pigs.

While the technology and use of AI in the pig industry is advancing at a rapid rate with the advantage of increasing the rate of genetic gains, e.g., growth rates, efficiency of food conversion and carcass quality and uniformity, the down side is an ever increasing threat of a pathogen being transmitted into AI centres and not being immediately detected (Table 23).

Two recent reports highlight the serious difficulties in detecting the presence of viral diseases in boars located in AI centres. Christopher-Hennings (2000) outlined the detection and control of Porcine Reproductive and Respiratory Syndrome Virus (PRRSV) in boar semen. The following factors highlight the complexity of this disease in relation to boar stud disease control management.

- Clinical signs in boars are variable but typically they are absent.
- Semen quality may not be affected.
- Transmission to sows of PRRSV does occur through semen resulting in seroconversion of sows with no obvious signs of reproductive failure, but can infect embryos and ovaries.
- Boars can become viraemic and shed PRRSV in semen prior to seroconversion (antibody response).
- Shedding of the virus may be intermittent, therefore several samples will be required to detect the virus in boars.
- The location of the PRRSV is most consistently found in the 'cell fraction' of the semen, within seminal macrophages.
- The PRRSV does not need to enter semen via the testicles or epididymis – vasectomized boars shed PRRSV in semen.
- Boars can shed PRRS virus for at least 100 days.
- Polymerase chain reaction (PCR) has a high sensitivity and specificity for detection of PRRSV in individual semen samples.
- Control involves strict biosecurity of PRRSV negative boars, strict quarantine and semen testing of incoming replacement boars. At least 60 days isolation is necessary during the testing and screening period (Althouse and Kuster 2000).

The second example is the outbreak of Classical Swine Fever in The Netherlands during 1997-98. Two AI centres became infected and the distribution of semen from these centres was considered to have infected at least 36 of the 429 herds that had infection, although the actual number could have been higher (Bouma *et al.*, 2000). The pertinent findings of this outbreak in relation to AI and the spread of disease are as follows:

- Clinical signs are not always obvious in adult boars in AI centres compared to younger pigs or in the on-farm situation, therefore the perceived incubation period is much longer in boars in AI centres compared with herd-incubation time.
- Semen is likely to become infected well before the disease is diagnosed.
- Semen usually remains of normal quality.
- Virus can be isolated from raw semen 7 to 9 days after infection, while neutralizing antibodies may not develop until 21 days post-infection.
- Induction of 'carrier sows' and the birth of persistently infected piglets can result from insemination with infected semen.
- Testing of semen with PCR is more reliable than virus isolation.

Table 24. Bacteria found in boar semen (Almond *et al.*, 1998).

Commonly found	Infrequently found
Staphlococcus spp.	Coynebacterium spp.
Pseudomonal spp.	Streptococcus spp.
Escherichia spp.	Proteus spp.
Klebsiella spp.	Serratia spp.
Citrobacter spp.	Bacillus spp.
Micrococcus spp.	Enterobacter spp.
Eubacterium suis	Aerobacter spp.
	Bordatella spp.
	Mycoplasma spp.
	Leptospira spp.
	Brucella suis
	Actinobacillus
	Pasteruella spp.
	Erysipelothrix rhusopathiae
	Salmonella spp.

Table 25. Viruses found in boar semen (Almond *et al.*, 1998).

Adenovirus African swine fever*	Porcine parvovirus*
Aujeskzy's disease (pseudorabies)*	PRRS*
Cytomegalovirus	Reovirus
Enterovirus	Swine influenza
Foot and mouth disease	Swine vesicular disease
Hog cholera (classical swine fever)	Transmissable genital papilloma
Japanese encephalitis	

*Transmitted through semen

The pig industries of both Europe and North America have had extensive experience in implementing biosecurity for AI centres, in some cases 'after the horse has bolted'. However it is worth considering the recommendations that have been made by both government and swine industry veterinarians in these countries and asking the questions:

- How do our present biosecurity standards compare?
- Are they likely to be adequate to reduce as much as possible the risk of a potentially pathogenic organism getting into one of our AI centres in the light of EU and USA experiences?
- Are our monitoring procedures sufficient to rapidly detect a breakdown before semen is distributed to a large number of commercial herds?

Biosecurity recommendations of porcine artificial breeding centres registered in Europe and/or North America

Biosecurity has been defined as: *'The quality or state of minimizing the risk of loss due to a biological component(s) e.g., bacterial or viral pathogen.'* The epidemiology of these pathogens should dictate the biosecurity protocol (Althouse and Kuster, 2000). Biosecurity is essential for:

a) Preventing transmission of disease to breeding herds via semen, and

b) maintaining boar stud viability to produce a quality assured product.

Biosecurity programs recommended in the EU and USA include most of the following:

- Site location — AI centres should be at least 3 km (EU) or 6.4 km (USA) distant from any other pigs, based on airborne transmission, and at least 1 km from roads used by vehicles carrying pigs.
- All AI centre buildings should be fly, insect, bird and rodent proof and be surrounded by a perimeter fence, and a 2 metre high 0.5 metre deep compound fence.
- The laboratory and boar holding facilities should have provision for staff to 'shower-in' with supply of a complete change of clothing that is laundered after 2 days use.
- Staff working in the animal holding facilities must not be employed in the laboratory and if they are required to enter the laboratory must do so only after showering and changing.
- Personal items such as mobile phones, calculators, notebooks and the like should be removed before entering the centre.
- Visitors should be discouraged at all times. A visitors' book must be signed before entering and give details of last contact with pigs.
- All staff and visitors must respect the required time interval between contact with other pigs and entering the AI stud (in the EU — 3 nights and 2 full days; in the USA can be up to 5 days).
- Isolation and quarantine accommodation for incoming boars:
  - Must have no direct contact with the AI centre and be a minimum distance of 1 km and preferably 3 km from the centre.
  - Biosecurity standards must be the same as for the AI centre.
  - Staff should be separate from the AI centre.
  - Operated on an all-in-all-out management basis of incoming boars and thoroughly cleaned and disinfected between batches.
  - Only boars of the same health status should be held at the same time except when a sentinel program is in operation.
  - Boars must be kept in isolation for a minimum of 60 days.
- Once resident in the boar stud:
  - Regular health monitoring by a veterinarian at least once a month (USA) or once every two weeks (UK) involving clinical examination of individual boars and random serologic profiling. Frequency and number of animals profiled dictated by the disease(s) of concern.
  - Post mortem by a veterinary pathologist of any boars that die.
  - Individual boar records kept of health, frequency of collection, sperm profiles and ejaculates discarded.

(Connor *et al.*, 1994; Bobb *et al.*, 1995; Torrison, 1995; Molitor *et al.*, 1997; Althouse and Kuster, 2000; Bouma *et al.*, 2000; Christopher-Hennings, 2000).

Semen quality assurance

Contamination of boar semen at the point of collection, or during processing can be caused by both pathogenic and non pathogenic organisms, mainly bacteria (Table 24). In most cases these can be prevented by day to day 'housekeeping' i.e., hygiene during collection and processing, strict hygiene procedures such as regular cleaning and disinfecting of the collection area and holding pens, and washing boars before collection if necessary. Laboratory and equipment hygiene is also critical to avoid bacterial contamination.

The presence of bacteria in semen can adversely affect its shelf-life and fertility (Almond *et al.*, 1998) and can increase the risk of uterine infections (Madec and Vannier, 1992). The addition of antibiotics does not always eliminate all bacteria and if the bacteria are killed, the by-products can also be detrimental to semen quality and shelf-life. Regular monitoring of random semen samples, preferably at the point of dispatch, for the presence of bacteria (culture and antibiotic sensitivity) should be carried out at least once every 4 to 6 weeks.

The aim of this paper is to draw attention to the importance of biosecurity in AI centres. As deregulation and privatisation of artificial breeding centres continues to take place in Australia it is imperative that the Australian pig industry develops a standard code of biosecurity that all AI centres adhere to in order to:

- Reduce the risk of a major disease being spread by contaminated semen. Because of the Australian pig industry's high health status exotic diseases are of particular concern.
- Provide the consumer with a high degree of quality assurance for the product (semen) they are purchasing.

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SYMPOSIUM CONCLUSIONS

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Australia has so far failed to wholeheartedly adopt AI, a technology which much of the rest of the world has recognised to be of considerable commercial benefit. This may be due to a combination of reasons, primarily amongst which are:

- the risk of semen quality being sub-optimum,
- possible reductions in fertility and fecundity, and
- increased risk of disease transfer into the breeding herd.

The aim of this symposium was to review how the success of AI could be optimised by production of quality semen doses and the implementation of good oestrus detection and insemination procedures. In addition, the specific issue of biosecurity associated with AI use was reviewed. It is clear from the information presented here that the conditions under which quality semen doses can be produced are well understood. There is little doubt that both commercial semen collection centres and, in most cases, on-farm collection centres can, and do, produce quality semen doses. Similarly, the evidence presented here, when added to that of Flowers and Alhusen (1992), indicates that the use of AI instead of natural mating should not adversely affect subsequent fertility and fecundity if quality semen is inseminated and the technique used for insemination is good. In addition, AI offers an exceptionally high level of protection from disease importation into a piggery, assuming that the required biosecurity programme is followed.

The one key area that remains unresolved is that of semen transport. Unfortunately, the pig industry remains relatively uninformed regarding the specific issue of how to ensure that, under Australian conditions, the quality of semen doses is maintained in the period between it leaving the collection centre and arriving on-farm. Much of this problem would appear to revolve around the logistics of getting relatively low value packages (from the carriers perspective) transported from a central collection centre to a remote piggery site at the correct time and in good condition. The specific problem of late delivery appears to be one that should be amenable to resolution through discussions between semen suppliers, transporters and piggery owners and managers. Even where the system fails, and old semen is supplied, there are longer-acting semen extenders available and oxytocin treatment at insemination may be used to boost semen transport within the uterus. This does not, of course, resolve the problem if the sows that were to be inseminated with the late-delivered doses are out of oestrus by the time the semen arrives. The problem of temperature fluctuations in the semen dose during transport remains debatable and is unlikely to be resolved until their is more data on which to judge the true extent of the problem. This will require study of both the actual temperature fluctuations occurring within the semen dose under different packaging, transport and ambient temperature conditions and the impact of these fluctuations on the fertility and fecundity of the inseminated gilts and sows.

In general, AI clearly does offer considerable advantages to the vast majority of Australian pig farms. Most of the perceived problems associated with AI are readily soluble through the application of current knowledge. The only real question mark that remains is that of alterations to semen quality during transport, particularly during the summer months. Even this problem, which is, of course, considerably diminished on those piggeries that collect semen from their own boars, is open to solution in most cases through better communication between transporters and end-users, improvements in packaging, change of extender type, and use of pharmaceuticals in association with the insemination.

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INTRAUTERINE SEMINAL PLASMA INCREASES OVARIAN STEROIDOGENESIS DURING EARLY PREGNANCY IN THE PIG

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Boar seminal plasma, generally believed to function simply as a transport and survival medium for spermatozoa, is extensively diluted when semen is prepared for artificial insemination in the pig industry. However, recent experiments in pigs suggest additional roles for SP including the advancement of ovulation (Waberski *et al.*, 1995), and increased progesterone secretion by granulosa cells and thecal tissue *in vitro* (Armstrong *et al.*, 1999). In this preliminary study the *in vivo* effect of SP treatment on ovarian function in gilts from ovulation until day 9 of pregnancy was investigated.

At the onset of gonadotrophin-induced oestrus, ten Large White x Landrace gilts were given a cervical infusion of either 100 ml SP or saline (PBS) 90 minutes prior to the first of two artificial inseminations with extended semen. Serial blood samples were collected via an ear vein catheter for the first 9 days of pregnancy. Serum progesterone concentrations were measured using radioimmunoassay. Animals were euthanased with a captive bolt at a commercial abattoir and ovarian tissues collected; ovulation rate and corpora lutea (CL) weight were determined. Data were compared by ANOVA repeated measures (SPSS) on $\log_N$-transformed data (P=0.006).

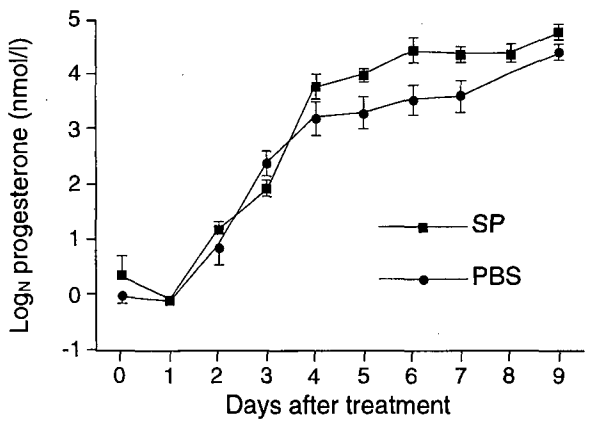

Figure 1: *Effect of intrauterine seminal plasma (SP) and saline (PBS) infusion on serum progesterone for 9 days post treatment (mean ± SEM).*

Seminal plasma treatment induced an increase in serum progesterone concentration for the 9 days post treatment (P=0.006) (Figure 1) and an increase in the weight of CLs [8.7 ± 0.7 g (SP) vs 5.8 ± 0.9 g (PBS), P=0.039; mean ± SEM], without a change in ovulation rate. This result suggests that SP treatment of gilts enhances ovarian steroidogenesis during early pregnancy. Since progesterone mediates endometrial priming for embryo implantation, these data indicate that seminal factors may influence the pre-implantation uterine environment via a previously unreported semen-ovarian-uterine axis. Thus dilution of seminal plasma may be responsible for the diminished litter sizes observed after AI when compared with natural service. Identification of active constituents of SP may lead to novel strategies for enhancing implantation rate and increasing litter sizes.

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COMPARISON OF BOAR SEMEN FREEZING METHODS

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Artificial insemination of pigs using cryopreserved semen is not commonly practised. This is largely due to the low fertility rates obtained compared with those using unfrozen semen or natural mating. Cryopreservation can be a cost-effective and an efficient way of transporting semen within and between countries, thereby facilitating widespread proliferation of superior genotypes. Cryopreservation may also maintain semen quality long term for the conservation of genetically superior stock.

The aim of this experiment was to compare the *in vitro* quality of boar spermatozoa obtained after using three methods of freezing: the Minitüb GmbH (Landshut, Germany; MT); Instruments de Médicine Vétérinaire (L'Aigle, France; IMV); and Flat Pack (FP) (Eriksson, 2000).

The sperm-rich fraction was collected from three Large White X Landrace boars aged 12 to 18 months using the gloved hand method. The fraction was split three ways and each aliquot was frozen as described in brochures distributed by IMV and Eriksson (2000) using a controlled rate freezer, or MT using liquid nitrogen (LN_2) vapour. The IMV method was altered slightly in that a slower freezing rate was used due to the limitations of the available freezer. After thawing, the sperm motility, capacitation status (CTC staining) and viability (Hoechst 33258 staining) (Abeydeera *et al.*, 1997) at zero hours and the motility at three hours after incubation at 37°C were assessed. The experiment was replicated on three days. Normally distributed data were analysed using three way ANOVA and a Tukey test, otherwise a Friedman repeated measures ANOVA on ranks was applied (SigmaStat Version 2.0). The post-thaw results for motility and the viability are shown in Table 1.

Table 1. Percentage post-thaw motility at zero and three hours and viability of spermatozoa after freezing by different methods (mean ± SEM).

Freezing method	Motility 0 h (%)	Motility 3 h (%)	Viability 0 h (%)
Flat Pack (FP)	36.0 ± 0.4^b	19.0 ± 0.2^c	64.0 ± 0.4^c
Minitüb (MT)	13.0 ± 0.4^a	8.0 ± 0.2^a	53.0 ± 0.4^b
IMV	36.0 ± 0.4^b	13.0 ± 0.2^b	46.0 ± 0.4^a

^{a,b,c}Means in the same column with different superscripts differ significantly ($P \leq 0.05$).

There were no differences in any of the parameters measured among days or boars ($P > 0.05$). Overall, motility at three hours and viability of spermatozoa were higher ($P \leq 0.05$) for FP frozen semen than the other methods. Motility of FP and IMV frozen semen at zero hours were similar and both were higher than MT-frozen semen. There were no statistical differences in the CTC staining patterns among the three methods.

These preliminary results suggest a benefit of using FP over the other two methods in terms of motility, viability and longevity of spermatozoa. This could be partly explained by the freezing package (a flat bag). The large surface-area:volume ratio allows more uniform freezing and thawing rates within the sample than in the straws used for the IMV and MT methods (Eriksson, 2000). This is thought to have a beneficial effect on sperm motility (Berger and Fischerleitner, 1992). The MT method could possibly be improved by use of a controlled rate freezer, rather than LN_2 vapour, which gives a less regulated freezing rate.

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IMPROVED PROGENY PERFORMANCE BY ELEVATING NUTRIENT INTAKE TO SOWS DURING GESTATION

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Increasing the nutrient intake of sows between day 28-56 of gestation, has resulted in a positive effect on the growth and feed efficiency of the progeny produced (Penny *et al.*, 2000). This improved performance between 85-127 days of age is thought to be associated with changes to muscle fibre numbers during foetal development. The type of diet fed during this growth phase could further enhance this possible change in muscle fibre numbers. The aim of this study was to test this hypothesis by offering different dietary specifications between 85-127 days of age.

Forty-eight multiparous Large White x Landrace (Genepacker 90) sows were randomly allocated (balanced for parity) between two treatments, Standard (ST) 2.5 kg/d or Elevated (EL) 5.0 kg/d during day 28-56 of gestation. Three boars and three gilts were weaned from each sow with a mean (± SD) live weight of 8.2 ± 1.2 kg, age 25.9 ± 1.3 days. This provided a total of 288 piglets, which were allocated to a 2 x 2 factorial design consisting of ST and EL derived progeny and two dietary treatments. Pigs were housed in groups of twelve (six boars + six gilts). From weaning to day 85, both ST and EL derived progeny received identical diets. Between day 85 and 127 two diets differing in total lysine and lysine to energy ratio were offered to ST and EL derived progeny. These contained either 12.5 g lysine/kg, 0.9 g lysine/MJ DE, high lysine (HL) or 10.5 g lysine/kg, 0.75 g lysine/MJ DE low lysine (LL). Pigs were weighed at weaning, day 57, 85, 127 and 157 slaughter. Data were analysed by ANOVA, based on a 2 x 2 factorial design, treatment means were separated by least significant difference.

Table 1. Effect of sow feeding (Standard, ST; Elevated EL) on the performance of progeny fed high (HL) and low (LL) lysine diets between day 85-127. Start weight at day 85 was used as a covariate, data presented are the adjusted means.

	ST progeny		EL progeny		Significance	
	HL	LL	HL	LL	Progeny	Diet
Day 85 weight (kg)	37.4	35.5	38.1	36.2	NS[1]	**
Day 127 weight (kg)	73.2	73.2	75.2	74.9	***	NS
Average daily gain (g)	866	866	914	908	**	NS
Feed intake (g/d)	1907	1886	1936	1831	NS	NS
Feed:gain	2.18	2.22	2.09	2.02	*	NS

[1]NS, not significant. *P≤0.05, ** P<0.01, *** P<0.001.

Total quantity of feed consumed during gestation was significantly lower for ST than EL sows (309 vs 381 kg, P<0.01). Both ST and EL progeny had similar average daily gain (ADG) from weaning to day 85 (461 vs 473 g/d, respectively). Between day 85-127 ST progeny produced a significantly lower ADG compared to EL progeny (866 vs 911 g/d, P<0.01) (Table 1). This positive increase in growth for EL progeny was evident for both HL and LL dietary treatments. Feed:gain of ST progeny was significantly increased compared to EL (2.20 vs 2.06, P≤0.05). This response was represented by both HL and LL dietary treatments.

These data confirm that elevated maternal nutrition during day 28-56 of gestation, increased progeny growth and feed efficiency. Progeny derived from EL sows obtained no additional benefits in performance when offered a HL diet as hypothesised.

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EFFECT OF FEED INTAKE DURING GESTATION ON THE GROWTH PERFORMANCE OF PROGENY TO SLAUGHTER

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Muscle fibre number influences the growth potential of pigs. Secondary fibre number in pig foetuses was increased by elevating feed intake in mid gestation (Dwyer *et al.*, 1994) possibly mediated through elevated maternal plasma IGF-1 concentrations (Musser *et al.*, 1997). The objective of this experiment was to test the hypothesis that increasing maternal feed intake between day 25 and 50 of gestation would improve the growth performance of the progeny.

Following insemination using meat-line semen, 46 parity two to four Landrace x Large White sows were fed at 30 MJ DE/d. At day 25 of gestation, sows were blocked on parity and weight and assigned to one of two nutritional treatments: 30 MJ DE/d or 60 MJ DE/d between day 25 and 50 of gestation. From day 50 to 110 of gestation sows were fed at 30 MJ DE/d. A gestation diet (6.2 g lysine/kg; 12.8 MJ DE/kg) was used. From day 110 of gestation to weaning a lactation diet (8.6 g lysine/kg; 14 MJ DE/kg) was fed to appetite. Progeny were weaned at 27 ± 0.1 days of age (mean ± SE) and one mixed sex pair of pigs of average weight was penned from each litter. In total, 46 mixed sex pairs of pigs were offered *ad libitum* a sequence of diets: 2 kg/pig of diet 1 (17.4 g lysine/kg; 16.1 MJ DE/kg), 5 kg/pig of diet 2 (15.0 g lysine/kg; 15.3 MJ DE/kg) which when consumed was followed by diet 3 (13.6 g lysine/kg; 14.0 MJ DE/kg) to day 47 postweaning. From day 47 to slaughter at 131 days postweaning, pigs were formed into single sex groups of 12 pigs and were offered diet 4 (11.2 g lysine/kg; 13.5 MJ DE/kg) *ad libitum* using a transponder feeding system. Data was analysed using the GLM procedures of SAS for a completely randomised design.

Table 1. The effect of feeding either 30 MJ DE/d or 60 MJ DE/d to sows between 25 and 50 days of gestation on progeny mean live weight.

Treatment	30 MJ DE/d	60 MJ DE/d	SE	P-value
Birth weight (kg)	1.55	1.53	0.042	0.69
Weaning weight (kg)	8.0	8.2	0.18	0.38
Day 27[1] weight (kg)	20.0	19.9	0.41	0.85
Day 48[1] weight (kg)	35.6	35.3	0.63	0.90
Day 131[1] weight (kg)	96.9	95.9	1.01	0.54

[1]Days postweaning

By day 50 of gestation sow weight was 226 and 244 ± 5.0 kg (P<0.01) for sows fed 30 MJ DE/d and 60 MJ DE/d, respectively. However, there was no significant difference in sow live weight between treatments at day 110 (268 ± 6.2 kg) and at weaning (238 ± 5.4 kg). Sow back-fat thickness was similar for both treatments at day 25 (19.1 ± 0.68 mm), day 50 (20.5 ± 0.70 mm), day 110 (21.7 ± 0.69 mm) and at weaning (17.3 ± 0.49 mm). The number born alive (10.9 ± 0.75 pigs) and the number born dead (0.9 ± 0.32 pigs) were similar for both treatments. Pig performance from birth to slaughter was not significantly affected by treatment (Table 1). Days taken from birth to slaughter were 158.5 and 158.1 ± 1.16 (P>0.05) and daily gain from birth to slaughter was 602 and 600 ± 7.9 g (P>0.05) for progeny of sows fed 30 MJ DE/d and 60 MJ DE/d, respectively.

In conclusion, these data do not support the original hypothesis. It could be speculated that the period of over feeding used in the present study was not sufficient. Growth rate of progeny increased when feed intake was increased between day 25 and 80 of gestation (Dwyer *et al.*, 1994).

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BOAR EXPOSURE INCREASES CONCEPTION RATE IN INDUCED 'ONCE-BRED' PRE-PUBERTAL GILTS

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The production of once-bred gilts is a strategy where primiparous sows are slaughtered after weaning at a weight suitable for the export market. The success of the strategy is dependent on the reproductive performance of the gilt and a suitable price for the carcass (Ellis *et al.*, 1996). Ovulation can be induced in gilts as young as 20 weeks of age when exogenous hormones are used (Tilton *et al.*, 1995). It is widely accepted that boar contact enhances the fertility of gilts mated at 30-32 weeks of age. This experiment tested the hypothesis that the presence of boars during exogenous hormone treatment would improve the fertility of pre-pubertal gilts.

Six hundred female finisher progeny from Large White x Landrace F1 cross sows were allocated at 18, 21 or 24 weeks of age to either boar presence (+B) or absence (-B) prior to and during mating. Gilts were housed in groups of 45 (0.7 m^2/gilt) and offered a female finisher diet (13.5 MJ DE/kg; 160 g crude protein/kg) *ad libitum*. An aisle 1.5 m wide with solid panels separated pens of +B and -B treatments. At their specified treatment age, all gilts were injected in the morning with 1000 i.u. PMSG (Folligon™) followed by 500 i.u. hCG (Chorulon™) after 72 hours. Four vasectomised boars (15 months of age) were introduced into the pens of +B gilts for 20 minutes when PMSG was administered and daily until 2 days after mating. Gilts were mated (3×10^9 cells) in the pen at 18 or 21 or 24 weeks of age 30-32 hours after hCG by a single fixed-time insemination. Boars were present at the time of mating in pens of +B gilts only. After mating, the daily amount of feed offered was restricted to 2 kg/gilt in the group of 45 gilts. At 35 days post-mating, gilts were checked for pregnancy using real-time transabdominal ultrasound (PieMedical™ 485). One-way analysis of variance and Chi-square were used to statistically evaluate differences between treatments.

Table 1. Mean live weight at mating (by AI) at three ages, and the pregnancy percentage assessed at 5 weeks post-mating of once-bred gilts.

Age mated (A)	18 weeks		21 weeks		24 weeks		Significance		
Boar presence (B)	+B	-B	+B	-B	+B	-B	A	B	AxB
No. mated	96	88	107	106	98	95			
Live weight (kg)	69.3	69.2	83.9	83.5	98.8	98.4	***	NS[1]	NS
Pregnancy %[2]	26.0	12.5	35.5	17.9	55.1	34.7	***	***	NS

***Comparisons of means for main effects differ significantly P≤0.001. [1]NS, mean values not significantly different P>0.05. [2]Pregnant/mated x 100.

There was a significant increase (P<0.001) in the proportion of mated gilts confirmed pregnant by 35 days post-mating when vasectomised boars were present in the pens (Table 1). Boar presence may have elevated endogenous hormone release and/or improved semen uptake during insemination. There was also a significant effect of gilt age at the time of induction on gilt fertility. Inducing gilts at 24 weeks of age significantly (P≤0.05) increased the percentage of gilts pregnant (44.9%) compared to induction at either 18 (19.8%) or 21 weeks (28.3%). Sixty-five litters were born to gilts mated at 24 weeks of age, with a litter size born alive averaging 6.7 ± 2.4 (mean ± SD). There were too few litters born from the gilts mated at 18 week and 21 weeks of age to report on litter size from these groups. Under the conditions imposed in this experiment the fertility of once-bred gilts was maximized by mating gilts at 24 weeks of age in the presence of boars.

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CHANGES IN WEIGHT AND BODY FATNESS OF SOWS OFFERED DIETS *AD LIBITUM* DURING PREGNANCY

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The practice of restricting the intake of group-fed sows during pregnancy often causes fighting, and the associated stress may result in reduced reproductive performance (Einarsson *et al.* 1996). Offering a diet containing a supplement, such as sugar beet pulp or straw, *ad libitum* to satiate the sow is often practiced in Europe to minimise fighting in group-fed pregnant sows. In the absence of sugar beet pulp in Australia, an experiment was conducted to evaluate a number of commercially available ingredients for their potential use in a pelleted gestation diet to be offered *ad libitum* to group-housed sows.

At the fifth week of gestation, 80 Large White x Landrace cross gilts, and third and fourth parity sows were weighed and housed individually. Fat thickness was measured over the eye muscle on the last rib by ultrasound at 6.5 cm from the midline (gilts) or 7.5 cm from the midline (sows). Sows were randomly allocated to one of five treatments: 80% millmix diet (A); 28% lucerne diet (B); 23% rice pollard diet (C); 18 % albus (bitter) lupins diet (D); a Control diet formulated with wheat/barley/triticale (E). Gilts and sows allocated to Treatment A-D were offered the diets *ad libitum*, whereas those allocated to Treatment E were fed 2.1 kg/d (gilts) and 2.6 kg/d (sows). Diets A, B, C, and E contained 135-140 g crude protein (CP)/kg. Diet D contained 150 g CP/kg. Animals remained on their treatment regimen until 110 days of gestation. All sows were then offered a diet (14.0 MJ DE/kg; 10 g total lysine/kg; 185 g CP/kg) *ad libitum* until weaning (27±0.1 days). Means values were compared by ANOVA.

Table 1. Gain in live weight (LWT) and fat thickness from the fifth week of gestation until the first day post-farrowing and the corresponding losses during lactation in gilts and sows offered diets either *ad libitum* or a restricted amount during pregnancy.

	5 weeks gestation		Pregnancy gain		Lactation loss	
Diets provided during pregnancy (DE MJ/kg)	LWT (kg)	Fat (mm)	LWT (kg)	Fat (mm)	LWT (kg)	Fat (mm)
A. Millmix (10.3 MJ/kg)	193.9	16.2	49.2^{bc}	7.3^{b}	14.4^{b}	3.6^{b}
B. Lucerne (10.3 MJ/kg)	203.5	17.3	57.2^{c}	8.3^{b}	25.9^{c}	5.4^{b}
C. Rice pollard (11.4 MJ/kg)	205.4	16.4	44.3^{b}	8.9^{b}	27.9^{c}	5.0^{b}
D. Albus lupins (11.5 MJ/kg)	204.3	17.9	52.3^{bc}	8.5^{b}	21.0^{bc}	5.9^{b}
E. Control (13.0 MJ/kg)	205.7	16.9	13.0^{a}	-1.3^{a}	1.5^{a}	0.3^{a}
SED	5.7	0.5	2.6	0.7	2.0	0.6
P value	0.969	0.836	0.001	0.001	0.001	0.004

^{a,b,c}Mean values in a column with different superscripts are significantly different, P≤0.05.

Gilts and sows offered diets A-D *ad libitum* had significantly greater increases in live weight and fatness compared to the Control animals (Table 1). The cost of offering diets A-D *ad libitum* during gestation was significantly higher (P≤0.05) compared to diet E (41 ¢/day). The millmix and the rice pollard diets were the cheapest of the diets offered *ad libitum* (73 ¢/day). There were no significant differences among treatments in litter size (born alive 10.4 ± 1.6; total born 11.2 ± 2.4) or still-birth percentage (6.6 ± 6.4%) (mean ± SD). Intake during lactation was significantly (P≤0.001) lower for animals offered diets A-D *ad libitum* (pooled mean 5.0 ± 0.2 kg/d) compared to those fed the restricted Control diet (6.7 ± 0.3 kg/d). There was no evidence from this experiment of a benefit to reproductive performance when diets were offered *ad libitum* to gilts and sows during a single parity. Millmix and rice pollard were identified as cheap ingredients that could be used in diets offered to group-housed sows *ad libitum* during pregnancy.

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THE USE OF OXYTOCIN TO IMPROVE FERTILITY IN SOWS

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Oxytocin stimulates contraction of the smooth musculature of the uterus to produce rhythmic contractions. It has been used, with some measure of success, to improve sow productivity associated with artificial insemination (AI) (Levis, 2000). Several trials have been conducted to investigate the efficacy of oxytocin to improve prolificacy and fertility in sows during periods of low fertility. Pena *et al.* (1998a) and Levis (2000) have demonstrated a beneficial use of oxytocin in reducing seasonal effects on sow reproduction. The aim of this project was to determine whether the use of oxytocin supplementation of semen, with AI-only matings, would significantly improve sow productivity.

At mating 50 commercial hybrid sows were inseminated with semen that was supplemented with oxytocin (10 IU per dose) within two minutes of AI. The 62 control sows were inseminated without the oxytocin supplement. Inseminations were only done in the morning. Sows were selected at random for inclusion in the trial and sow parities varied from 0 to parity 6. Additionally, this trial was conducted during a period when seasonality (summer infertility) has a deleterious effect on sow reproductive performance. The sows were mated during February and started farrowing in late May. Sow reproductive data was analysed using Generalised Linear Models with normal or binomial errors. Statistical evaluation was performed using Genstat 5 for Windows, Release 4.1 (Lawes Agricultural Trust, Rothamsted Experimental Station).

Oxytocin mixed with semen just prior to AI resulted in a significant improvement in farrowing rate (Table 1). However, average litter size born alive and average number of stillborn pigs was significantly lower for the group inseminated with semen supplemented with oxytocin.

Table 1. Comparison of reproductive performance for AI only matings (mean ± SEM).

Treatment	Total mated	Total farrowed	Farrowing rate %	Number born alive	Number born dead	Number of mummified foetuses
Oxytocin	50	36	72.0[a] (±6.3)	8.50[a] (±0.49)	0.39[a] (±0.10)	0.14 (±0.06)
Controls	62	31	50.0[b] (±6.4)	10.20[b] (±0.57)	0.84[b] (±0.16)	0.32 (±0.10)

[a,b]Values in a column with different superscripts are significantly different (P≤0.05)

The improved farrowing rate associated with the use of oxytocin in semen with AI during a period of summer infertility is in agreement with the findings of Pena et al. (1998b) and Levis (2000). In this trial the control sows had a significantly greater number of pigs born alive, which is in contrast to the results of Levis (2000) who reported that the use of an oxytocin supplement to the semen did not significantly affect litter size. Conversely, Pena et al. (1998b) found that litter size increased when sows were inseminated with semen supplemented with oxytocin. Although the trials were all conducted during periods of summer infertility, there are a number of other influencing factors, including sperm concentration in semen, nutrition, genetics, herd health, environment, housing type and stock management, which in addition to climate and temperature, act to affect litter size. Differences in the results between earlier trials and the present study may have arisen as a result of numerous interactions among these influences. Nonetheless, the supplementation of semen doses with 10 IU of oxytocin was found to be an effective method for increasing farrowing rate associated with AI-only matings during periods of low fertility.

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FEEDING STRATEGIES TO IMPROVE FERTILITY IN GILTS

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High level feeding (41 MJ DE/d) increases progesterone clearance rates and results in lower circulating progesterone concentrations in ovariectomized gilts (Prime and Symond, 1993). The rise in plasma progesterone after ovulation is also delayed in gilts fed at a high level and results in increased embryonic losses (Jindal et al., 1997). As a consequence, restricted feeding is recommended in early pregnancy to reduce embryonic mortality. However, high energy feeding has a positive effect on uterine secretions and may improve embryo survival (Soede et al., 1999). The aim of the study was to investigate if a low feeding level for the first 10 days post-insemination, followed by a period of high level feeding, would capture the benefits of both of the above observations.

Twenty-four crossbred (Finnish Yorkshire X Landrace) gilts (7-8 months) were used in a study carried out in Southern Finland in autumn. Gilts were randomly allocated to three groups and housed in three pens with individual feeding stalls. Oestrus was synchronized using the orally active progestagen, altrenogest (Regumate®, Hoechst) and gilts inseminated twice. Prior to insemination all gilts were fed 40 MJ/d of a commercial ration (13 MJ DE and 7.4 g lysine/kg). Following insemination gilts were fed 27 MJ/d (LLL) or 54 MJ/d (HHH) for 34 days or 27 MJ/d for 10 days, 54 MJ/d for 7 days followed by 27 MJ/d to day 34 post-insemination (LHL). Blood samples were collected twice each week (day 0, the day of ovulation was determined by ultrasonography) and analyzed for progesterone by radioimmunoassay. Gilts were slaughtered at day 34 to determine embryo survival.

The percentage of pregnant gilts was significantly higher ($P \leq 0.05$) for the HHH group (100%) than for the LLL group (25%) or the LHL group (38%), but there was no significant effect on embryo survival at day 34, which was 68%, 75%, and 71%, respectively. The LLL group had significantly higher serum progesterone concentrations compared to group HHH on days nine and twelve after ovulation ($P \leq 0.05$; Figure 1).

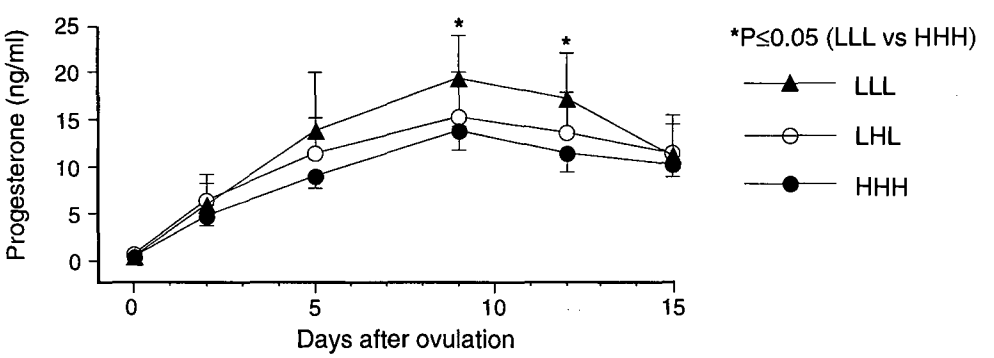

Figure 1. *Serum progesterone (mean ± SD) in different feeding groups for 15 days after AI.*

The LHL feeding strategy in early pregnancy did not provide the benefits anticipated. However, there was a distinct advantage in pregnancy rate for the HHH group. This implies that, although high feed intake may reduce progesterone concentration and possibly reduce embryonic survival, this is more than offset by an increase in pregnancy rate. It appears that feeding level has to be increased before day 10 to derive this benefit. The mechanism has yet to be determined.

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SEMINAL PLASMA-INDUCED EXPRESSION OF CYTOKINE mRNA IN PIG ENDOMETRIUM DURING EARLY PREGNANCY

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Uterine receptivity and embryo implantation appear to be facilitated by the generation of an inflammatory response induced at insemination. Previously, abundant populations of leukocytes have been shown to accumulate in the pig endometrium following exposure to seminal plasma (O'Leary *et al.*, 2000). It is hypothesised that pro-inflammatory cytokines regulate this response at the molecular level. The aim of this study was to examine whether seminal plasma can induce cytokine expression in the endometrium during early pregnancy in pigs.

At the onset of gonadotrophin-induced oestrus, Large White X Landrace gilts (aged 24 weeks) were given trans-cervical intrauterine infusions of either seminal plasma (SP) or phosphate buffered saline (PBS) prior to artificial insemination with extended semen. On day 0 (36.5 h post infusion), day 5 and day 9 of pregnancy, gilts were sacrificed and endometrial tissue was collected for reverse-transcription polymerase chain reaction (RT-PCR). Total RNA was extracted (Tel-Test), reverse transcribed (Boehringer Mannheim), and quantified by real-time PCR amplification (5700 Sequence Detection System, Applied Biosystems). Cytokine and β-actin specific primers were designed using Genebank sequences.

Endometrial exposure to seminal plasma induced elevated expression of granulocyte-macrophage colony stimulating factor (GM-CSF) (4-fold increase over mean PBS-treated value) and interleukin (IL) IL-6 (8-fold) mRNA on day 0 (Table 1). Expression of mRNA encoding GM-CSF, IL-1α, IL-1β, tumour necrosis factor-α (TNFα) and macrophage chemotactic factor (MCP) MCP-1 was significantly elevated on day 0 compared with days 5 and 9 (except IL-1α) of pregnancy. In contrast, IL-6 mRNA expression was significantly elevated on day 5 compared with days 0 and 9.

Table 1. Endometrial cytokine mRNA expression, mean ± SEM normalised to β-actin and expressed as a percentage of day 0 PBS group mean.

Day		GM-CSF[1]	IL-1α[1]	IL-1β[1]	IL-6[1]	TNFα[1]	MCP-1[1]	n
0	PBS	100 ± 22	100 ± 12	100 ± 17	100 ± 18	100 ± 13	100 ± 12	4
	SP	397 ± 65[a]	228 ± 147	64 ± 30	772 ± 282[a]	230 ± 113	182 ± 63	4
	Combined	248 ± 64	164 ± 73	82 ± 17	436 ± 182	165 ± 58	141 ± 33	
5	PBS	94 ± 36	21 ± 8	3 ± 3	2189 ± 766	24 ± 19	93 ± 28	4
	SP	36 ± 16	21 ± 8	5 ± 2	1709 ± 704	27 ± 8	60 ± 12	6
	Combined	59 ± 19[b]	21 ± 5[b]	4 ± 1[b]	1900 ± 500[b]	25 ± 8[b]	73 ± 13[b]	
9	PBS	115 ± 39	82 ± 19	9 ± 3	2005 ± 825	43 ± 13	106 ± 20	6
	SP	62 ± 20	179 ± 69	4 ± 1	176 ± 64	27 ± 13	45 ± 11	7
	Combined	86 ± 22[b]	134 ± 39[c]	7 ± 2[b]	1020 ± 449[c]	34 ± 9[b]	73 ± 14[b]	

[a]Significantly different from PBS as determined by Mann-Whitney Test P≤0.05. [b]Significantly different from day 0 combined PBS/SP data as determined by Kruskal-Wallis Test P≤0.05. [c]Significantly different from day 5 combined PBS/SP data as determined by Kruskal-Wallis Test P≤0.05. [1]See text above for explanation of terms.

These data show that several pro-inflammatory cytokines are produced in the pig endometrium, and that cytokines, notably GM-CSF and IL-6 are regulated by exposure to seminal plasma prior to ovulation. These two cytokines are identified as key mediators of seminal plasma-induced immune changes in the mouse (Robertson *et al.*, 1992), and may together with differential expression of other pro-inflammatory cytokines promote an environment conducive to embryo growth and development during early pregnancy.

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THE EFFECT OF DIETARY VITAMIN C SUPPLEMENTATION TO BOAR DIETS ON SPERM QUALITY

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Pig diets are not usually supplemented with vitamin C as the animals do have a limited capacity to synthesise vitamin C (Grollman and Lehninger, 1957). However, it has been shown that supplementation with vitamin C can alleviate some of the negative effects associated with heat stress and also boost sperm production in boars (Lin *et al.*, 1990). In Australia the summers are hot and heat stress is often associated with summer infertility as a result of the effect of high ambient temperatures on the sow. There has been some limited evidence that seasonal infertility can be caused by heat stress and semen quality attributes of the boar as well. The increasing use of artificial insemination (AI) throughout Australia also highlights the need to ensure maximum boar fertility throughout the year to obtain maximum results.

The experiment was a simple randomised design with two dietary treatments: a standard diet (Control) based on a commercial boar diet of 14 MJ DE/kg and 10 g of lysine/kg and a treatment diet (VitC) (control diet + 2 kg/t of ethyl cellulose coated vitamin C (Rovimix® C-EC)). The experiment commenced in January 2001. Ten Large White boars approximately 10 months of age were allocated to each treatment. They were fed a restricted amount (2.6 kg/d) of the treatment rations for six weeks and trained for semen collection. Boars physically capable of being used in an AI program were then selected and collections made over the next 10 weeks. Six control and eight VitC Boars produced 43 and 62 ejaculates respectively over the 10-week period. Semen volume was recorded, and density of sperm was analysed by spectrophotometer and microscopic assessment. The semen was ranked by microscopic assessment on morphological characteristics for motility and abnormalities into three categories: discarded semen (ranked 0), poor to fair semen (ranked 1) and good quality semen (ranked 2). Acceptable ejaculates were then extended into doses comprising 3 billion sperm per doses. The results were analysed by ANOVA and are shown in Table 1.

Table 1. The effect of dietary addition of vitamin C on sperm quality of young boars.

Treatment	No. of boars	No. of collections Total	Vol. per ejaculate (ml)	Sperm density per ejaculate (billion/ml)	Total sperm per ejaculate (billion)	Doses/ ejaculate	Assessment score
Control	6	43	231.2	0.267	58.89	15.28	1.49
Vitamin C	8	62	236.8	0.288	66.99	21.55	1.81
P-value			0.711	0.155	0.079	0.000	0.016
SEM			7.38	0.007	2.09	0.87	0.07

The addition of 2 kg/t of vitamin C to the diet of boars significantly increased the average number of doses obtained from each ejaculate. This was probably the result of a significant improvement in sperm quality and a tendency to increase the total sperm per ejaculate (Table 1). Two physiological functions of vitamin C are as an antioxidant in the body and in the synthesis of steroid hormones. Both these processes are important for spermatogenesis in boars. Thus vitamin C supplementation may help to reduce the negative effects on spermatogenesis during the highly stressful summer period. These results are subjective and need to be confirmed with more in depth experiments evaluating the effect of vitamin C on spermatogenesis.

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THE USE OF HORMONAL SYNCHRONIZATION TO ASSIST IN THE ARTIFICIAL INSEMINATION OF GILTS

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The use of artificial insemination in gilts can be limited by the variable nature of gilt oestrous activity, its shorter duration compared to sows and the timely availability of freshly collected semen. The use of artificial insemination for gilt matings may be increased if gilts could be successfully synchronized to coincide with regular semen delivery routines.

At 22 weeks of age 330 Large White x Landrace gilts of approximately 90 kg live weight were selected. Over the next five weeks they were exposed to daily contact with a mature vasectomised boar. At 27 weeks of age the gilts were allocated to one of three treatments, the feeding of Altrenogest (Regumate®, Intervet) in the diet for 18 days, at a rate of 20 mg per day, prior to introduction to the boar shed; an injection of 1000 iu of Serum Gonadotrophin (SG) (Folligon®, Intervet) followed 72 hours later by an injection of 500 iu of Chorionic Gonadotropin (CG) (Chorulon®, Intervet) prior to introduction to the boar shed; and a control group. Gilts were introduced into the boar shed at 29 weeks of age and tested twice daily for the onset of oestrous using the back pressure test in the presence of a boar. Gilts detected in oestrous were inseminated twice, once on the day of detection and again the following day. The results were analysed by ANOVA and are shown in Table 1.

Table 1 Percentage of gilts detected and inseminated after entry to the boar shed and subsequent conception rate.

Treatment	Detected and inseminated within 5 days of entry	Detected and inseminated within 10 days of entry	Detected and inseminated within 15 days of entry	Detected and inseminated within 20 days of entry	Conception %
SG[1]/CG[2]	44[b]	49[a]	50[a]	80[a]	68[a]
Regumate	15[a]	73[b]	75[b]	80[a]	80[a]
Control	32[b]	55[a]	74[b]	85[a]	71[a]
SEM	6	7	6	5	7

[a,b]Means in columns with different superscripts are significantly different (P≤0.05).
[1,2]Treated with serum gonadotrophin (SG)/chorionic gonadotrophin (CG).

The use of Regumate was the most effective treatment in terms of concentrating gilt oestrous activity with 73% of treated gilts cycling within 10 days following cessation of Regumate, compared to 49% and 55% for the SG/CG and Control groups respectively. Neither hormone treatment was any better than the control group in terms of the total percentage of gilts cycling within 20 days of entering the boar shed. There were no significant differences between treatments for the percentage of gilts still in pig at 35 days post mating.

In terms of synchronization of gilts and resources for a successful artificial insemination programme, the use of Regumate does seem to offer potential. Its use however is limited by the cost of providing the single penning to ensure animals ingest their daily dose.

EFFECTS OF INCREASING XYLANASE SUPPLEMENTATION OF DIETS CONTAINING HIGH AND LOW QUALITY WHEATS

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Partridge et al. (1999) showed that exogenous xylanase could maximize growth performance of growing pigs by decreasing the anti-nutritional effects and improving nutritive value of sub-optimal quality wheats. However the recommended dosage of commercial xylanase products have generally not been cost effective for pigs over 20 kg live weight, even when diet specifications were reduced.

To establish the optimum dosage of a heat stable xylanase (Thermomyces spp.), 120 entire male pigs (Bunge commercial genotype) housed in individual pens, were allocated at 27 ± 2.0 kg live weight to 10 treatments. The treatments consisted of two different qualities of wheat, pre-characterized in an earlier growth sudy, and 5 increasing activities of xylanase. The diets contained 13.6 MJ/kg of DE, 0.72 g/MJ DE available lysine and were pelleted at an average temperature of 82oC. Feed and water were offered ad libitum for 35 days. The results for average daily gain (ADG), feed:gain (F:G) and average daily intake (ADI) were measured after 21 and 35 days. The growth performance results for the 0 to 21 day period are shown in Table 1.

Table 1. Effects of exogenous xylanase supplementation of diets on the growth performance of pigs during the 0 to 21 day period.

	Thermomyces xylanase inclusion (g/t)						Effect[1]	
	0	100	200	300	400	SEM	L	Q
High quality wheat								
Average gain (kg/d)	0.885	0.903	0.912	0.913	0.894	0.012	NS	NS
Feed:gain	1.95	1.86	1.85	1.87	1.87	0.020	NS	NS
Average intake (kg/d)	1.711	1.665	1.689	1.702	1.677	0.023	NS	NS
Weight at 21 d (kg)	44.9	45.8	46.2	46.3	45.6	0.516	NS	NS
Low quality wheat								
Average gain (kg/d)	0.798^{b}	0.900^{a}	0.867^{a}	0.927^{a}	0.888^{a}	0.012	*	*
Feed:gain	2.24^{a}	1.92^{b}	1.92^{b}	1.89^{b}	1.93^{b}	0.097	**	**
Average intake (kg/d)	1.778	1.725	1.650	1.772	1.719	0.022	NS	NS
Weight at 21 d (kg)	43.7	45.8	45.5	46.4	45.6	0.540	NS	NS

[1]Linear (L) and quadratic (Q) effect: NS, not significant; *P≤0.05, **P<0.001. ^{a,b}Means in a row with different superscripts are significantly different (P≤0.05).

The high quality wheat produced a superior F:G during the 0 to 21 day period (P=0.003; two way ANOVA), however no significant difference between wheat types was observed after 35 days. Overall, the enzyme improved F:G (P<0.01; two way ANOVA) throughout the experiment. The enzyme had significant linear and quadratic effects on F:G and ADG of pigs offered the low quality wheat (Table 1) and the optimum enzyme dosage was found to be 100 g/t (P≤0.05). There was an interaction between wheat type and enzyme supplementation on F:G (P=0.02) in the 0 to 21 day period.

Responses to low level exogenous xylanase dietary supplementation suggest that the enzyme can be cost effective in enhancing growth performance of growing pigs fed wheat based diets.

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OPTIMUM XYLANASE ACTIVITY IN WHEAT-BASED DIETS FOR PIGS BETWEEN 28 AND 49 DAYS OF AGE

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The optimum exogenous xylanase activity in diets for growing pigs between 70 and 105 days of age has recently been found to be significantly lower than current industry recommendations (Cadogan et al. 2001). Exogenous enzymes are more effective in young pigs (Moughan and Ravindran, 2001), however there is little or no evidence to show that the optimum benefit for weaner pigs occurs at a higher level of enzyme activity than for grower pigs. The current experiment was designed to determine the optimum exogenous xylanase activity in diets for male weaner pigs.

Sixty male pigs (Bunge commercial genotype) were selected between 6.5 and 7.5 kg live weight, placed in individual crates, and offered a common nursery diet for 3 days. Animals were then reweighed and randomly allocated to a wheat-based diet containing five increasing levels (0 to 400 g/t) of a commercial heat stable xylanase (Thermomyces spp.). Pigs were offered diets and water ad libitum for 21 days. The basal diet used in the study was formulated to contain 65% of a medium quality wheat, pre-characterized during an earlier growth study, and highly digestible raw ingredients. The diets were formulated to contain 14.5 MJ DE/kg, 0.85 g available lysine/MJ DE and were pelleted at 80oC. Average daily gain (ADG), feed:gain (F:G) and average daily intake (ADI) were measured at weekly intervals during the 21 day period of the experiment (Table 1).

Table 1. The effects of increasing the amount of xylanase in the diet on the growth performance of male pigs during the 0 to 21 day period.

	Thermomyces xylanase inclusion (g/t)						Effect[1]	
	0	100	200	300	400	SEM	L	Q
Starting weight (kg)	6.20	6.34	6.53	6.16	6.25	0.08	NS	NS
Average gain (g/d)	368^{b}	378^{ab}	376^{ab}	421^{a}	393^{ab}	10.20	NS	*
Feed:gain	1.09	1.10	1.09	1.05	1.06	0.15	NS	NS
Average intake (g/d)	401	415	408	443	415	14.20	NS	NS
21 day weight (kg)	13.93	14.28	14.43	15.00	14.50	0.27	NS	NS

[1]Linear (L) and quadratic (Q) effect: NS, not significant; *P≤0.05. ^{a,b}Means in a row with different superscripts are significantly different ($LSD_{P\leq0.05}$).

There was a significant quadratic effect on ADG during the 0 to 21 day period (Table 1). Animals offered the diet supplemented with 300 g/t of the xylanase exhibited a significantly higher ADG (P=0.042; $LSD_{P\leq0.05}$) than the control diet. The enzyme had no significant effect on F:G or ADI between 0 and 21 days. There was, however, a quadratic effect of the enzyme on ADI and F:G in the final 7 days, and the greatest response to xylanase was produced at 300 g/d.

The results showed the optimum dosage of the exogenous xylanase for male pigs offered the experimental wheat based diets was 300g/t. The significant quadratic effect of the enzyme on growth performance suggests excessive inclusions may reduce the response to exogenous xylanase. The present data also suggests young pigs may require up to a three fold higher level of xylanase in the diet to maximise growth performance compared to pigs over 25 kg live weight (Cadogan *et. al.*, 2001).

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RELATIONSHIP BETWEEN THE QUANTITY AND QUALITY OF CARBOHYDRATES AND THE DIGESTIBLE ENERGY CONTENT OF WHEATS FOR WEANER PIGS

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Both the quantity and the quality of non-starch polysaccharides (NSP) of wheat are known to influence the apparent metabolisable energy (AME) content for broiler chickens (Annison, 1991). The quantity of NSP and composition of the soluble NSP fraction are negatively correlated to the AME value of wheat (Choct and Annison, 1990; Annison, 1991). It is thought that the branching structure of starch (amylopectin) and arabinoxylan (arabinose branching from a xylose backbone), which is the major NSP in wheat, may disturb the close packing between the polysaccharide polymer chains making it more digestible than a less-branched polysaccharide structure (Bacic and Stone, 1981). The aim of this study was to establish correlations between the quantity and quality of carbohydrates and the digestible energy (DE) content of wheats fed to weaner pigs.

Wheat samples (n=11) harvested in 1999/2000 from south-western Australia were used. The experimental diet consisted of 90% wheat and 10% additives (canola oil, vitamin-mineral mix, Celite® as an indigestible marker). The NSP (total, soluble and insoluble) and starch (amylose, amylopectin) content of wheats were analysed 5-7 weeks after harvest and the DE content of each wheat was determined previously (Kim *et al.*, 2001). Pearson's correlation analysis was used to establish relationships between DE and chemical parameters.

Table 1. Linear correlations between carbohydrate composition and digestibility coefficients of dry matter (DC_{DM}), gross energy (DC_E), and digestible energy (DE) content of wheat.

	DC_{DM} (%)	DC_E (%)	DE (MJ/kg as is)
Total Starch	0.423	0.459	0.554
Amylose	-0.526	-0.585	-0.513
Amylopectin	0.579	0.635*	0.673*
Amylose:amylopectin ratio	-0.634*	-0.698*	-0.648*
Soluble-NSP	-0.612*	-0.676*	-0.696*
Soluble-xylose	-0.730*	-0.760**	-0.678*
Soluble-arabinoxylan	-0.624*	-0.592	-0.522
Arabinose:xylose ratio	0.521	0.654*	0.474

*P≤0.05, **P<0.01.

The soluble NSP content, but not the total or insoluble NSP content, of wheat was negatively correlated to the digestibility of dry matter, energy and DE content of wheat (P≤0.05). Amylopectin branching from the amylose backbone of starch was positively correlated (P≤0.05) to digestibility of gross energy and DE content of wheat. Consequently, a significant negative correlation (P≤0.05) was found between the amylose:amylopectin ratio and digestibility parameters, indicating the importance of the chemical structure of starch in the digestion process. Similarly, arabinose branching from the xylose backbone (arabinose:xylose ratio) was positively correlated to digestibility of energy. The results demonstrate the importance of the chemical structure of the carbohydrate fraction for digestion processes in wheat-based diets for weaner pigs.

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CAN A CHANGE IN STARCH CONTENT FOLLOWING STORAGE PREDICT THE CHANGE IN DIGESTIBLE ENERGY CONTENT OF WHEAT FED TO WEANER PIGS?

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Kim *et al.* (2001a) reported a decrease in the amylose ($P \leq 0.01$) and total starch contents ($P=0.075$) of a cohort of south-Western Australian wheats after 7 months storage, suggesting that the available energy content of stored wheat might also have decreased. The aim of this study was to determine the relationship between changes in the carbohydrate composition of these wheats associated with storage and their digestible energy (DE) content for weaner pigs.

Eleven wheat samples representing four different cultivars grown throughout south-western Australia in 1999 were used. Chemical composition and DE content were measured 5-7 weeks after harvest and again seven months later. The grain was stored in sealed, metal-sided bins in a grain shed during this time. Wheat samples were analysed for amylose, amylopectin and non-starch polysaccharide (NSP) content using established techniques. Protein content was also determined. The DE content of each wheat was measured as described previously (Kim *et al.*, 2001b). Analysis of variance was used to test the effect of storage on DE content, and Pearson's correlation analysis was used to determine relationships between changes in chemical composition and DE content.

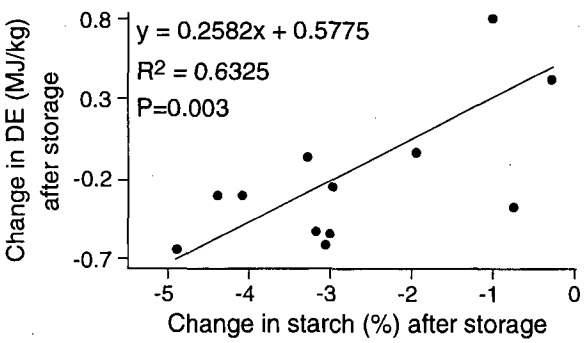

Figure 1. *Relationship between changes in starch content and change in DE content after storage.*

The DE content decreased after storage (13.6 vs 13.3 MJ/kg, $P=0.084$). These data are in contrast to those of Choct and Hughes (1997) who showed an increased energy value of wheats for broilers following 4 months of storage. There was considerable variation, however, in the response of individual wheats to storage. Some wheats showed an increase in DE content (up to 0.8 MJ/kg), while others showed a decrease (up to 0.6 MJ/kg) or remained unchanged (Figure 1). The change in starch content after storage predicted a significant proportion (63%) of the decrease in DE content ($P<0.001$, Figure 1). The change in DE content was not related to the absolute amounts of starch, protein or NSP, nor to the change in protein and NSP contents. These data indicate that weaner pigs derived less DE from certain wheats if they were stored for longer than 6 months. It is not known though whether this difference translates into compromised performance of pigs fed stored wheat.

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EFFECTS OF LIQUID FEEDING AND ADDING PHYTASE TO WHEAT-BASED DIETS ON PERFORMANCE OF WEANER PIGS

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Between 60% and 80% of the total phosphorus (P) in cereals and their by-products is present as phytate-P (Lei and Stahl, 2000). Monogastric animals possess negligible endogenous phytase and do not have the capacity to completely utilise phytate-P (Pallauf and Rimbach, 1997). Since liquid feed provides an ideal medium for endogenous enzyme activation, an opportunity exists to exploit phytate-P in grains through liquid feeding. The hypothesis was that soaking activates endogenous phytase in wheat and its by-products. These enzymes may act on the dietary phytate similarly to exogenous enzymes, breaking up phytate complexes and increasing the availability of P and other bound nutrients.

An experiment was conducted to examine processing (meal vs pelleted), feed form (dry vs liquid) and enzyme (nil vs 100 ppm Natuphos® Phytase, BASF Australia) in a 2 x 2 x 2 factorial design. Ninety-six male, multi-cross pigs, weaned at 27 d, were fed a wheat-based meal diet (55%) containing millrun (10%). The diet was formulated to contain a marginal DE (13.8 MJ DE/kg DM), available lysine (0.75 g/MJ DE) and available phosphorus (4.7 g/kg DM). Liquid diets contained 2.5 l water/kg feed, soaked for 15 h. Results are shown in Table 1. Feed form had a significant influence on feed intake ($P \leq 0.001$) and daily gain ($P=0.008$). Feed:gain ratio was improved through liquid feeding and processing, however, the two effects were not additive. Digestibility data support these findings with increases ($P \leq 0.05$) in DE due to liquid feeding. The feed form x enzyme interaction showed a negative influence of phytase on intake and daily gain for liquid treatments, however no effect was observed in dry diets.

Table 1. Performance of male pigs 0-21 days post-weaning fed wheat-based meal and steam pelleted diets in dry and liquid form with or without phytase supplementation (n=96).

Processing (Pr)	Feed form (F)	Enzyme (E)	Feed intake[1] (g/d)	Feed:gain[1]	Daily gain (g/d)	Faecal DE (MJ/kg DM)
Meal	Dry	-	522^{cd}	1.26^{c}	417^{bc}	14.46^{ab}
Meal	Dry	+	554^{d}	1.29^{bc}	431^{bc}	14.80^{abc}
Meal	Liquid	-	440^{ab}	1.10^{a}	400^{bc}	15.16^{c}
Meal	Liquid	+	396^{a}	1.23^{bc}	324^{a}	14.96^{c}
Steam pellet	Dry	-	443^{abc}	1.15^{ab}	387^{ab}	14.36^{a}
Steam pellet	Dry	+	503^{bcd}	1.12^{a}	453^{c}	15.13^{c}
Steam pellet	Liquid	-	461^{abc}	1.16^{ab}	402^{bc}	15.16^{c}
Steam pellet	Liquid	+	422^{a}	1.11^{a}	379^{ab}	15.05^{c}
Pr			P=0.281	P=0.001	P=0.468	P=0.535
F			P≤0.001	P=0.027	P=0.008	P=0.952
E			P=0.907	P=0.359	P=0.784	P=0.223
Pr x F			P=0.021	P=0.022	P=0.348	P=0.339
Pr x E			P=0.655	P=0.013	P=0.123	P=0.212
F x E			P=0.021	P=0.396	P=0.010	P=0.937

[a,b,c,d]Means in a column with different superscripts differ significantly ($P \leq 0.05$). [1]100% DM.

Liquid feeding can improve feed conversion of meal diets based on wheat and by products for weaner pigs. There was no additive benefit of pelleting diets to be fed in liquid form. The negative effect of phytase in liquid diets for feed intake, daily gain and feed:gain ratio warrants further investigation.

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EFFECTS OF LIQUID FEEDING AND ADDING XYLANASE TO WHEAT-BASED DIETS ON PERFORMANCE OF WEANER PIGS

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Liquid feed provides a medium for activating endogenous enzymes in cereal grains, enhancing nutrient availability in diets (Brooks *et al.*, 1996). Offering diets in a liquid meal rather than the conventional dry steam pellet can reduce the cost of feed through less feed wastage, milling costs and dust linked to feeding dry meal. Liquid feed also gives more flexibility in controlling and adding new ingredients to diets for weaners. The hypothesis was that steeping meal diets can activate enzymes present in, and added to, wheat-based diets. Enzymic activation could lead to increased nutrient availability and improved performance while reducing milling costs.

The experiment used processing (Pr, meal vs steam pellet), feed form (F, dry vs liquid) and xylanase (E, 0 and 300ppm Biofeed Wheat®, Roche Australia) in a 2 x 2 x 2 factorial design. Ninety-six male, multi-cross pigs weaned at 27 d, were fed a wheat-based (55%) meal diet containing millrun (10%). The diet was formulated to contain a marginal DE (13.8 MJ DE/kg DM) and available lysine (0.75 g/MJ DE). Liquid diets contained 2.5 l water/kg feed, soaked for 15 h.

Results are shown in Table 1. Feed intake was lower (P=0.039) and feed:gain ratio was more efficient (P=0.038) for liquid vs dry treatments. There was a strong tendency towards an interaction (P=0.056) between Pr x E for daily gain. Enzyme had no effect in dry meal diets, though it depressed daily gain in liquid. In steam pelleted diets daily gain increased following enzyme supplementation regardless of feed form. Liquid meal diets were more efficiently used (P=0.004) than dry diets.

Table 1. Performance of male pigs 0-21 days post-weaning fed wheat-based meal and steam pelleted diets in dry and liquid form with or without xylanase supplementation (n=96).

Processing (Pr)	Feed form (F)	Enzyme (E)	Feed intake[1] (g/d)	Feed:gain[1]	Daily gain (g/d)	Faecal DE (MJ/kg DM)
Meal	Dry	-	521^{b}	1.25^{b}	419^{ab}	14.46^{a}
Meal	Dry	+	500^{b}	1.23^{b}	411^{ab}	14.47^{a}
Meal	Liquid	-	440^{ab}	1.10^{a}	401^{ab}	15.17^{a}
Meal	Liquid	+	424^{a}	1.11^{a}	389^{a}	14.91^{a}
Steam pellet	Dry	-	443^{ab}	1.16^{ab}	385^{a}	14.52^{a}
Steam pellet	Dry	+	513^{b}	1.08^{a}	471^{b}	14.96^{a}
Steam pellet	Liquid	-	461^{ab}	1.16^{ab}	402^{ab}	13.80^{a}
Steam pellet	Liquid	+	484^{ab}	1.13^{a}	437^{ab}	14.43^{a}
Pr			P=0.812	P=0.133	P=0.286	P=0.380
F			P=0.039	P=0.038	P=0.456	P=0.937
E			P=0.470	P=0.269	P=0.158	P=0.614
Pr x F			P=0.070	P=0.004	P=0.759	P=0.119
Pr x E			P=0.105	P=0.401	P=0.056	P=0.383
F x E			P=0.611	P=0.493	P=0.460	P=0.973

^{a,b}Means within a column different superscripts differ significantly (P≤0.05). [1]100% DM.

In summary, liquid feeding meal can significantly improve feed efficiency of weaner diets based on wheat and its by-products. The results also suggest that liquid feeding could also reduce diet costs by increasing the nutrient digestibility of wheat by-products and negating the requirement to steam pellet diets.

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FAST DIGESTIBLE STARCH CONTENT AS A MEASURE OF AVAILABLE ENERGY IN BARLEY FED TO PIGS AND POULTRY

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The nutritional quality of cereals for both pigs and poultry varies significantly (Hughes and Choct 1999; van Barneveld, 1999). Moran (1982) and van Barneveld (1999) suggested that the composition and structure of starch in feed grains affects their respective digestibility and nutritional value for different classes of livestock. The aim of this experiment was to develop a rapid *in vitro* technique for the measurement of digestible starch in barley and to assess the potential of this fast digestible starch (FDS) assay to predict the digestible energy (DE) content and apparent metabolisable energy (AME) content of barley for pigs and poultry, respectively.

The FDS index of 11 barley samples was determined by calculating the amount of FDS as a proportion of the total starch content. The FDS content of each grain was determined in duplicate using a modification of the Megazyme™ assay based on AOAC-996.11 (1995) to determine the total starch content of barley grains. Modifications were based on a preliminary 3 x 3 factorial *in vitro* experiment undertaken to select the optimal combination of temperature, time and enzyme concentration for FDS measurements. For all the barley samples DE and AME were determined using total faeces collection procedures with growing pigs and broiler chickens, respectively. The relationship between DE and AME, and the FDS index was determined using simple linear regression analysis.

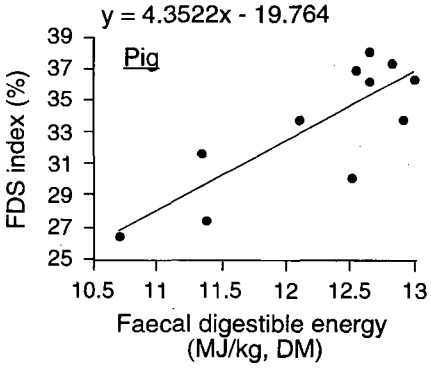

Figure 1. *Correlation between the fast digestible starch index (FDS) index and DE of barley in pigs (R^2=0.67, P=0.002).*

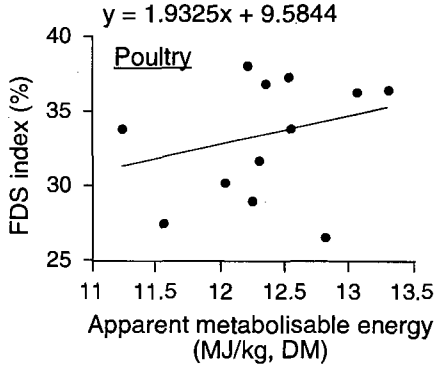

Figure 2. *Correlation between the fast digestible starch index (FDS) index and AME of barley in poultry R^2=0.085, P=0.384).*

Linear regression analysis revealed that the FDS index was significantly correlated (P=0.002) with the DE values in pigs (Figure 1) but not with the AME values in poultry (P>0.05) (Figure 2). This strong correlation (r^2=0.67) with DE in barley for pigs suggests that the FDS index may have some potential as a rapid means of assessing nutritional quality. However, further research may be required to refine the assay so the relationship with DE is improved and the reliability of the assay enhanced. The results also suggests that enzyme access to starch granules in pigs influences the DE values of the grain.

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COMMON VETCH (*VICIA SATIVA* CV. MORAVA) IS AN ALTERNATIVE PROTEIN SOURCE FOR GROWER PIGS

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Common vetch is a winter growing pulse that is grown in the Mallee region of Australia as a break crop in cereal production. Although over 200,000 hectares were planted to vetch in 2000, only a small proportion was harvested as grain. The nutritional components in the seed suggests that vetch has potential as a valuable ingredient in pig diets. This experiment examined the growth responses of pigs grown from 66 to 101 days of age to graded levels of dietary vetch (*Vicia sativa* cv. Morava).

Thirty-six male crossbred pigs were allocated at a mean (± SE) age of 66.2 ± 0.4 days and a mean (± SE) live weight of 25.7 ± 0.5 kg to six diets containing 0, 50, 100, 150, 200 and 250 g/kg common vetch for the subsequent 35 days. Vetch replaced peas on a 1:1 basis with the level of the other protein sources remaining the same across the diets. All diets contained 14.3 MJ DE/kg and 12.3 g lysine/kg by manipulation of the levels of tallow and synthetic amino acids and diets were offered *ad libitum* to all pigs. Data were subjected to analysis of variance for treatment effects in a randomised block design.

Vetch contained 284 g crude protein/kg, 17.7 g lysine/kg and 2.6 g methionine/kg. There were no significant differences in growth rate, feed conversion ratio or feed intake of pigs offered diets containing up to 250 g/kg of vetch (Table 1). Furthermore there was no evidence of any significant linear or quadratic response to the level of vetch. However, there was a significant linear response in feed intake to increased level of dietary vetch between 66 and 87 days of age, such that, as the level of vetch (V, g/kg) increased, feed intake (FI, kg/d) decreased, particularly during the early part of the period; FI = 2.119 ±0.0148 – 0.00097 ±0.00010V, (R^2=0.96, P<0.001). Reductions in feed intake of up to 10% have been observed in broiler chickens (Johnson and Eason, 1991) and pigs (van Barneveld *et al.*, 1997) in response to 150 to 200 g/kg *Vicia sativa* cv. Blanchefleur. However, van Barneveld *et al.* (1997) concluded that Blanchefleur had some potential for inclusion in finisher pig diets up to a level of 140 g/kg.

Table 1. The effect of common vetch (*Vicia sativa* cv. Morava) on the growth performance of grower pigs between 66 and 101 days of age.

	Vetch content (g/kg)						
	0	50	100	150	200	250	SED[1]
Daily gain (g)	1028	933	950	938	962	957	48
Feed intake (kg/d)	2.27	2.18	2.21	2.12	2.10	2.08	0.09
Feed:gain	2.22	2.34	2.34	2.28	2.19	2.18	0.10

[1]SED, Standard error difference.

The results of this growth study indicate that common vetch (*Vicia sativa* cv. Morava) may affect voluntary feed intake but it could be safely included at levels up to 250 g/kg in diets offered *ad libitum* to growing pigs between 66 and 101 days of age. It appeared that while initial voluntary feed intake was depressed at the higher dietary levels of vetch, pigs soon became accustomed to these higher levels, such that overall growth performance was not adversely affected.

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APPARENT ILEAL NUTRIENT DIGESTIBILITY OF PRE-PRESS SOLVENT EXTRACTED COTTONSEED MEALS FED TO PIGS

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Cottonseed meal is a valuable nutrient source for livestock and is usually derived from one of three oil extraction procedures – continuous screw-pressing, pre-press solvent extraction or direct solvent extraction (Tanksley, 1990). Pre-press solvent extraction is a common processing method for oilseeds in China, and while this procedure results in low amounts of residual lipid and free gossypol and high protein quality through reduced heat damage, precise manufacturing conditions must be maintained for this to be accomplished. Cottonseed meal (CSM) production is second only to soya bean meal production in China, the top six production regions being the Xinjiang, Henan, Hebei, Shandong, Hunan and Hubei provinces. Despite similar oil extraction processes, each province grows cotton varieties best suited to the local environmental conditions, hence introducing a potential source of variation among meals. The aim of this experiment was to assess the apparent ileal digestibility of dry matter, crude protein and lysine in cottonseed meals.

Six Chinese provinces each provided samples of cottonseed meals, which were derived following pre-press solvent extraction using the same make of equipment. Hence any differences will be due to operation of the equipment and/or the source of cottonseed. Diets used to determine apparent ileal digestibility of nutrients were starch based and contained between 344-386 g/kg of cottonseed meal as the sole protein source to equalise dietary protein content at 167.5 g/kg. Chromic oxide was added to the diets as an indigestible marker. Six Large White x Landrace x Duroc barrows (31 kg live weight) fitted with simple T-piece ileal cannulas were provided diets based on a 6 x 6 Latin square design. Diets were fed restrictively for 6 d prior to digesta collections over 2 consecutive days.

Table 1. Apparent ileal digestibility of dry matter, crude protein and lysine and free gossypol content in samples of pre-press solvent extracted cottonseed meals.

		Apparent ileal digestibility (Proportion of total)		
Sample	Gossypol (ppm)	Dry matter	Crude protein	Lysine
Province of origin				
Hubei	244	0.71^{ab}	0.72^{ab}	0.59^{ab}
Hunan	201	0.68^{a}	0.74^{bc}	0.61^{b}
Shandong	190	0.68^{a}	0.70^{a}	0.60^{b}
Hebei	360	0.74^{b}	0.78^{d}	0.61^{b}
Henan	253	0.75^{b}	0.75^{c}	0.55^{a}
Xinjiang	399	0.69^{a}	0.69^{a}	0.54^{a}
Statistics				
SEM[1]		0.013	0.009	0.014
P value		0.001	<0.001	0.005

[1]SEM, Standard error of mean. ^{a,b,c,d}Values in a column with different superscripts differ significantly ($P \leq 0.05$).

Free gossypol content of all meals was at the lower end of the range (0.01-0.5% free gossypol in CSM) and was unrelated to the ileal digestibility of dry matter, protein or lysine (Table 1). Despite a significantly higher dry matter and protein digestibility than most other samples, cottonseed meal produced in Henan province had a significantly lower lysine digestibility suggesting heat damage during oil extraction. Cottonseed meal quality varies among the provinces of origin in China. Further research is required to establish whether routine assessment of quality is required prior to pig diet formulation.

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POTENTIAL FOR SWEET POTATO AS A LIQUID FEED INGREDIENT FOR WEANER PIGS

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Sweet potato is an important human food crop due to its high starch content (80-90%) and it is grown widely in northern Australia and Asia. The high starch content of the tuber is consistent with low levels of protein, fat and fibre, however, analysis reveals it could be a useful source of ascorbic acid, thiamine, riboflavin and niacin. With increasing interest in liquid feeding in Australia, the objective of this experiment was to assess the potential of sweet potato as a liquid feed ingredient for weaner pigs, 8-17 kg live weight.

Thirty commercial genotype male pigs with a live weight of 8.0 ± 0.48 kg (mean ± SD) were housed in individual pens and allocated to one of three dietary treatments based on a randomised block design and 10 pigs/treatment. A control diet was formulated to contain 40% triticale and a diet balancer to supply 14.7 MJ/kg of digestible energy (DE) and 0.9 g available lysine/MJ DE. Test diets contained either 20% or 40% sweet potato at the expense of triticale. Uncooked sweet potato was mashed using an industrial blender prior to addition. All diets were liquid fed at a 2.5:1 water to dry feed ratio. Sweet potato dry matter varied between 250-300 g/kg, hence additional water was not added to this component of the diet. Pigs were fed *ad libitum* with free access to additional water for a period of 18 days.

Table 1. Performance of pigs (initial weight 8.0 kg ± 0.48, mean ± SD) fed diets containing 0, 20 or 40% uncooked sweet potato (SP) for 18 days.

	Treatment			Statistics	
Performance variable	Control	20% SP	40% SP	SEM[2]	P[1]
0-7 d					
Live weight gain (g/d)	292	270	221	25.0	NS
Feed conversion ratio[3]	0.90	0.93	1.09	0.141	NS
Feed intake (g/d)	253[a]	221[b]	209[b]	9.0	**
7-14 d					
Live weight gain (g/d)	581[a]	490[b]	384[c]	27.0	***
Feed conversion ratio[3]	0.90[a]	0.91[a]	1.16[b]	0.059	**
Feed intake (g/d)	517[a]	440[b]	421[b]	15.0	***
14-18 d					
Live weight gain (g/d)	614	510	503	42.0	NS
Feed conversion ratio[3]	1.13	1.22	1.31	0.166	NS
Feed intake (g/d)	688[a]	561[b]	570[b]	27.0	**
0-18 d					
Live weight gain (g/d)	476[a]	409[b]	347[c]	20.0	***
Feed conversion ratio[3]	0.96[a]	0.94[a]	1.11[b]	0.041	*
Feed intake (g/d)	452[a]	382[b]	372[b]	13.0	***

[1]NS, not significant; *P≤0.05; **P<0.01; ***P<0.001. [2]SEM, Standard error of mean. [3]Dry matter intake/live weight gain. [a,b,c]Values in a row with different superscripts differ significantly.

Feed intake over the entire experimental period was significantly (P<0.001) reduced in pigs fed the sweet potato treatments, with a depression evident as early as 7 d and no improvement relative to the control over time (Table 1). Depressed growth rate and feed conversion ratio are most likely due to poor starch digestibility consistent with uncooked sweet potato and depressed feed intake. In conjunction with a short shelf life, these results suggest that there is limited potential for uncooked sweet potato as a liquid feed ingredient for weaner pigs. Cooking sweet potato prior to feeding may improve intake and digestibility, but is unlikely to be cost-effective.

THE EFFECT OF AN ESSENTIAL OIL BLEND ON THE PERFORMANCE OF FINISHING PIGS

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CRINA is a blend of essential oils designed to have beneficial effects on the digestive function in pigs. The present experiment was designed to investigate the effects of CRINA on the apparent availability or metabolism of dietary protein and energy. The effect was measured as the growth performance of pigs offered diets ranging from deficient to adequate in amino acid but maintaining a constant digestible energy level.

One hundred entire male and 100 female pigs (Bunge commercial genotype, 80 kg initial live weight) in a 2 x 2 x 5 factorial experiment (Table 1) were offered the experimental diets ad libitum for 28 days. Available lysine content was 0.35, 0.40, 0.45, 0.50 and 0.55 g/MJ DE in the five different diets. All the diets were formulated at 13.6 MJ digestible energy (DE) and the contents of CRINA are shown in Table 1. Average daily gain (ADG), average daily intake (ADI), feed:gain (F:G) and blood urea nitrogen (BUN) were measured after 28 days.

Table 1. Effect of feeding different dietary levels of available lysine and CRINA for 28 days on the performance and blood urea N of finishing pigs (80 kg initial live weight).

AL[1] (g/MJ DE)	CRINA (ppm)	Final mass (kg)	Daily gain (g)	Feed intake (kg/d)	Feed:gain	BUN[2] (mol/l)
0.35	0	108.9	1011	3.003	3.03	3.6
0.35	75	109.9	1042	3.176	3.10	3.7
0.40	0	108.5	993	2.940	2.99	3.7
0.40	75	110.1	1044	2.923	2.84	4.0
0.45	0	110.1	1050	3.031	2.95	3.6
0.45	75	110.9	1074	2.966	2.81	4.1
0.50	0	109.4	1033	2.936	2.91	3.8
0.50	75	109.7	1048	2.952	2.83	4.2
0.55	0	110.8	1068	2.939	2.84	4.2
0.55	75	110.0	1039	2.841	2.82	4.3
Significance (two way analysis)[3]						
Lysine (L)		NS	NS	NS	<0.01	NS
CRINA (C)		NS	NS	NS	NS	NS
Sex (S)		<0.01	NS	NS	<0.01	NS
L x C		NS	NS	NS	NS	NS
L x S		NS	NS	NS	<0.01	NS
C x S		NS	NS	NS	0.05	NS

[1]AL, available lysine. [2]BUN, blood urea nitrogen. [3]NS, not significant (P>0.05).

Increasing the available lysine content of the diet significantly improved F:G. CRINA significantly improved F:G in females, but had no influence on the F:G of the males (C x S, P=0.05). Males responded significantly in F:G to increasing levels of available lysine, whereas females did not (L x S, P=0.039). Thus, it seems that the requirement of available lysine of males was at least 0.55 g/MJ DE. Blood urea nitrogen (BUN) was not significantly affected by the treatments. There were no significant interactions between available lysine and CRINA. This indicates CRINA improved F:G by increasing the availability of energy rather than essential amino acids. The results suggest the essential oil additive can improve the F:G of presale pigs significantly, particularly when the energy to protein ratio is optimized.

THE EFFECTS OF AN ESSENTIAL OIL BLEND ON THE PERFORMANCE AND CARCASS CHARACTERISTICS OF FINISHING PIGS

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The feed additive CRINA for pigs and sows® (patented by AKZO NOBEL) is a blend of compounds of ether extractable "essential oils", selected for their effects on digestibility, and gut health and integrity (Losa and Williams, 2001). The present experiment was designed to test the hypothesis that CRINA® improves digestibility of nutrients resulting in improved growth performance and carcass quality in finishing pigs.

The pigs (Large White x Landrace (AusGene) crossed to a PIC 337 boar), average age 146 days, were offered a commercial finisher diet *ad libitum* with or without 75 ppm of CRINA®, during the last five weeks of production. The dietary treatment was randomly allocated to eight pens of gilts and eight pens of barrows (18 pigs/pen; in total 288 pigs) by sex and treatment in a 2 x 2 factorial experiment at the Burton Russell Research Farm, Frankfort, Indiana, USA. Fat and loin depth were measured at 65 mm from the midline at the level of the 10th rib; lean (%) was calculated from fat and loin depths using the Iowa Beef Packer (IBP) equation. Initial live weights (mean ± SD) of gilts and barrows were 100.8 ± 5.1 and 100.5 ± 6.9 kg, and final weights 125.3 ± 3.7 and 122.9 ± 5.6 kg respectively.

The feed additive CRINA® significantly improved daily weight gain of all pigs but the improvements in feed intake and feed to gain ratio were not significant (Table 1). Improved growth performance was due mainly to barrows; the response in gilts was not significant. There was a marginal reduction in fat depth and a marginal increase in the lean fraction of the carcass in favour of the pigs provided with CRINA® but at no times were the differences significant.

Table 1. Growth performance.

n=16	Control	CRINA®	P
All pigs			
Weight gain (kg/d)	0.744	0.826	0.03
Feed intake (kg/d)	2.735	2.880	0.10
Feed/gain	3.68	3.49	0.10
Barrows			
Weight gain (kg/d)	0.730	0.848	0.02
Feed intake (kg/d)	2.794	3.062	0.04
Feed/gain	3.86	3.60	0.11
Gilts			
Weight gain (kg/d)	0.762	0.803	0.41
Feed intake (kg/d)	2.672	2.703	0.78
Feed/gain	3.50	3.38	0.45

Table 2. Carcass quality.

n=16	Control	CRINA®	P
All pigs			
Fat depth, mm	21.3	20.1	0.12
Loin depth, mm	67.6	68.3	0.47
Lean, %	54.3	54.6	0.14
Yield, %	75.3	75.2	0.91
Barrows			
Fat depth, mm	22.6	21.3	0.22
Loin depth, mm	66.0	67.3	0.37
Lean, %	53.7	54.2	0.22
Yield, %	75.2	74.5	0.48
Gilts			
Fat depth, mm	20.1	19.1	0.30
Loin depth, mm	69.1	69.1	0.87
Lean, %	54.8	55.1	0.38
Yield, %	75.4	75.9	0.59

The use of CRINA® during the last five weeks of production improved daily weight gain of finishing pigs. Indeed, it appeared to stimulate feed intake and probably improved nutrient digestibility and/or availability since the feed to gain ratio tended to decrease. These effects were predominant in barrows. Due to the small differences, none of the carcass quality parameters reached statistical significance. Overall, the use of CRINA® appears advantageous but the exact mechanism or conditions under which it is most effective requires further study.

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INCLUSION OF COLOSTRUM POWDER AND BOVINE PLASMA IN STARTER DIETS INCREASES VOLUNTARY FEED INTAKE

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The use of spray-dried plasma in diets for weaner pigs generally results in an improvement in voluntary feed intake and growth rate, which has been linked to the immunoglobulin (Ig) fraction of plasma (Gatnau *et al.*, 1995). Use of an Ig-rich colostrum powder in starter diets has shown similar improvements in performance (Pluske *et al.*, 1999). The aim of this study was to compare the performance of weaner piglets offered starter diets containing spray-dried colostrum powder and spray-dried plasma.

The study used 330, 28 day old PIC 231x22 pigs (7.4 ± 0.09 kg live weight), and was conducted on a 280-sow commercial piggery. Piglets were blocked at weaning by litter of birth and live weight, and randomly allocated to one of three wheat-based starter diets: CON (Control), BP and CP. Diets BP and CP contained 6% spray-dried bovine plasma (AP820™, Proliant Inc., USA) and 6% spray-dried bovine colostrum powder (Immulac™, NZ Dairy Group, NZ), respectively, which replaced skim milk powder on an isolysine basis. Diets were formulated to contain 15 MJ DE/kg, 1.7% total lysine, and 12.5% lactose. Pigs were housed in environmentally-controlled weaner rooms, and were offered the experimental diets *ad libitum* for 7 days after weaning, after which time all pigs received the CON diet for a further 7 days. Feed intake and weight gain were measured weekly on a pen basis. Data were analysed using the GLM procedure of SAS.

Table 1. Performance of piglets offered a control diet (CON) with the addition of spray-dried bovine plasma (BP) or spray-dried bovine colostrum powder (CP) from day 1-7 after weaning, followed by the control diet from day 8-14 (least square means, LSM).

	Diet				Diet
	CON	BP	CP	SEM	P-value
Average gain, day 1-7 (g/d)	201	228	240	17	0.34
Average food intake, day 1-7 (g/d)	209[a]	246[ab]	261[b]	13	0.06
Average gain, day 8-14 (g/d)	407	408	428	28	0.84
Average food intake, day 8-14 (g/d)	479	478	489	36	0.97
Feed:gain, day 0-14	1.14	1.14	1.12	0.04	0.90

[a,b]LSM with different superscripts are significantly different (P≤0.05, LSD).

Pigs offered diets BP and CP ate 18% and 25% more from day 1-7 than those offered CON (P=0.09 and P=0.02, respectively). The ADG of pigs offered diets BP and CP was 13% and 19% higher from day 1-7 than that of pigs offered CON (Table 1), although these differences were not statistically significant (P=0.34 and P=0.15, respectively). Feed conversion ratio was unaffected by diet, and pigs in all treatments showed similar performance during the second week after weaning. These results suggest spray-dried bovine colostrum powder can enhance post-weaning performance in a similar fashion to spray-dried bovine plasma.

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RESPONSE OF PIGS TO OXYGEN ACTIVATED CHALK INCLUSION IN GROWER-FINISHER DIETS

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It has been demonstrated that feeding pigs a diet containing oxygen activated chalk (OAC) powder (BioActive®) improves feed conversion efficiency, improves the immune system, and reduces the level of ammonia in the pig sheds (Weber, 2001; Weber *et al.*, 2001). The aim of this study was to examine the growth performance of pigs from 14 to 100 kg live weight (LW) when fed diets containing OAC powder.

Two hundred Large White x Landrace pigs (49 ± 4 days of age; mean ± SE) were allocated at 14.7 ± 0.14 kg LW to a 2 x 2 factorial experiment involving two sexes (male and female) and two levels of dietary OAC powder (0 g/t or 300 g/t). Ten replicate pens were used, with 10 pigs per pen. A weaner diet (15 MJ DE/kg, 1.2 g available lysine/MJ DE) was fed from 14 to 30 kg LW. A grower diet (14.0 MJ DE/kg, 0.72 g available lysine/MJ DE) was fed from 30 to 65 kg LW. From 65 kg LW (day 56 of study) the female pigs were fed a diet containing 12.8 MJ DE/kg, 0.54 g available lysine/MJ DE, and the males were fed a diet containing 13.2 MJ DE/kg, 0.56 g available lysine/MJ DE. The diets were pelleted and offered *ad libitum*. The pigs were slaughtered at 140 ± 4 days of age.

Table 1. Least Square means (± SE) for weight at start (kg), weight at day 56, total weight gain (kg), average daily gain (ADG; g), feed intake (kg), feed conversion ratio (FCR) for the 91 days of feeding, and carcass weight (kg), and backfat depth at P2 (mm) at slaughter.

Parameter	Control diets		OAC[1] diets		Statistics	
	Male	Female	Male	Female	SE	P values
Weight at start (kg)	14.9	14.8	14.9	14.8	0.27	0.87
Weight at day 56	66.9	65.1	65.9	66.2	1.05	0.97
Weight gain (kg)	80.6^{a,b}	78.3^{b}	83.3^{a}	80.7^{a,b}	0.78	0.01
ADG (g)	885.7^{a}	860.8^{b}	915.5^{c}	886.7^{a}	10.2	0.01
Feed intake (kg)	201.4^{a}	196.5^{b}	188.3^{b}	189.6^{b}	23.1	0.25
FCR	2.49^{a}	2.50^{a}	2.26^{b}	2.34^{b}	0.1	0.01
Carcass weight (kg)	73.5^{a}	73.4^{a}	76.9^{b}	75.2^{a,b}	1.04	0.02
Backfat P2 (mm)	12.8	12.7	12.8	13.0	0.16	0.91

[1]OAC diets contained oxygen activated chalk powder at 300 g/t. ^{a,b,c}Values within rows with different superscripts differ significantly (P≤0.05).

The pigs fed the diets containing OAC powder had a lower (P=0.01) FCR than the control pigs (Table 1). The FCR was approximately 9% lower for male pigs fed OAC, and 7% lower for the female pigs compared with their respective controls. The FCR results from this study were similar to the 8% improvement reported by Weber *et al.* (2001) for pigs fed diets containing OAC.

Both the male and female pigs fed the OAC diets grew faster (P=0.01) than their respective sexes in the control group. The OAC fed males were had the heaviest carcass (P=0.01), however, carcass weights of the control male and female pigs, and the OAC females were similar. It is not clear why the diet containing the OAC powder had such an effect on FCR. Further studies are required to gain an understanding of the process by which OAC powder works in the pig.

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RELATIONSHIPS BETWEEN DIETARY FIBRE CONTENT AND DRY MATTER INTAKE OF PIGS AFTER WEANING

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The pathways that control appetite in the weaned pig are not understood, but involve complex interactions between signals originating from different body organs and diverse regions of the brain. Several gut-derived hormones, such as glucagon-like peptide-1 (GLP-1), have been suggested as candidates for appetite control, with elevated concentrations of GLP-1 decreasing food intake (Gunn *et al.*, 1997). Fermentation of dietary fibre (DF) in the ileum and large intestine is thought to enhance GLP-1 release (Tappenden *et al.*, 1996; Reimer *et al.*, 1997). The aim of this experiment was to examine the influence of dietary DF content on voluntary food intake and fermentation indices in weaner pigs, where low food intake is a major production problem.

Thirty male (Large White x Landrace) pigs aged 26-29 days and weighing 5.6 ± 0.18 kg (mean ± SE) were allocated in a completely randomised design to receive one of five diets. These were: (i) cooked white rice (R) plus an animal protein supplement (R+AP); (ii) R+HiMaize® (high-amylose corn starch; Starch Australasia Ltd.); (iii) R+Lupin isolate; (iv) R+HiMaize®+Lupin isolate; and (v) weaner diet based on wheat (45.9%), barley (20%), lupins (15%), and animal protein sources (15%). All diets contained similar levels of calculated digestible energy (14.1 MJ/kg) and available lysine (0.8 g/MJ DE). Measured total DF levels (AOAC 991.43, 1995) were 53, 110, 229, 171 and 282 g/kg dry matter for diets (i) to (v), respectively. Pigs were fed on an *ad libitum* basis for 14 days. On the final day pigs were euthanased, and weights and samples were collected. Data were analysed by one-way analysis of variance and regression. Dry matter intake (DMI) was calculated for all diets.

Table 1. Dry matter intake (DMI) and indices of fermentation in pigs fed rice based (R+) or a control diet for 14 days after weaning.

Diet	DMI (g/d)	Caecum (grams)	Colon (grams)	VFA[1] pool in caecum	VFA[1] pool in colon
R+Animal protein	623[a]	28	152[a]	7.9	19.0[a]
R+HiMaize	559[ab]	31	196[bc]	17.8	44.4[b]
R+Lupin isolate	516[abc]	30	226[c]	14.6	44.6[b]
R+HiMaize®+Lupin isolate	421[c]	28	173[ab]	11.8	27.4[ac]
Weaner diet	468[bc]	36	198[bc]	11.1	35.5[bc]
SED[2]	74.1	4.4	24.0	3.77	6.64
P-value	0.037	0.241	0.027	0.064	<0.001

[1]VFA, Volatile fatty acids (mmol). [2]SED, Standard error of difference. [a,b,c]Means in the same column with different superscripts differ significantly (P≤0.05).

Pigs offered R+HiMaize®+Lupin isolate and the Weaner diet ate less (P=0.037) dry matter than pigs offered diet R+AP. Pigs fed diet R+AP had the lowest colon weight and colon VFA pool (P≤0.05). No relationships were found between DMI and the indices of fermentation. However, there was a tendency for total DF content to explain a proportion of the decrease in DMI after weaning (R^2=0.513, P=0.173). These data suggest that the DF content of the diet might influence food intake after weaning. Gut-derived hormones such as GLP-1 may mediate food intake through processes such as gastric emptying.

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EXTRACT VISCOSITY MEASUREMENTS VARY IN BARLEY SAMPLES OBTAINED FROM AUSTRALIA AND OVERSEAS AND MAY INFLUENCE ENERGY DIGESTION IN PIGS

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Acid extract viscosity and slow profile viscosity extract have been shown to account for up to 17% of variation in the ileal digestible energy (DE) content and up to 10% of the faecal DE content of Australian barley samples, respectively, assessed using stepwise regression analysis (van Barneveld *et al.*, 2001). In this study, van Barneveld *et al.* (2001) demonstrated that an acid extract viscosity range of 3.2-12.3 centipoise (cP) corresponded with a range in ileal DE of 7.7-11.3 MJ/kg, but the correlation between the two was poor (R^2=0.019). However, when combined with measurements of barley arabinoxylan content, 85% of the variation in ileal DE content was accounted for. These results suggest that both the non-starch polysaccharide content and composition influence the digestion of energy in the small intestine of the pig, assuming extract viscosity measurements reflect properties such as polysaccharide chain length. Consequently, extract viscosity measurements of cereals may contribute significantly to the prediction of ileal and faecal DE in pigs when combined with measurements of specific non-starch polysaccharides. The potential significance of barley extract viscosity measurements in the prediction of the ileal and faecal DE content can be established by examining the range in values obtained from the measurement of barley samples obtained from Australia and overseas over a period of three years.

Extract viscosity measurements were based on a method described by Bedford *et al.* (1993). This is a two-stage procedure designed to measure the viscosity of feed or grain by simulating conditions found during digestion in a chicken. Measurements were completed on a total of 1439 samples (Table 1).

Table 1. Range in barley extract viscosity measurements (cP) on samples obtained from both Australian and overseas sources.

Source and year	N	Minimum	Maximum	Mean	SD[1]
Australia					
1999	12	10.95	278.50	112.88	92.69
International					
1998	529	2.50	>1000.00	48.27	98.86
1999	478	3.07	>1000.00	111.37	103.52
2000	420	6.95	>1000.00	110.51	-

[1]SD, standard deviation.

Mean values were consistent across years regardless of barley source, as was the range in measurements (Table 1). Measurement range increased with the number of samples measured, hence it is important to establish the influence of measurement error on variation in barley extract viscosity, before including this parameter in an estimate of ileal and faecal DE.

The relationship between barley extract viscosity measurements, specific non-starch polysaccharide measurements and ileal and faecal DE in pigs needs to be further defined before the potential of this analysis as a contributor to the rapid prediction of DE can be assessed. This relationship may also provide a basis for the application of exogenous enzymes in pig production systems where barley is the predominant grain in the diet.

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DIGESTIBLE ENERGY CONTENT OF WHEAT, BARLEY AND TRITICALE SAMPLES MEASURED USING NEAR INFRA-RED SPECTROPHOTOMETRY BETWEEN 1997-2001

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Near infra-red spectrophotometry (NIRS) calibrations have been developed for the analysis of digestible energy (DE) in cereals fed to pigs to within an accuracy of 0.38 MJ/kg, as received (van Barneveld *et al.*, 1999). The aim of this paper was to collate results arising from NIRS analysis of wheat, barley and triticale submitted from across Australia between 1997 and 2001 to assess the range in estimates and variation in the mean for each grain over 5 distinct seasons.

Wheat, barley and triticale samples were ground using a 1 mm screen prior to scanning using an NIRSystems model 6500 spectrophotometer in reflectance mode. Digestible energy was predicted using global calibrations described by van Barneveld *et al.* (1999) for milled samples. For each cereal type, a separate analysis of variance was performed to compare years and account for differences in sample numbers among years (Table 1).

Table 1. Range in the digestible energy content (MJ/kg, as received) of wheat, barley and triticale samples measured using near infra-red spectrophotometry between 1997-2001.

Cereal type and year	n	Minimum	Maximum	Mean	SD[1]
Wheat					
1997	17	14.0	14.2	14.1[b]	0.06
1998	65	12.6	14.3	14.1[b]	0.20
1999	210	12.3	14.6	13.7[a]	0.39
2000	50	13.5	14.7	14.0[b]	0.24
2001	36	13.9	14.8	14.5[c]	0.17
Barley					
1997	23	11.9	13.5	12.9[ab]	0.43
1998	222	12.2	14.3	12.9[b]	0.26
1999	56	12.0	14.3	12.8[a]	0.53
2000	13	12.5	14.0	13.2[c]	0.43
2001	13	12.6	14.3	13.6[d]	0.49
Triticale					
1997	3	13.9	14.0	13.9[2]	0.06
1998	65	13.0	14.6	14.2[c]	0.25
1999	55	12.8	14.5	13.9[b]	0.41
2000	89	12.9	14.9	13.7[a]	0.35
2001	4	14.1	14.3	14.2[c]	0.12

[1]SD, standard deviation. [2]Insufficient observations for statistical comparison with other means. [a,b,c]Means within a grain type with different superscripts differ significantly ($P \leq 0.001$).

The mean DE content of wheat, barley and triticale, respectively, varied significantly ($P \leq 0.001$) across years. Ranges of between 0.9-2.3, 1.6-2.3 and 1.6-2.0 were shown within years where more than 20 samples of wheat, barley and triticale were analysed, respectively. Variation in the range in DE estimates across years may reflect differences in the prevailing environmental and cultural conditions in any one year. Ranges within a year also exceeded changes in the mean for each grain type across years. This suggests that use of mean DE values when formulating pig diets is insufficient if pig production efficiency is to be optimised.

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THE EFFECT OF AN ENZYME PREPARATION ON THE DEVELOPMENT OF DIGESTIVE ENZYMES IN PIGLETS

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Digestive enzymes play an important role in the development of digestive capacity of the gastrointestinal tract of piglets. While some studies have demonstrated that exogenous enzyme preparations can stimulate enzyme secretions in piglets (Bedford, 1995), the relationship between the endogenous and exogenous enzymes is not clear. In this experiment, a mixture of exogenous amylase and protease was used to study the effect of exogenous enzymes on the development of digestive enzymes for piglets.

Thirty-two male and 32 female piglets (Beijing Black × Duroc × Landrace) were selected at birth from eight litters, and were mixed and fostered equally to each sow. At 1, 7, 14, 21 and 28 d, two male and two female piglets (one from each of four different litters on each day) were slaughtered randomly. From day 10, all piglets were offered a creep diet based on corn, soya bean meal and whey powder. At 35 d, the remainder of the piglets were weaned and allocated to two groups. One group was fed the creep diet while the other group was fed the same diet supplemented with 47,500 IU of amylase and 5,000 IU of protease/kg feed. The piglets were housed in wired-floor pens (four pens for each group) and fed *ad libitum*. At 35, 42, 49 and 56 d, two male and two female piglets were slaughtered from each group. The chyme was collected from the duodenum, jejunum and ileum and the activity of digestive enzymes was analyzed according to Erlanger *et al.* (1966). One-way ANOVA was used to compare the activity of enzymes at different ages, and t-test was used to compare the effects of exogenous enzymes.

Table 1. The development of digestive enzymes in the jejunum of pigs supplemented with exogenous enzyme preparations[1].

Age (days)	Amylase (U×10³/g protein)	Lipase (U/g protein)	Trypsin (U/g protein)	Chymotrypsin (U/g protein)	Protease (U/g protein)
7	5.48^{a}	175^{a}	32^{a}	1.17^{a}	66^{a}
14	14.42^{ab}	145^{a}	80^{a}	1.17^{a}	42^{a}
21	18.12^{bc}	257^{a}	120^{ab}	2.40^{a}	67^{a}
28	16.84^{bc}	174^{a}	97^{ab}	2.41^{a}	174^{ab}
35	9.81^{ab} (15.98)[2]	186^{a} (210)	226^{b} (133)	3.10^{ab} (3.17)	313^{b} (337)
42	6.34^{a} (4.48)	220^{a} (475)	297^{b} (392)	1.90^{a} (2.17)	282^{a} (327)
49	26.42^{cd} (16.55)	498^{b} (857)	539^{c} (522)	5.47^{b} (4.67)	589^{c} (979)
56	32.85^{d} (27.06)	355^{ab} (318)	632^{c} (697)	8.47^{c} (9.17)	414^{abc} (1180)
SEM	3.43	68	55	0.83	78
P value	0.008	0.02	0.003	0.013	0.001

[1]Means in the same column with different superscripts differ significantly (P≤0.05).
[2]Values for pigs that received the exogenous enzyme preparation are in parentheses.

The development of digestive enzyme activity was similar at different sites. The activity of amylase was about 655 U/g protein before suckling and increased to 5,480 U/g at 7d, and reached a high level at 3 weeks of age. Activities of trypsin and chymotrypsin were not detected on the first day before suckling and were low before 42 days. The activity of protease was similar up to 21 days, increased dramatically to 35 days and was at high but variable concentrations thereafter. Weaning did not significantly affect the activity of any of the enzymes determined (P>0.05). Exogenous enzymes only increased the activity of protease at 49 and 56 days (P≤0.05), which differs from the results of Bedford (1995) who found increases in amylase, protease and lipase. Difference in weaning age, dietary components and composition of the exogenous enzyme preparations used most likely explain the differences observed between the two studies.

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VARIETY, GROWING REGION AND ADDITION OF EXOGENOUS XYLANASE INFLUENCES DIGESTIBLE ENERGY CONTENT OF WHEAT FED TO WEANER PIGS

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Variety, rainfall zone and addition of exogenous enzymes are known to affect the digestible energy (DE) content of wheat fed to pigs (Anderson and Bell, 1983; Wiseman, 1997; Choct *et al.*, 1999). However, few studies have been conducted to examine the influence of these three factors on the DE content of wheat simultaneously. The aim of this study was to examine the influence of the variety, growing region and arabinoxylanase on the DE content of wheat for weaner pigs.

A 3 x 3 x 2 factorial experiment {3 varieties of wheat: Arrino (A); Stiletto (S); Westonia (W) x 3 rainfall zones [High (H, ≥ 450 mm annual rainfall); Medium (M, 320-450 mm annual rainfall); Low (L, ≤ 320 mm annual rainfall)] x 2 enzyme treatments (presence or absence)} was conducted with 5-week old male pigs (Large White x Landrace, 6 kg average live weight). The enzyme was an arabinoxylanase having a minimum activity of 4000 U/g and was included in the diet at 0 or 1 kg/tonne. The experiment was completed 5-7 weeks after harvest. The experimental diet consisted of 90% wheat and 10% additives (i.e., canola oil, vitamin/mineral mix, Celite® as an indigestible marker). The test diets were fed for a 5-day adaptation period followed by 5 days of consecutive faeces collection for determination of DE content. Analysis of variance was used to examine the effects of variety, rainfall zone and enzyme and all interactions between these factors on DE content.

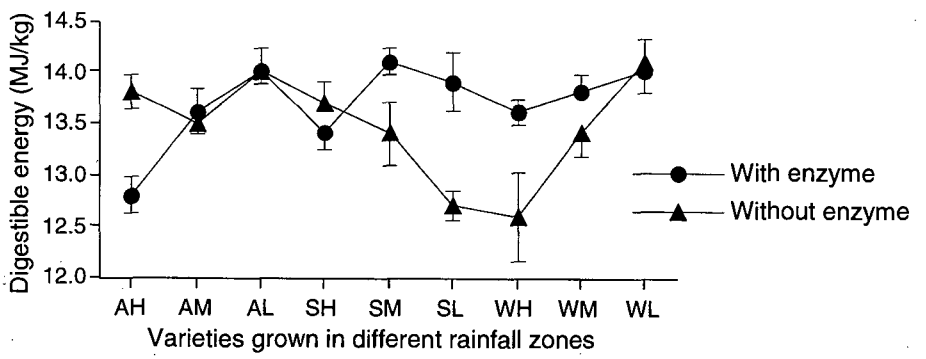

Figure 1. *Interaction line plot for DE content of three wheat varieties Arrino (A), Stiletto (S) and Westonia (W) grown in high (H), medium (M) and low (L) rainfall zones with or without arabinoxylanase.*

There was a 3-way interaction (P≤0.01) between wheat varieties, rainfall zone and enzyme use in determining the DE content of wheat fed to weaner pigs (Figure 1). These data highlight the need to account for a variety of factors when assessing the energy availability of wheat. The use of rapid assay techniques, such as near infrared spectrophotometry, to predict DE content will reduce errors in feed formulation associated with factors such as wheat variety and its growing region.

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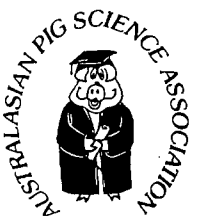

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A SYMPOSIUM - UNDERSTANDING THE NUTRITIONAL CHEMISTRY OF GRAINS WILL HELP TO IMPROVE THE PROFITABILITY AND SUSTAINABILITY OF THE PIG INDUSTRY

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Introduction

Reducing feed costs is the most efficient and effective way to improve piggery profitability. Fundamental to this is improvement in the utilisation of cereal grains and protein meals as the major components of Australian pig diets. With due consideration for an increasing demand for feed grains by all livestock sectors in Australia and overseas, increasing concerns related to nutrient loading of the environment, and future constraints on the use of traditional feed ingredients, such as meat and bone meal, due to consumer and legislative pressures, the importance of understanding the nutritional quality of grains as a means of improving utilisation cannot be underestimated. In this regard, the papers to be presented in this symposium are both timely and will serve as a cornerstone for future research in these fields.

A novel way of assessing factors influencing the nutritional quality of grains (e.g., available energy) for pigs is to compare the digestion of energy across a number of species, including ruminants. Comparisons of whole tract energy digestion and at the terminal ileum in pigs and chickens, might provide useful insights into the way energy utilisation is defined and indicate opportunities to improve the energy yield of grains for pigs. In this symposium, van Barneveld *et al.* (2001) compare the digestibility of energy from wheat, a weather-damaged wheat of the same variety, a waxy (low amylose) isoline of sorghum, and a normal isoline of sorghum in pigs, broiler chickens, sheep and cattle. This extensive comparison allows the relative importance of chemical characteristics and cell wall features of these grains to be assessed in relation to energy digestibility.

An area of increasing interest and active research is cell wall chemistry. Pigs obtain much of their available energy in cereals from starch. Knowledge of grain-related factors that maximise starch digestion in the small intestine offers potential to improve the efficiency of grain feeding for the pig industry, for example through manipulation of particle size via processing. Fundamental to understanding these factors is identification of the cell wall microstructure. In this symposium, Autio (2001) discusses the light microscopic techniques to determine the cell wall structures, particularly that of starch and its conformation when it gelatinises and is processed, in relation to digestibility in the pig.

The use of enzymes in diets to enhance nutrient and mineral digestibility and improve growth is well established in the chicken industries. Relatively less attention has focused on the use of enzymes in the pig industry, and evidence to support their use is often equivocal. This is largely because there has been a general ignorance to the basic premise that the digestive physiology of the pig contrasts markedly to that of the chicken. Nevertheless, there is a growing body of evidence that some enzymes under certain conditions (e.g., when incorporated into diets containing grains high in non-starch polysaccharides or ingredients high in phytate) can afford benefits. Of particular interest is the period after weaning. Choct and Cadogan (2001) ask the question in the final paper of this symposium as to the effectiveness of supplemental enzymes in pig diets. These authors have an impressive blend of scientific and practical experience in the area of feed enzymes, and their paper will provide much interest and further discussion.

COMPARATIVE DIGESTION OF ENERGY FROM GRAINS FED TO PIGS, POULTRY AND RUMINANTS: CAN THE EFFICIENCY OF PIG PRODUCTION BE IMPROVED?

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Abstract

The energy digested from four grain samples (weather-damaged wheat, undamaged feed wheat, waxy sorghum isoline, non-waxy sorghum isoline) fed to pigs, broiler chickens, sheep and cattle, respectively, was compared. Examination of the sites of energy digestion in pigs and broiler chickens provided some useful insights into the way the energy value of feeds for pigs could be defined, the ways to improve the yield of energy from cereal grains, and the relative importance of specific grain characteristics to the net energy yield from a grain. The comparison was undertaken in an attempt to assess the relative influences of: gross chemical composition; cell wall quantity; structure and composition; fatty acid content and composition; starch characteristics; protein matrix; grain hardness; and lignin bound to protein and phenols. Despite large differences in the characteristics of the grains tested, faecal digestible energy (DE) in pigs was insensitive to these differences, and represents a poor indicator of energy available from grains, particularly those with reduced starch content. Gross chemical composition explained some of the differences in DE yield from cereals, particularly in relation to the proportion digested in the small intestine, however, comparison among grain types demonstrated that gross chemical composition only goes part of the way to explaining energy digestion in pigs. Interestingly, amylose content does not appear to negatively affect the digestion of starch in the small intestine of pigs. Cell wall quantity, size and structure had a significant influence on energy yield in the pig. While little benefit is likely to arise from the additional processing of wheat for pigs, there may be significant benefits to reducing the grind size or additional heat processing of sorghum before incorporation into pig diets.

Introduction

Definition of the nutritional quality of feed ingredients before incorporation into pig diets can be improved resulting in an improvement in pig production efficiency. A significant research effort has been directed towards identifying those factors that influence the nutritional quality of grains for pigs (van Barneveld, 1999). However, a clear understanding of the mechanisms responsible for variation in nutritional quality and subsequent application of this knowledge in the form of rapid and objective analytical tests for feeding value is yet to occur. Fundamental to the definition of the nutritional quality of grains for pigs is measurement of energy available to the pig for growth and metabolism.

Attempts to identify the primary chemical components responsible for variation in the available energy content of grains for pigs have not progressed significantly beyond broad definitions of fibre components. Taverner and Farrell (1981) demonstrated that acid-detergent fibre content was the most important determinant of digestible energy (DE) in pigs. Similarly, Morgan and Whittemore (1982) presented 55 equations used to predict the DE content of feeds and compound diets for pigs, the vast bulk of which were based on the crude fibre or neutral detergent fibre content of the ingredients or diets. A fundamental reason why broad definitions of fibre components are the best correlates with nutritional quality to date could be the fact that DE is the chosen measure of available energy. Application of DE as a measure of available energy for pigs can be

shown to be highly insensitive and as a consequence, only those parameters that have a major influence on hind gut fermentation in the pig will have a significant influence on DE. When more sensitive measures of nutritional quality are applied, the influence of gross fibre characteristics on the nutritional quality of the grain becomes less pronounced. Yin *et al.* (1993) regressed the ileal and faceal apparent digestibility of energy with cell wall constituents and concluded that the apparent digestibility of nutrients cannot be predicted with sufficient accuracy by the contents of cell wall constituents alone. Again, the only significant correlations between cell wall components and energy digestibility were between neutral detergent fibre and faecal apparent energy digestibility, and between acid detergent lignin and ileal apparent energy digestibility. Similarly, van Barneveld *et al.* (1995) demonstrated that energy digestion in the small intestine is more variable than energy digestion along the entire digestive tract. More recently, R.J. van Barneveld (unpublished data) demonstrated that ileal energy digestibility can be correlated with specific non-starch polysaccharide components such as arabinoxylose (Table 1).

Table 1. Stepwise regression analysis of the chemical and physical composition of 11 barley cultivars against pig diet ileal digestible energy content (R.J. van Barneveld, unpublished data).

Step	Variable	Partial R^2	P value
1	Total arabinoxylose	0.6675	0.0021
2	Acid viscosity extract	0.1704	0.0199
3	Lectins (human)	0.0633	0.0720
4	Faecal digestible starch	0.0558	0.0315
5	Acid viscosity extract	0.0387	0.3125
6	Lectins (cow)	0.0267	0.0447
7	Vaccenic acid	0.0116	0.0929
8	Lectins (pig)	0.0082	0.0672
9	Others.....	0.0078	-

With the above in mind, it appears that a better understanding of the factors that influence the available energy supply from grains fed to pigs may be achieved by examining a more sensitive measure of available energy, such as ileal digestible energy, in addition to DE. Further to this, development of specific hypotheses relating to those grain characteristics that may have the greatest influence on available energy supply may allow selection of unique grain types to test these hypotheses. Black (2001) suggested that differences in the nutritional quality of grains could be largely attributed to combinations of the following factors:

- Gross chemical composition;
- Cell wall quantity, structure and composition;
- Fatty acid type and content;
- Starch composition;
- Protein matrix;
- Grain hardness, and
- Lignin bound to phenols and proteins.

In addition, the comparative ability of different animal species to digest nutrients from diverse grain types may also provide information on the relative importance of the above factors. The objectives of this paper are to compare the digestion of energy from four diverse grain samples fed to growing pigs, broiler chickens, sheep and cattle, respectively, in an attempt to rank the relative importance of some of the characteristics nominated by Black (2001). Where possible, potential applications for outcomes from this comparison will be identified with a view to improving commercial pig production efficiency.

Grain selection

Four grain samples were selected for this comparison: a standard feed wheat variety (Janz), a frost-damaged sample of the Janz feed wheat, a normal sorghum isoline and a waxy sorghum isoline. The basis for this selection was as follows:

- Wheat and sorghum are both cereals, but with diverse chemical and physical compositions. This allows some insight into the influence of gross chemical composition, cell wall quantity, structure and composition, fatty acid type and content, starch composition, protein matrix and grain hardness on available energy supply to the animal.
- Frosted wheat is characterised by significantly reduced starch content and altered cell wall characteristics allowing further insights into the influence of gross chemical composition and cell wall quantity, structure and composition on available energy supply to the animal.
- Waxy sorghum isolines have significantly reduced amounts of amylose in their starch allowing investigation into the influence of starch composition on available energy supply.

All samples were subjected to a wide range of chemical and physical analyses (Table 2; Figures 1-4). Obviously, the mean composition of wheat and sorghum differed markedly. The weather damaged and standard wheat samples appeared different in crude fat, crude fibre, acid detergent fibre, neutral detergent fibre, lignin, gross energy, specific weight, hydration capacity, total starch, enzyme digestible starch, resistant starch and hardness index (Table 2). The palmitic and stearic acid content of the wheat samples was similar (Figure 1) but there was some variation in the oleic and linoleic acid proportions. As expected, insoluble, soluble and free sugar content, together with specific components such as insoluble and soluble arabinoxylans and soluble β-glucans, respectively, were elevated in the weather damaged wheat sample (Figures 2-4). The normal and waxy sorghum isolines were remarkably similar in composition (Table 2, Figures 1-4) with the exception of hydration capacity, resistant starch content and amylose content. As such, these sorghum samples are valuable tools for this type of comparison as they vary largely in one parameter only (amylose), with resistant starch and hydration capacity being consequences of this variation.

Animal experimentation

The digestion of energy from the above grain samples was determined in growing pigs, broiler chickens, sheep and cattle, respectively. The varying anatomy and physiology of the digestive tracts of these animals (Figure 5), and the subsequent sites of energy digestion along these tracts, allows further insights into the relative importance of cell wall quantity, structure and composition and other grain characteristics in relation to available energy supply. With limited chewing following ingestion, ileal energy digestion in the pig is likely to provide the greatest insight into the role of cell wall quantity, structure and composition on energy availability. Comparison of ileal and faecal digestibility in pigs also allows the influence of microbial fermentation on available energy supply to be examined. By comparing energy digestibility values determined in pigs with those measured in poultry, the influence of cell wall integrity can be assessed. The gizzard in poultry (Figure 5) acts to grind feed particles to assist the digestive process and, as such, is effective in rupturing cell walls to facilitate enzyme access to the contents. The extensive fermentation of grains in the rumen of sheep and cattle prior to entry into the abomasum allows a comparison of the extent of energy derivation from fermentation in pigs and the potential to derive more energy from grains during passage through the digestive tract.

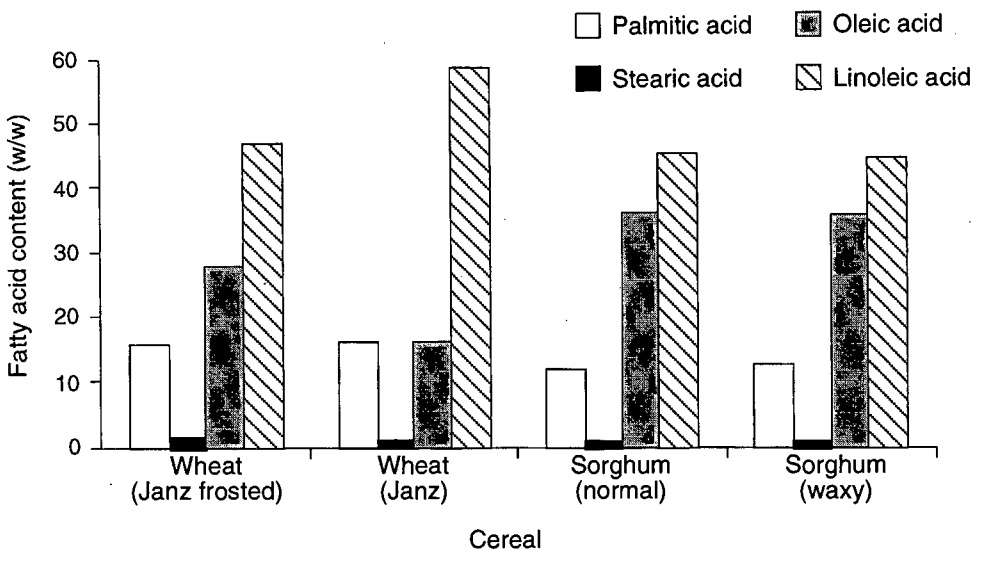

Figure 1. *Palmitic , stearic , oleic and linoleic acid content (w/w) of wheat and sorghum samples fed to growing pigs, broiler chickens, sheep and cattle for comparative analysis.*

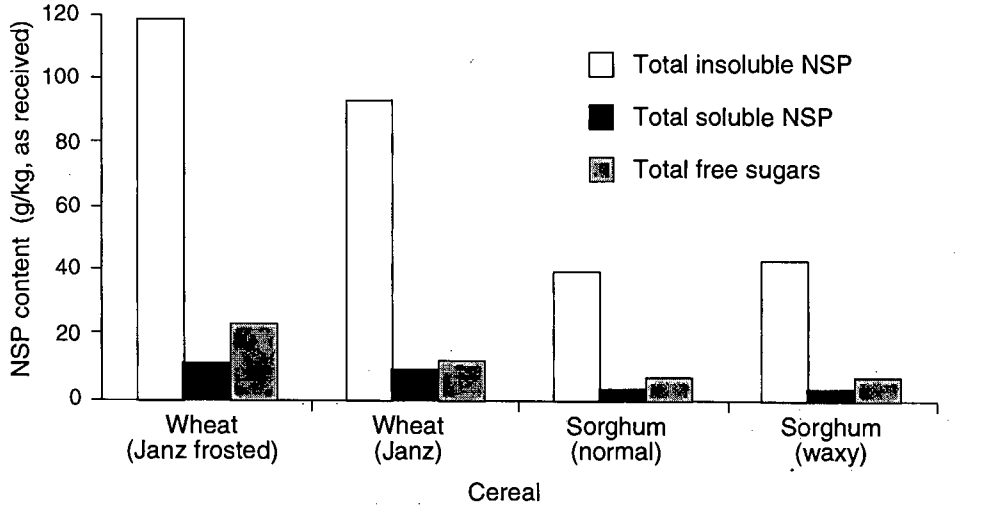

Figure 2. *Total insoluble and total soluble non-starch polysaccharides (NSP) and total free sugars (g/kg, as received) in wheat and sorghum samples fed to growing pigs, broiler chickens, sheep and cattle for comparative analysis.*

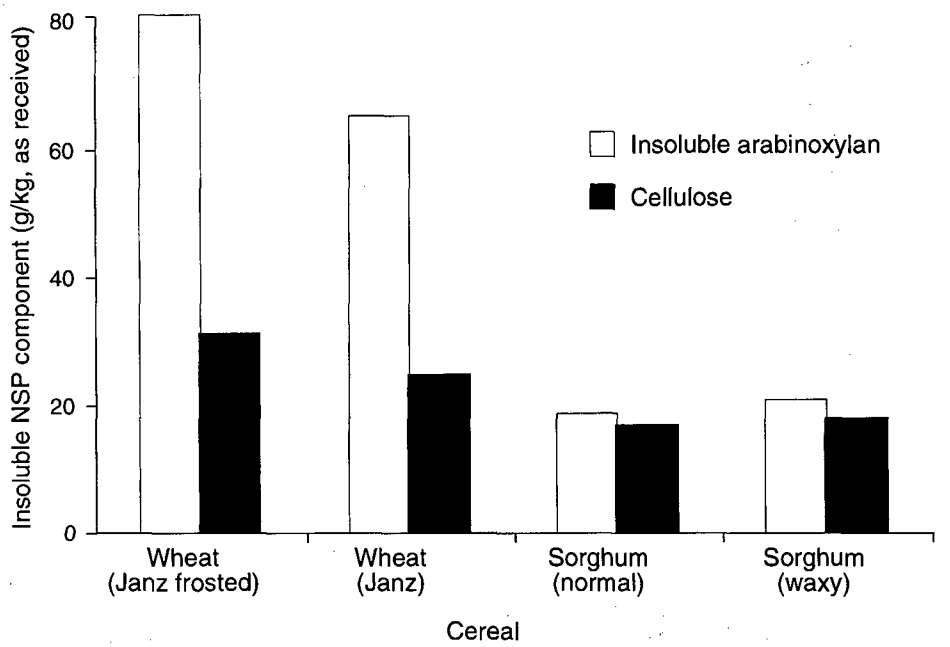

Figure 3. *Insoluble arabinoxylan and cellulose (insoluble NSP components) content (g/kg, as received) of wheat and sorghum samples fed to growing pigs, broiler chickens, sheep and cattle for comparative analysis.*

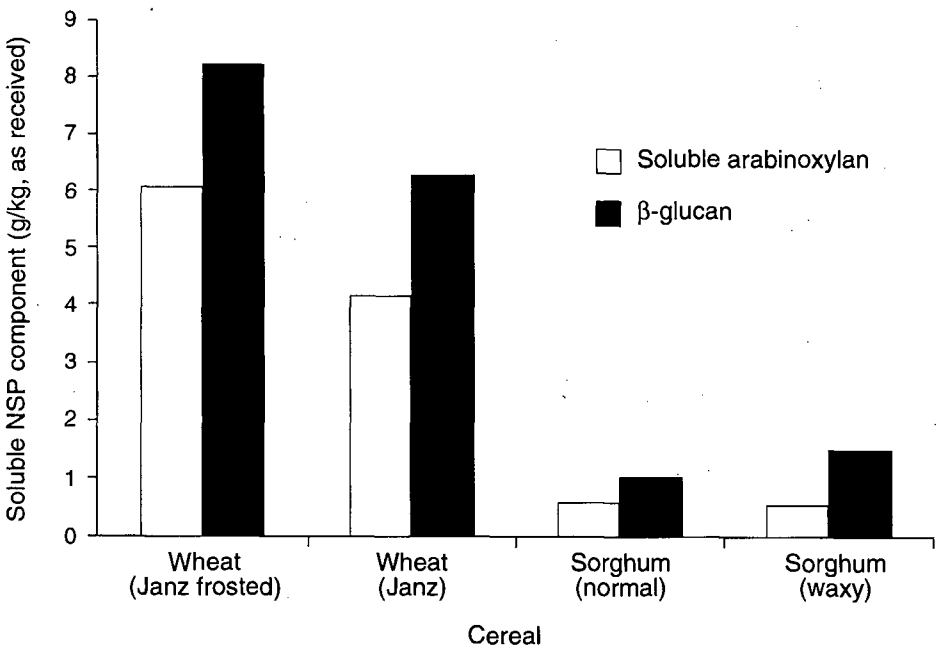

Figure 4. *Soluble arabinoxylan and β-glucan (soluble NSP components) content (g/kg, as received) of wheat and sorghum samples fed to growing pigs, broiler chickens, sheep and cattle for comparative analysis.*

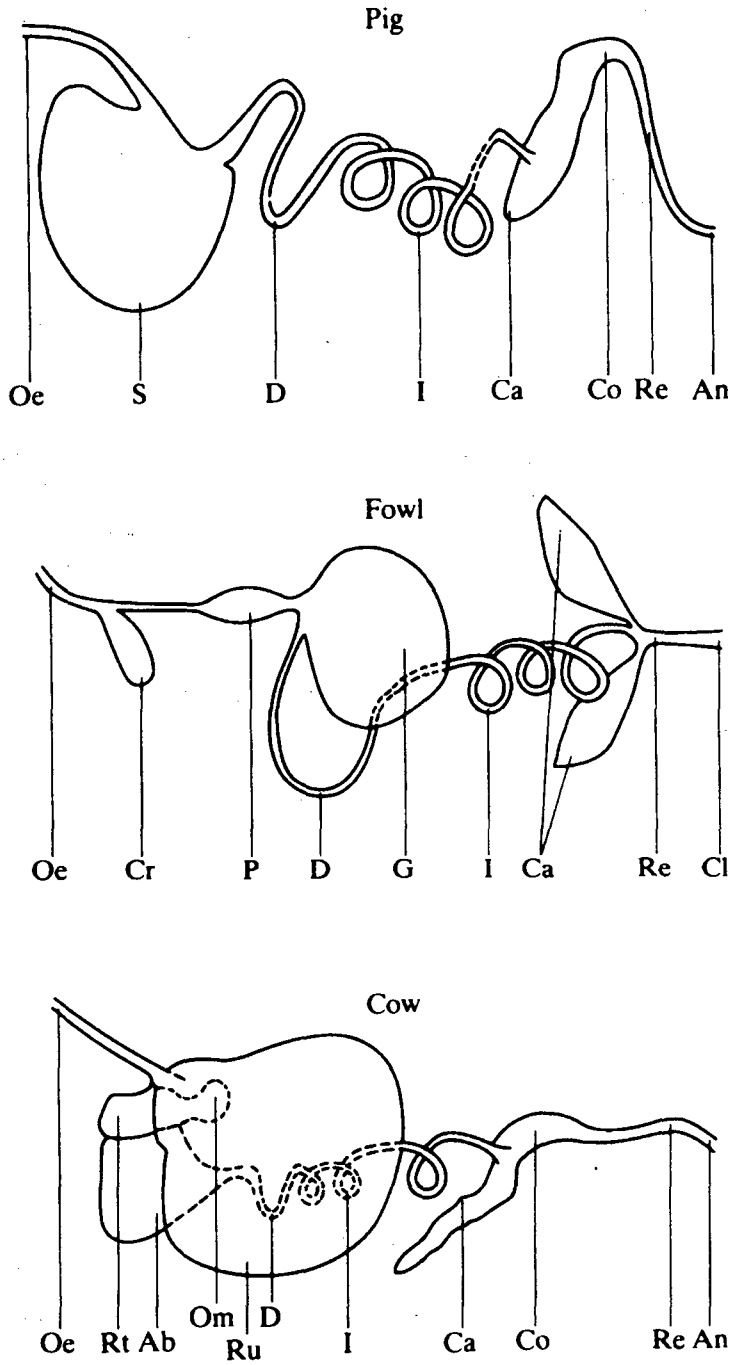

Figure 5. *Diagrammatic representation of the digestive tracts of pigs, poultry and ruminants (from McDonald et al., 1988). An, anus; Ab, abomasum; Ca, caecum; Cl, cloaca; Co, colon; Cr, crop; D, duodenum; G, gizzard; I, ileum; Oe, oesophagus; Om, omasum; P, proventriculus; Re, rectum; Rt, reticulum; Ru, rumen; S, stomach.*

Table 2. Chemical and physical composition (g/kg, as received) of wheat and sorghum samples fed to growing pigs, broiler chickens, sheep and cattle for comparative analysis of energy digestion.

Measurement	Wheat (Janz frosted)	Wheat (Janz)	Sorghum (normal isoline)	Sorghum (waxy isoline)
Moisture	94	101	110	110
Crude protein	164	162	108	124
Crude fat	27	15	36	37
Crude fibre	43	28	15	17
Acid-detergent fibre	51	35	34	37
Englyst neutral-detergent fibre	214	144	80	110
Lignin	14	8	3	3
Ash	18	18	18	18
Gross energy (MJ/kg)	17.43	16.84	16.83	16.87
Oligosaccharides	4	5	<1	<1
Phytic acid	14	11.2	14.1	14.5
Condensed tannins	0.4	0.1	0.8	0.6
Total tannins	2.5	2.1	3.6	3.2
Specific weight (kg/hL)	61.6	76.2	77.1	76.5
100 grain weight (g)	1.9	2.1	3.1	2.7
Hydration capacity (%)	91.6	57.1	33.1	44.5
Total starch	471	561	655	622
Enzyme digestible starch	475	518	644	630
Resistant starch	0.0	43.6	11.2	0.0
Amylose	279	279	271	45
RVA[1] – extracted starch (FV[2])	195	145	157	153
Acid extract viscosity (cP[3])	2.61	2.88	1.64	1.71
Single kernel analysis				
Weight (mg)	25.5	20.8	24.8	25.0
Diameter (mm)	2.1	1.8	2.0	2.1
Hardness index	48.2	74.9	86.0	84.7
Amino acids				
Aspartic acid	9.4	7.8	7.1	8.3
Threonine	4.9	4.7	3.5	4.0
Serine	7.6	7.8	4.9	5.6
Glutamic acid	35.5	42.5	22.1	25.5
Proline	13.5	16.1	8.8	10.2
Glycine	7.2	6.4	3.1	3.5
Alanine	6.5	5.3	9.6	11.0
Valine	7.4	6.8	5.8	6.8
Methionine	2.4	2.7	1.7	2.0
Isoleucine	5.2	5.1	4.2	5.0
Leucine	9.6	10.3	14.3	16.4
Tyrosine	4.5	4.9	4.1	4.7
Phenylalanine	6.5	7.2	5.6	6.4
Lysine	5.0	3.9	2.1	2.4
Histidine	4.7	4.1	2.7	3.0
Arginine	11.6	7.2	4.1	4.8
Cystine	3.3	3.6	1.8	1.9
Tryptophan	1.2	1.1	0.7	1.0

[1]RVA, rapid visco analysis. [2]FV, final value. [3]cP, centipoise.

Two pig experiments were completed. The first compared the weather damaged and standard feed wheat samples, while the second compared the two sorghum samples and a sample of the standard feed wheat. Both experiments were based on 5 x 5 Latin Square designs, with only data for the relevant grains presented (Tables 3 and 4). Experimental diets were formulated to contain 940 g/kg of the test grains, the remainder consisting of dicalcium phosphate, salt, minerals, vitamins, choline chloride and celite® (as an indigestible acid-insoluble ash marker). Large White male pigs (35-40 kg live weight (LW)) were fitted with simple T-piece ileal cannulas. Diets were fed for 7 d (3 x maintenance, i.e., $0.5LW^{0.75}$) prior to 8 h digesta collections over 2 consecutive days. Partial faeces collection was conducted simultaneously over the two-day collection period to facilitate diet and cereal DE measurements using the acid-insoluble ash marker. Digestibility values within each experiment were compared using an analysis of variance with treatment means separated by least significant difference.

Table 3. Ileal and faecal digestion of energy in diets containing weather damaged wheat (Janz) and standard feed wheat (Janz) determined using pigs fitted with simple T-piece ileal cannulas.

Parameter	Wheat (Janz frosted)	Wheat (Janz)	Cereal	SEM[3]
Diet ileal gross energy digestibility	0.58	0.67	P≤0.05	0.017
Diet faecal gross energy digestibility	0.79	0.82	P≤0.05	0.005
Diet ileal DE[1] (MJ/Kg, DM[2])	10.96	12.22	P≤0.05	0.291
Test cereal faecal DE (MJ/kg, DM)[5]	15.30	15.31	NS[4]	0.095
Ileal diet DE:Faecal diet DE	0.73	0.82	P≤0.05	0.022

[1]DE, digestible energy. [2]DM, dry matter. [3]SEM, standard error of mean. [4]NS, not significant (P>0.05). [5]Determined by difference using pre-determined DE values for other diet components.

Table 4. Ileal and faecal digestion of energy in diets containing standard feed wheat (Janz), a normal sorghum isoline and a waxy sorghum isoline determined using pigs fitted with simple T-piece ileal cannulas.

Parameter	Wheat (Janz)	Sorghum (Normal)[1]	Sorghum (Waxy)[2]	Cereal	SEM[5]
Diet ileal gross energy digestibility	0.72	0.75	0.72	NS[6]	0.035
Diet faecal gross energy digestibility	0.85[a]	0.88[b]	0.86[ab]	P≤0.05	0.008
Diet ileal DE[3] (MJ/Kg, DM[4])	12.90	13.55	12.96	NS	0.552
Test cereal faecal DE (MJ/kg, DM)[7]	15.79[a]	16.40[b]	16.06[ab]	P≤0.05	0.131
Ileal diet DE:Faecal diet DE	0.84	0.85	0.83	NS	0.042

[1]Normal, normal isoline. [2]Waxy, waxy isoline. [3]DE, digestible energy. [4]DM, dry matter. [5]SEM, standard error of the mean. [6]NS, not significant (P>0.05). [7]Determined by difference using pre-determined DE values for other diet components. [a,b]Values in the same row with different superscripts differ significantly (P≤0.05).

To facilitate the comparison with pigs, the same wheat and sorghum samples were offered to broiler chickens (commercial genotype, 22-29 days of age), sheep and cattle. Apparent metabolisable energy (AME) and ileal DE of the grains were determined (Table 5) across three broiler chicken experiments as part of a standard AME bioassay similar to that described by Hughes *et al.* (2000). In these experiments the test cereals comprised 800 g/kg of the experimental diets. As the measurements were derived across three experiments, they were considered as independent measurements on each grain and

statistical analysis was not completed. The wheat and sorghum grains were also fed to sheep as part of a larger experiment assessing a total of 40 grains. Each grain was fed in rolled form to a total of 8 sheep, together with chaffed lucerne hay, in a 70:30 grain:hay mixture. All diets were fed at a maintenance level of intake for a total of 30 days (10 days introduction, 10 days adaptation, 10 days measurement). Digestibility of all diets was measured as the percentage difference between feed eaten and faeces excreted, and were expressed as dry matter digestibility (DMD). Dry matter digestibility of the grains was calculated by difference on the assumption that there was no interaction between the grain and chaff components of the diets (Table 6). Only the weather-damaged wheat was fed to cattle with DMD determined using the same method described for sheep (Table 6). Analysis of the DMD values derived for the wheat and sorghum samples revealed no significant difference ($P>0.05$) within a grain type. Given the diversity of experimental designs across species, it was not acceptable to apply statistical analysis across animal types and hence discussion of results achieved across species is based on apparent differences in energy utilisation only.

Table 5. Ileal digestible energy (MJ/kg, DM) and apparent metabolisable energy (MJ/kg, DM) content of diets containing weather damaged wheat (Janz), standard feed wheat (Janz), a normal sorghum isoline and a waxy sorghum isoline fed to broiler chickens.

Measurement	Wheat (Janz frosted)	Wheat (Janz)	Sorghum (normal isoline)	Sorghum (waxy isoline)
Diet ileal DE[1] (MJ/kg, DM[2])	14.01	13.12	16.08	15.63
Diet ileal viscosity (cP[3])	10.6	24.4	3.3	3.0
Test cereal AME[4] (MJ/kg, DM)[5]	13.84	13.27	15.90	15.98
Ileal diet AME:faecal diet AME	1.01	0.99	1.01	0.98

[1]DE, digestible energy. [2]DM, dry matter. [3]cP, centipoise. [4]AME, apparent metabolisable energy. [5]Determined by difference using pre-determined values for other diet ingredients.

Table 6. Dry matter digestibility of weather damaged wheat (Janz), standard feed wheat (Janz), a normal sorghum isoline and a waxy sorghum isoline fed to sheep and cattle.

Measurement	Wheat (Janz frosted)	Wheat (Janz)	Sorghum (normal isoline)	Sorghum (waxy isoline)
DMD[1] Sheep	0.85	0.89	0.90	0.91
DE[2] Sheep[3] (MJ/kg, DM[4])	16.17	16.67	17.02	17.25
DMD Cattle	0.84	-	-	-
DE Cattle[5] (MJ/kg, DM)	15.98	-	-	-

[1]DMD, dry matter digestibility. [2]DE, digestible energy. [3]Calculated using DMD sheep x gross energy (MJ/kg, dry matter). [4]DM, dry matter. [5]Calculated using DMD cattle x gross energy (MJ/kg, dry matter).

Influence of gross chemical composition

Based on the current comparisons, gross chemical composition appears to have the greatest influence on net energy utilisation in pigs when it influences total nutrient supply or digestion in the small intestine. Comparison of the weather damaged and standard feed wheat samples of the same genotype reveals no difference in the faecal DE content (Table 3). This reflects the high capacity for fermentation in the hind gut of pigs, and serves to emphasise the insensitivity of DE to significant changes in gross chemical composition. The frosted wheat sample did, however, have a significant lower energy

yield following digestion in the small intestine. Given that a very high proportion of starch is digested in the small intestine of pigs (R.J. van Barneveld, unpublished data), an ileal DE value of 14.5 MJ/kg (which is equivalent to the faecal DE value) can be assigned to starch. Based on a difference of 90 g of starch/kg (Table 2), a difference of 1.3 MJ/kg in ileal DE would be expected between the two wheat samples, which is almost exactly the observed value. Hence, total starch content above all other grain characteristics accounted for the differences between the frosted and standard wheat sample in this instance. This is despite observed differences in grain hardness and differences in the viscosity of the starch from the respective wheat samples.

Comparison among grain types is a useful way to demonstrate that gross chemical composition does not account for all differences in energy digestion in pigs. Wheat and sorghum grains have a similar gross energy content, but this energy is derived from different chemical components. Using the current samples as an example, and considering digestion in the small intestine alone, comparatively more energy in the wheat would be derived from protein digestion, while in the sorghum, more energy would be derived from fat and starch. Again, assigning ileal DE values of 16.0 MJ/kg for protein, 36.0 MJ/kg for fat and 14.5 MJ/kg for starch, more than 1.5 MJ/kg more DE would be expected to be derived from sorghum compared with wheat by the end of the small intestine in pigs, the bulk of this difference being attributable to starch digestion. From the current comparisons (Table 4), this is clearly not the case suggesting that factors other than gross chemical composition are having an influence on energy digestion. These factors may include those discussed by Autio (2001).

Influence of cell wall quantity, structure and composition

The cell wall quantity, structure and composition differ significantly between wheat and sorghum. Sorghum is characterised by small, tightly packed, angular cells containing uniform-sized starch granules encapsulated in a protein matrix (Figure 6a and b). In contrast, wheat consists of elongated cells containing a mixture of two-thirds large, lenticular starch granules (8-30 μm; A granules) and one-third near spherical granules of <8 μm in diameter (B granules; Evers *et al.* 1999; Figure 7a and b). The elongated cells of wheat are likely to be easier to rupture through chewing or processing prior to feeding, making the cell contents more accessible to enzyme degradation. In contrast, the nature of the cells in sorghum means they are more likely to remain intact following chewing or processing. Pigs appear to digest similar amounts of energy from wheat and sorghum in the small intestine (Table 4), however, the lower starch and fat content in wheat may mean that enzymic access is superior in wheat with a higher energy yield per unit of substrate.

Comparison of results obtained for pigs and broiler chickens allows examination of the potential influence of cell structure on energy yield and provides a medium to examine the potential benefits of decreasing the particle size of some grains prior to feeding. The amount of energy derived in the small intestine of pigs from standard feed wheat (12.2-12.9 MJ/kg, DM; Tables 3-4) is similar to the amount of energy digested in the small intestine of broiler chickens (13.1 MJ/kg, DM; Table 5). In contrast, broiler chickens can digest 2.5 MJ/kg DM more than pigs in their small intestine when they are fed sorghum. It is likely that the grinding action of the gizzard in broiler chickens is an effective way of increasing the proportion of energy available from sorghum in the small intestine, presumably because it reduces particle size sufficiently to rupture a larger proportion of cells. The nature of wheat cells appears to dilute the benefits of this additional physical disruption to the cells. This is supported by the findings of Wiseman (1997) who reported little influence of grind size on the digestible energy content of wheat and barley (Table 7). Wiseman (1997) demonstrated that the DE content of wheat and barley is significantly lower when whole seed is fed with grinding increasing the DE content. However, the degree of grinding has little impact on the energy digestibility coefficient.

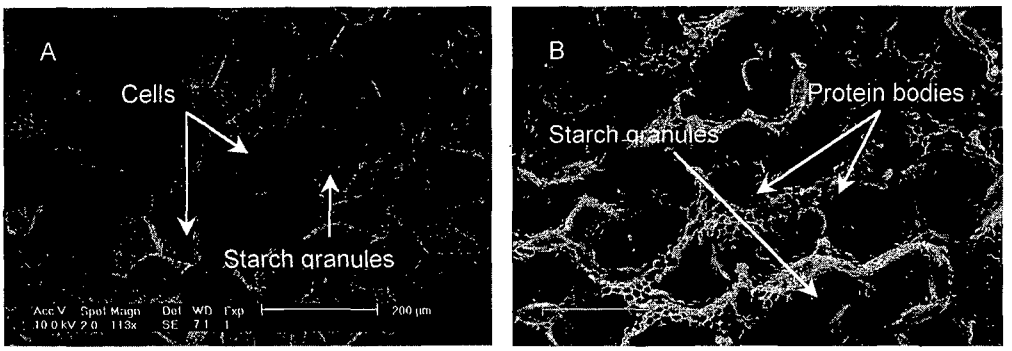

Figure 6a and b. *Physical arrangement of sorghum cells, starch granules and protein matrices viewed using an electron microscope (Figure 6a, scale bar 200 μm; Figure 6b, scale bar 20 μm) (M.R. Zarrinkalam, unpublished).*

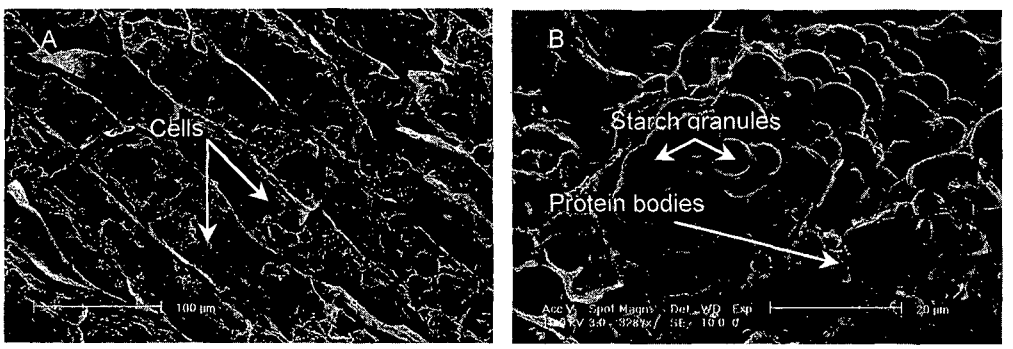

Figure 7a and b. *Physical arrangement of wheat cells, starch granules and protein matrices viewed using an electron microscope (Figure 7a, scale bar 100 μm; Figure 7b, scale bar 20 μm) (M.R. Zarrinkalam, unpublished).*

Table 7. Influence of processing of wheat and barley on dry matter and energy digestibility in pigs (Wiseman, 1997).

	Whole	Fine ground	Coarse ground	Rolled
Dry matter				
Wheat	0.76	0.86	0.82	0.87
Barley	0.64	0.81	0.78	0.81
Gross energy				
Wheat	0.75	0.86	0.83	0.86
Barley	0.64	0.80	0.78	0.80

The above results suggest that cell wall quantity, size and structure can have a significant influence on energy yield in the pig. They also suggest that while little benefit is likely to arise from the additional processing of wheat for pigs, there may be significant benefits to reducing the grind size of sorghum before incorporation into pig diets. Alternatively, further research may be required to identify suitable exogenous enzymes for use with sorghum to increase the proportion of energy digested in the small intestine of pigs (Choct and Cadogan, 2001).

Fermentation in the rumen followed by enzymic digestion in the small intestine and additional fermentation in the hind gut of sheep and cattle results in a higher DE yield than that observed in pigs and broiler chickens (Table 6). Compared with pigs, the DE values obtained for sheep and cattle are between 0.5 and 1.0 MJ/kg DM higher, however, as a much larger proportion of this energy is derived from volatile fatty acids in ruminants, the additional DE is still likely to yield a lower net energy contribution than that obtained in pigs. Based on the results for ruminants, it is unlikely that an increase in the fermentative capacity in the hind gut of pigs (using probiotics or grain pre-treatment) would be of significant benefit, with more to be gained through increasing the proportion of energy digested in the small intestine.

Influence of starch composition

A reduction in the amylose content of starch did not significantly improve the ileal or faecal DE of the waxy sorghum isoline fed to pigs. The level of error associated with this experiment was high and it alone should not be used to define the role of amylose in starch digestion in pigs, however, in both pigs and broiler chickens the ileal DE value for the normal sorghum isoline was numerically higher than the waxy isoline, which is contrary to expectations. Black (2001) highlighted that amylose consists of long chains of α-(1-4)-linked glucose units that form tight helical structures making the bonds comparatively inaccessible to amylases. In contrast, amylopectin contains some α-(1-6) linkages that produces branches in the molecule more susceptible to enzymic cleavage. As a consequence, starches high in amylose are less digestible than than those that consist predominantly of amylopectin. While *in vitro* data demonstrates that starch digestion in sorghum and maize declines substantially as the amylose content increases, the current *in vivo* data is to the contrary. Further to this, amylose content did not influence the DE of sorghum fed to sheep. In pigs, the capacity for starch digestion appears high regardless of the amylose content, and selection of grains for reduced levels of amylose appear to be of little benefit.

Influence of other grain characteristics

Despite some large differences in the attributes of the grains tested, the ileal and faecal DE contents were similar, or could be explained by "macro" attributes of the grains (e.g., starch content). In some cases the fatty acid composition, protein matrix, grain hardness and lignin-protein matrices, to name a few, may have an influence on the energy digested in the pig. However, not until a more sensitive way of assessing these influences is defined will their true impact on net energy yield be revealed.

Conclusions

Comparison of the energy digested from four grain samples fed to pigs, broiler chickens, sheep and cattle, and examination of the sites of energy digestion in pigs and broiler chickens has provided some useful insights into the energy value of feeds for pigs is defined, and ways to improve the yield of energy from cereal grains. The following conclusions can be drawn from this exercise:

- Despite large differences in the characteristics of the grains tested, faecal DE in pigs was insensitive to these differences, and represents a poor indicator of energy available from grains, particularly those with reduced starch content. The use of ileal DE, or ileal DE:faecal DE, would provide more insight into the potential net energy yield from a grain;

- Gross chemical composition explains some of the differences in DE yield from cereals, particularly in relation to the proportion digested in the small intestine, however, comparison between grain types demonstrates that gross chemical composition only goes to part of the way to explaining energy digestion in pigs;

- Cell wall quantity, size and structure have a significant influence on energy yield in the pig;
- While little benefit is likely to arise from the additional processing of wheat for pigs, there may be significant benefits to reducing the grind size of sorghum prior to incorporation in pig diets, or subjecting sorghum to additional heat processing. These potential benefits will have to be offset against the additional mechanical energy inputs required to produce a finer grind or apply heat processes, and the potential influence of finer grain particle sizes on the incidence of gastric ulcers.
- Enhancing the fermentative capacity of the hind-gut of pigs through grain pre-treatment or probiotic use is likely to derive little benefit in terms of net energy yield to the pig.
- Amylose does not appear to negatively affect the digestion of starch in the small intestine of pigs.

Acknowledgements

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LIGHT MICROSCOPIC TECHNIQUES TO UNDERSTAND STARCH DIGESTIBILITY

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Abstract

Starch is the second most abundant plant polymer and is the major source of energy in pig diets. The rate of starch digestion in the small intestine by α-amylase has significant implications for human and animal nutrition. For the animal nutritionist, characterising factors influencing nutrient digestibility to maximise enzymatic digestion of starch in the upper part of the gut is an important, yet not fully understood, problem. Many food factors that reduce the rate of amylolysis also lower total starch digestibility in the small intestine. In a whole cereal grain the intact cell walls protect starch from digestion. Processes such as milling and heat treatment influence the way in which plant tissues undergo amylolysis during *in vivo* digestion, cell wall structure being the key determinant. The characteristics of starch *per se* are also of crucial importance. Amylose-rich starches are more resistant to amylolysis than waxy or normal starches. *In vitro*, native starches are hydrolyzed very slowly, and to a limited extent, by amylases. The rate and degree of amylolysis can be greatly increased by heating the starches in the presence of water, during which their ordered structures are disrupted. In this paper, the microstructures of the cell walls and starches in cereal-based products and feeds and the effect of processing will be presented in relation to starch digestibility. Bright-field and fluorescence microscopic methods are used because they allow selective staining of different chemical components. In research on cereal-based products or feeds, fluorescence microscopy provides resolution, chemical specificity, and sensitivity rarely matched by other techniques. Confocal laser scanning microscopy gives three-dimensional information about the cellular structure and about the encapsulation of starch by proteins. Some examples of the potential of this new technique will be given.

Introduction

The intensively reared pig obtains its energy predominantly from the cereal portion of the diet, which contains starch as the main energy source. Cereal grains have a well-organized microstructure. In native grains, starch granules and proteins are surrounded by cell walls. The cell walls in different parts of the kernel differ in terms of chemical components and architecture (Bacic and Stone, 1981; Autio, 1995). In pigs and poultry, the cell wall components are known to reduce the digestibility of proteins and starch, partly by surrounding the starch granules in the grain, and partly by increasing the viscosity of the intestinal contents (King and Taverner, 1975; Choct and Annison, 1992). *In vitro* studies have demonstrated that the protein matrix in cereal (Holm and Björck, 1988; Jenkins *et al.*, 1988) and legume products (Tovar *et al.*, 1990) limits the accessibility of starch to amylase. Water-soluble non-starch polysaccharides (NSP), when incorporated into starchy foods, attenuate the postprandial rise in blood glucose and insulin concentrations in healthy and diabetic subjects (Jenkins *et al.*, 1978; Ellis *et al.*, 1981; Ellis *et al.*, 1991) by increasing the viscosity of digesta in the upper part of the gastrointestinal tract (Cherbut *et al.*, 1990; Ellis *et al.*, 1995; Ellis *et al.*, 1996).

The different physical and chemical characteristics of starches influence the extent of digestion and absorption in the small intestine and the degree of fermentation in the large intestine. This has resulted in the need for a nutritional classification of starch (Englyst *et al.*, 1992). Both the raw material and processing affect the amount of resistant starch (RS). Resistant starch can be further subdivided into three types: physically inaccessible starch, resistant starch granules and retrograded starch (Cairns *et al.*, 1996). In pig production, where maximum utilization of dietary energy for growth and development is the focus, an increase in the amount of starch escaping to the large intestine will lead to fermentative

(as short-chain fatty acids), rather than enzymatic (as glucose), use of starch. The use of starch as an energy source via fermentation is less efficient (Yen *et al.*, 1991) and causes a decrease in nutritional benefit for the pig.

This paper will review microscopic methods that may be used to study the physical structures of grains that are difficult to characterise using conventional chemical analyses and bioassays. Emphasis will be given to various starches including physically inaccessible starch, resistant starch granules and retrograded starch, that can be present in native ingredients and (or) produced during feed processing. In turn, these characteristics will be related to nutrient digestibility in the pig.

Sample preparation and staining techniques

For microstructural characterization, the samples (grains, feeds, digesta content etc.) can be prepared for sectioning either by freezing with or without fixation or by plastic embedding including fixation, dehydration and embedding in plastic (Autio, 2001; Autio and Salmenkallio-Marttila, 2001). Cryo-sectioning involves freezing, and the formation of ice-crystals may damage the structure. Preparation for plastic embedding involves dehydration, which may cause shrinkage (Kalab *et al.*, 1995). The most commonly used staining systems for different components in bright field (Flint, 1988) and fluorescence microscopy (Fulcher and Wong, 1980) are presented in Tables 8 and 9. Iodine staining allows demonstration of both amylose and amylopectin. Amylose stains blue and amylopectin brown. Some feed components are naturally fluorescent. In cereal cell walls, the main sources of autofluorescence are phenolic compounds, such as ferulic acid and lignin. The majority of components, however, are not fluorescent and must be converted to fluorescent by chemical treatment. Some of the fluorochromes shown in Table 9 can also be used in confocal laser scanning microscopy (CLSM). One of the main advantages of this technique is the minimal degree of sample preparation (Dürrenberger *et al.*, 2001).

Table 8. Most commonly used stains for cereals.

Component	Stain	Colour
Starch	Iodine/KI solution	Black, Violet
Amylose	Iodine/KI solution	Blue
Amylopectin	Iodine/KI solution	Beige, Brown
Lignin	Phloroglucinol	Red
Pectin	Ruthenium red	Red
Cellulose	Thionin	Violet
Protein	Light green	Green
Lipid	Sudan III and IV	Red
	Oil Red O	Red
	Sudan Black B	Blue-black

Table 9. Most commonly used stains for cereals in fluorescence microscopy.

Component	Stain	Colour
Protein	ANS*	White or Blue
	Acid Fuchsin	Red, Brown, Orange
Starch	Periodic acid Schiff's	Yellow
	Acridine orange	Green
β-Glucan	Calcofluor White M2R	Blue
	Congo red	Orange
Fat	Nile blue	Yellow

*1-Anilo-8-naphthalene sulphonic acid

Microstructure of grains in relation to digestibility

Microstructure of cereal cell walls

Cell walls of plants are composed mainly of non-starch polysaccharides (NSP) and phenolics. The general effect of NSP on nutrient digestion and absorption in pig diets has been reported by several researchers (Bach Knudsen and Hansen, 1991; Jørgensen *et al.*, 1996), however the roles of specific cell wall components on diet digestibility are not known. A possible reason for this is the inability of conventional techniques used in nutritional studies to identify these components before and after digestion along the gastrointestinal tract of pigs. NSP from different parts of grains are digested differently in pigs and poultry (Choct and Kocher, 2000).

The microstructure of wheat grain is presented in Figure 8. The four morphologically different tissues common to all cereal grains are (a) the layers of fruit and seed coats, (b) the embryo, (c) the aleurone and (d) the starchy endosperm (Evers and Bechtel, 1988). The pericarp, or the fruit coat, is composed of an outer epidermis, hypodermis, remnants of thin-walled cells, intermediate cells, cross and tube cells. The outer layers are mainly composed of lignin, cellulose and gluconoarabinoxylans. Although the morphologies of cereal grains share many similar features differences do exist, especially in the chemical composition and distribution of components. In cereal cell walls, the main sources of autofluorescence are polyphenolic compounds, such as ferulic acid and lignin (Fulcher *et al.*, 1972). Lignin has been identified as a limiting factor for the enzymatic degradation of plant cell walls (Brillouet and Mercier, 1981). The cell walls of barley, rye and wheat around aleurone cells are rich in polyphenolic compounds (mainly ferulic acid), since only aleurone cell walls and the layers of seed coat (mainly lignin) exhibit autofluorescence (Autio, 2001). In the case of maize, rice and sorghum, the inner endosperm cell walls are also autofluorescent, suggesting that they too contain large amounts of polyphenolic compounds. Ferulic-acid-containing cell wall polysaccharides of fruits and vegetables play a key role in the thermal stability of cell-to-cell adhesion (Waldron *et al.*, 1997). Aleurone cell walls of cereal grains are very resistant to digestion (Autio *et al.*, 1996; Tervilä-Wilo *et al.*, 1996; Parkkonen *et al.*, 1997). With the current microscopic technique, the different tissues of the cell walls can be identified and their microstructural features characterised. This may have a significant role in studying, for example, the effect of supplemental enzymes in pig diets.

Physical structure of starch in relation to digestibility

Physically inaccessible starch

Particle size of feed has a marked effect on diet digestibility in pigs (Selby, 1999). This is because cell walls or proteins encapsulate starch, which limits starch hydrolysis by α-amylase (Colonna *et al.*, 1990; Brennan *et al.*, 1996; Fardet *et al.*, 1998). A linear relationship has been found between the proportion of barley kernels and the glycaemic response in humans (Liljeberg and Björck, 1994). When the barley grains were milled to flour, the corresponding wholemeal bread produced equally high glucose and insulin responses, as did the white bread reference product. Similar results have also been shown with wheat, rye and oats. When starch was encapsulated by κ-carrageenan (from red marine algae), the *in vitro* digestibility decreased markedly (Autio *et al.*, 2001). Without microscopic techniques, the encapsulation of starch is impossible to determine.

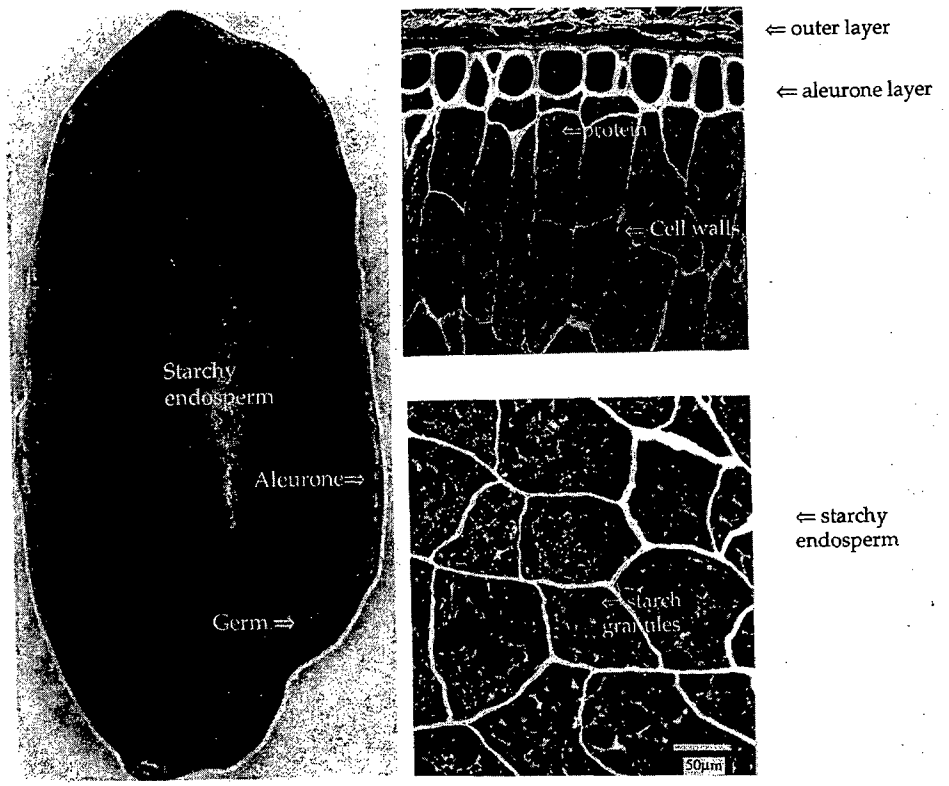

Figure 8. *Micrograph sections of wheat grain at a low magnification and at higher magnifications of the aleurone layer and starchy endosperm.*

Resistant starch granules

Native starch granules are generally digested slowly by α-amylase (Björck, 1995). Banana starch, potato starch and high-amylose maize starch, however, contain high amounts of resistant starch (54.1-61.4 %; Englyst *et al.*, 1992). As a result of gelatinization, the *in vitro* rate of amylolysis increases dramatically (Holm *et al.*, 1988). The amylose to amylopectin ratio in cereal grains varies widely depending on the grain species, variety and growing conditions (Moran, 1982; Snyder, 1984), but its implications for the pig industry are not known. Zarringkalam *et al.* (2000) reported that a positive relationship appeared to exist between the amylopectin content and the available energy value in wheat and barley for pigs and poultry. The swelling of starch granules and the location of amylose, which are dependent on the degree of gelatinisation, can be studied by microscopic methods (Autio and Salmenkallio-Marttila, 2001).
The restricted swelling of starch during cooking of pasta also limits the α-amylase susceptibility of starch, as opposed to fully gelatinized starch (Cunin *et al.*, 1995). When amylose has leached out of the starch granule, the increased amount of leached amylose resulting from starch subjected to temperatures in excess of 71 °C almost certainly becomes retrograded and decreases starch digestibility. Starch granule structure is probably very important in relation to the conditioning and steam pelleting of feed.

Retrograded starch

Starch gels originating from waxy maize or amylose-rich maize starch, HYLON VII (amylose content about 70%), were digested very differently by α-amylase (Vesterinen *et al.*, 2001; Table 10). The digestibility of starch gels is dependent on the amylose:amylopectin ratio and rigidity of the gels. The highest yields of RS are obtained with leguminous seeds because these contain a higher amount of amylose (above 30%, in contrast many cereal starches contain less than 30%). Resistant starch in common ingredients can be increased by heating and cooling cycles. The extent of retrogradation of amylose has been found to be of primary importance in determining the RS content of starch. Resistant starch produced *in vitro* by hydrolysis of retrograded pea starch gels and amylose gels by porcine pancreatic α-amylase consisted of semi-crystalline, mostly linear material, which was present in two main molecular sub-fractions: degree of polymerization (DP)>100, and DP 20-30 (Cairns *et al.*, 1996). By iodine staining it is possible to demonstrate the location of amylose, for example, amylose leaching out of the granule. Retrograded amylose is a poor substrate for amylase action. It is hypothesised that starch digestion in the upper part of the intestine of pigs fed steam pelleted diets having a high level of pulses could be low, and the current technique may be used to study such effects of processing on pig performance. This will provide valuable answers to the Australian pig industry.

Table 10. The extent of hydrolysis of starch in different gels *in vitro* by mimicking the human mouth (Vesterinen *et al.*, 2001).

Samples	The amount of reducing sugars as a % of starch
8 % HYLON VII[1]	4.5 ± 0.3
5 % HYLON VII	6.5 ± 0.4
2.7 % HYLON VII	7.1 ± 0.6
2.0 % HYLON VII	6.8 ± 0.7
5 % Waxy maize starch	16.9 ± 0.7

[1]8 g HYLON VII/100 ml water.

Conclusions

The factors affecting nutrient digestion and absorption are multi-faceted. Some of these factors appear to be related to the physical structure of the grain, such as encapsulation by cell walls and, to an extent, the microstructure of the nutrients such as resistant starches. Non-digestible starch can, for example, be divided into three categories according to its resistance to digestion: physically inaccessible starch, resistant native starch granules, or retrograded starch. With conventional chemical and bioassay methods, the structural features of feed that influence nutritive value in pigs cannot be studied. However, the use of microscopy techniques allows cell wall components, and the different types of starches to be distinguished. With confocal laser scanning microscopy the three dimensional structure of cells can be demonstrated. The digestibility of cell wall components and protein in different parts of the grain may be elucidated. In many cases the aleurone layer is most resistant to digestive systems. The microscopic technique may also have a role in identifying and characterising the effect of various processing methods of grains and complete feed on nutrient digestion, in particular, starch digestion, along the gastrointestinal tract of the pig.

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HOW EFFECTIVE ARE SUPPLEMENTAL ENZYMES IN PIG DIETS?

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Abstract

Enzymes are used widely in pig diets to improve nutrient digestibility and growth performance. The main enzymes commercially used in pig diets are phytase, xylanase and β-glucanase, although many other enzymes, including cellulase, pectinase, amylase, protease, lipase, and α-galactosidase have been tested for their efficacy. The benefit of using phytase to release phosphorus from phytic acid as well as alleviating its anti-nutritive effect in monogastric animal feed is well established, and its use in pig diets is on a steady increase throughout the world. Whilst there is still disagreement on the merit of supplemental glycanases in pig diets under commercial situations, their benefits are more consistent when the quality of grain is sub-optimal. One of the more reliable applications is to use glycanases in pig diets, especially for weaner pigs, to overcome the large variation in feed intake, and hence daily weight gain seen in these animals. The mechanisms by which enzymes improve feed intake in pigs are not known. It is hypothesised that: (a) non-starch polysaccharides (NSP) increase the water holding capacity of the digesta, affecting gut fill and inducing satiety; (b) viscous NSP could increase the secretion of endogenous proteins and affect the regulation of some hormones such as gastrin, and (c) the cell wall microstructure of the poorly digestible grains may impede the hydration rate of starch. This will lead to an increase in the amount of digesta in the small intestine and delaying the passage of digesta.

Introduction

The use of enzymes in monogastric animal diets is a common practice today, although the benefit of supplemental glycanases on pig performance has been less consistent compared with their use in poultry. This is largely because the use of enzymes in pig diets closely followed their application in poultry without a clear understanding of the factors influencing digestibility of nutrients in grains in pigs. One example is the use of viscosity-reducing enzymes in pig diets. There is no doubt that an elevated level of viscous substance in the digesta can impair nutrient digestion and absorption in poultry by impeding the efficient mixing of digestive enzymes with their substrates (Edwards *et al.*, 1988), increasing endogenous loss of protein (Angkanaporn *et al.*, 1992), and interfering with the gut microflora (Choct *et al.*, 1996). However, in the pig, a high level of dietary soluble NSP does not lead to a high digesta viscosity (Dierick, 1989), possibly because pig digesta is more dilute than chicken digesta. In addition, the capacity of the pig gut is much larger than that of the chicken. Recently, Partridge (2001) comprehensively reviewed the literature on the use enzymes in pig diets. Thus, the current paper will focus on enzyme-substrate interactions and develop some hypotheses on the possible factors that affect feed intake in pigs.

Enzymes used in pig diets

A variety of enzymes have been tried in pig diets over the past five decades. These include: proteases, glycanases (amylase, xylanase, β-glucanase, cellulase, pectinase, α–galactosidase), and phytase. The rationale for using proteolytic and amylolytic enzymes is based on the understanding that these enzyme systems are usually deficient in young pigs. However, the effectiveness of protease in monogastric animal diets has yet to be demonstrated. This is probably because the levels of amylolytic and proteolytic enzymes in the pig increase rapidly after weaning to reach amounts sufficient for the

digestion of dietary substrates (Aumaitre and Corring, 1978; Corring *et al.*, 1978). Perhaps the most successful and widely used enzyme in pig diets is phytase. Phytase is used for two purposes: (a) removal of the anti-nutritive effect of phytate, and (b) reduction of the phosphorus and nitrogen levels in the excreta. Since the use of meat and bone meal in feed was banned in Europe, the price of inorganic phosphorus has increased markedly, making phytase supplementation highly attractive as a means of increasing available phosphorus in the diet. A comprehensive review of phytase use in monogastric animals has recently been published (Kornegay, 2001). The topic of phytase supplementation of pig diets will therefore be covered briefly, and the focus will be on the mechanism of action of NSP-degrading enzymes.

Phytase

Supplementation of pig diets with microbial phytase increases the availability of dietary phosphorus in the order of 26.5% to 44.2% (Mroz *et al.*, 1992; Mroz *et al.*, 1994). This increase comes from the effect of the enzyme on phytate phosphorus, which has a typical digestibility value of 30% in young pigs (Jongbloed and Kemme, 1990). Mroz *et al.* (1992) found in experiments using cannulated pigs that the hydrolysis of phytate by microbial phytase occurs mainly in the stomach (43%) and, to a lesser extent, in the small intestine (6.8%). The overall effect of microbial phytase on the extent of dephosphorylation of phytate within the upper tract is around 50%. Phytic acid also binds divalent cations such as calcium (Pallauf *et al.*, 1992a), magnesium and zinc (Palluaf *et al.*, 1992b), forming insoluble complexes under the pH conditions of the small intestine (pH 5-7). All authors reported a significant increase in mineral digestibility following microbial phytase addition to wheat-based diets. However, the increases were not of the magnitude of the increase in phosphorus digestibility (Pallauf *et al.*, 1992a,b). This is expected because phytase, being a phosphotase, is able to catalyse the hydrolysis of a phosphate-ester, cleaving off the phosphate from phytic acid to make the phosphorus available to the animal. However, in practical applications, phytase has other benefits including improved digestibility of amino acids in pigs (Mroz *et al.*, 1994) and poultry (Namkung and Leeson, 1999), and an increase in the apparent metabolisable energy of wheat in broiler chickens (Ravindran *et al.*, 1999). In a recent study, when weaner pigs were offered diets soaked in water for 24 hours, the addition of phytase was shown to depress feed intake (Chesworth, Cadogan, Brooks and Choct, unpublished data), whereas phytase significantly improved feed intake of pigs offered the unsoaked diets. It was postulated that steeping the diet enhanced the efficacy of the supplemental phytase, leading to the release of an excessive amount of phosphorus. This is supported by the study of Cabahug *et al.* (1999) who reported that phytase supplementation depressed the performance of chickens fed diets containing high levels of phytate and inorganic phosphorus. An imbalance in the available calcium to phosphorus ratio may be responsible for the depression in feed intake. Thus, it appears that to use phytase efficiently, the amount of phosphorus that will potentially be available to the animal must be taken into account when formulating the diet. There is also increasing evidence and recognition that phytic acid has a negative impact on protein digestibility and inhibits stomach and pancreatic proteolytic enzyme activity. The current understanding of the mechanisms of protein-phytate interactions and protein responses to exogenous phytase in monogastric animals has recently been reviewed (Selle *et al.*, 2000).

Xylanases

Enzymes capable of degrading NSP are used in pig diets on the presumption that the presence of these substrates impairs the digestibility of nutrients (King and Taverner, 1975). Xylanase (pentosanase) is one of the major glycanases used in the pig industry in Australia, since the main energy source for pigs is wheat, which contains high levels of arabinoxylans. The structure of wheat arabinoxylans is well characterised. It consists of a (1-4)- β-xylan backbone carrying side chains of arabinose on the second and/or the third carbons (Annison *et al.*, 1992). However, glycanase supplementation of wheat-based pig

diets elicited variable responses (Dierick, 1989, Dierick and Decuypere, 1994). Often a combination of enzymes has been used in pig studies, making it difficult to define the specific activities that are responsible for any increase in growth performance. For chickens fed wheat- and barley-based diets, one of the primary modes of action of feed enzymes is to reduce digesta viscosity in the small intestine (Choct and Annison, 1992). This effect is attributable to a reduction in the polymer length of soluble NSP such as arabinoxylans and β-glucans. Partridge (2001) pointed out the importance of predetermining the substrate level and the nutritional characteristics of the grain in relation to enzyme supplementation. Cadogan *et al.* (1999) demonstrated that when different wheat samples were included in a balanced, commercial-type weaner diet, the voluntary feed intake and growth rate of the pigs varied by 47% and 48%, respectively. Feed intake was negatively correlated (R^2=0.556) to the amount of non-starch carbohydrates (NSC=the sum of NSP, mono- and oligo-saccharides). In subsequent studies, enzymes were added to wheat-based diets to target these carbohydrates (Cadogan, 1999).

Table 11. Effects wheat type and supplementation of an enzyme with affinity for insoluble NSP on the performance of male pigs from 35 to 56 days of age commencing at 9 kg live weight (Cadogan, 1999).

Wheat variety	Enzyme addition	Weight at end (kg)	Daily gain (g)	Daily feed intake (g)	FCR[2] (g:g)
Currawong	-	14.01	309^{ab}	389^{a}	1.30
Currawong	+	13.62	253^{a}	323^{a}	1.28
Dollarbird	-	16.76	435^{c}	537^{b}	1.24
Dollarbird	+	15.44	345^{b}	442^{a}	1.29
Rosella	-	17.70	476^{c}	551^{b}	1.16
Rosella	+	18.06	478^{c}	583^{b}	1.21
Triller	-	19.29	562^{d}	691^{c}	1.23
Triller	+	20.23	596de	730^{c}	1.22
Lawson	-	19.34	567^{d}	691^{c}	1.21
Lawson	+	20.65	630^{e}	733^{c}	1.15
SEM		0.31	14.2	17.4	0.01
P values					
One way analysis[1]		0.01	0.01	0.01	0.17
Two way analysis					
Wheat (W)		0.01	0.01	0.01	0.52
Enzyme (E)		0.68	0.58	0.70	0.88
W x E		0.04	0.04	0.21	0.51

[a,b,c,d,e]Means in the same column with different superscripts are significantly different, P≤0.05). [1]One-way ANOVA was performed out to make multiple comparisons of means. [2]FCR, feed conversion ratio.

When a glycanase with affinity for only the insoluble NSP was added to diets based on five wheat samples having very different effects on feed intake, there was a significant interaction between the wheat variety and enzyme supplementation for daily gain (Table 11). The enzyme reduced daily gain and feed intake of the low quality wheats (Currawong and Dollarbird) but tended to increase voluntary feed intake and weight of pigs offered good quality wheats (Triller and Lawson). There was no effect on the wheat with moderate quality (Rosella). In a follow-up study, a xylanase with affinity for both the soluble and insoluble arabinoxylans was used on three wheats with predetermined nutritive quality (Currawong, Cacamba and Lawson – three varieties of wheat harvested

in 1997 which had distinctly differently effects on feed intake in weaner pigs: Currawong caused the largest, Lawson the least, and Cacamba an intermediate depression of feed intake) (Choct *et al.*, 1999). The enzyme had a marked effect on all three samples, in particular Currawong wheat, for which daily gain was increased by 50.6% and feed intake by 42.8% (Table 12). These data indicate that both soluble and insoluble NSP have negative effects on feed intake, and hence growth rate, in young pigs. This is clearly indicated by the interaction between the enzyme type and wheat quality on feed intake. As shown in Table 11, an enzyme that only solubilizes the insoluble NSP worked well in good quality wheat (Lawson), but had a negative effect on the poor quality wheat (Currawong). The difference between the two wheats was the level of NSC (Lawson 12.5% vs Currawong 16.5%). Thus, it is hypothesised that when the level of free sugars (some are osmotically active) and soluble NSP is low in the gut, it may be beneficial to break down cell walls (insoluble NSP) to release entrapped nutrients. However, when the background level of free sugars and soluble NSP is high, such as in the case of Currawong, the release of a large amount of soluble NSP could lead to increased digesta viscosity, which masks the benefit of breaking down the cell walls. Further support of this hypothesis comes from the data presented in Table 12, where an enzyme capable of rupturing the insoluble cell walls and breaking down both the native and released soluble NSP improved the feed intake of pigs fed various wheats.

Although responses to enzyme supplementation have been more consistent and prevalent in younger pigs, a number of studies have recorded improvements in growth performance of older pigs offered wheat-based diets supplemented with exogenous glycanases (Partridge, 2001). Recent studies (Tables 13 and 14) at Bunge Meat Industries have shown large improvements in growth performance of older pigs (over 25 kg) resulting from exogenous xylanase supplementation of diets containing low quality wheats and wheat by-products (Cadogan *et al.*, 2000).

Table 12. Effect of wheat type and supplementation of a xylanase with affinity for both soluble and insoluble NSP on the performance of male pigs offered diets for 21 days commencing at 7.3 kg live weight (Choct *et al.*, 1999).

Wheat variety	Enzyme addition	Weight at end (kg)	Daily gain (g)	Daily feed intake (g)	FCR[2] (g:g)
Currawong	-	12.10[a]	230[a]	318[a]	1.38
Currawong	+	17.10[b]	466[b]	556[b]	1.23
Cocamba	-	16.26[b]	425[b]	540[b]	1.27
Cocamba	+	16.72[b]	445[b]	521[b]	1.20
Lawson	-	16.96[b]	460[b]	525[b]	1.14
Lawson	+	17.31[b]	479[b]	570[b]	1.20
SEM		0.296	13.9	13.4	0.02
P value					
One way analysis[1]		0.01	0.01	0.01	0.06
Two way analysis					
Wheat (W)		0.01	0.01	0.01	0.07
Enzyme (E)		0.01	0.01	0.01	0.12
W x E		0.01	0.01	0.01	0.21

[a,b]Means in the same column with different superscripts are significantly different ($P \leq 0.05$). [1]One-way ANOVA was carried out to make multiple comparisons of means. [2]FCR, feed conversion ratio.

Table 13. Effect of xylanase on performance of pigs, commencing at 27 kg live weight, offered high, medium and low quality wheat based diets (Cadogan et al., 2000).

Treatment	Xylanase addition	Finish weight (kg)	Daily gain (g)	Daily feed intake (kg)	FCR[2] (g:g)
Control (wheat-high)	-	61.9	960[a]	1.77[a]	1.84
Wheat- medium	-	60.2	918[ab]	1.62[ab]	1.80
Wheat- medium	+	61.2	945[a]	1.71[ab]	1.81
Wheat- low	-	58.3	878[b]	1.58[b]	1.76
Wheat- low	+	61.5	952[a]	1.73[a]	1.81
SED[1]		0.65	12.4	0.033	0.021

[a,b]Means in the same column with different superscripts are significantly different (P≤0.05). [1]SED, standard error of difference between means. [2]FCR, feed conversion ratio.

Table 14. Effects of xylanase supplementation on wheat and wheat by-product (millrun) based diets commencing at 27 kg live weight (Cadogan *et al.*, 2000).

Treatment	Xylanase addition	Finish weight (kg)	Daily gain (g)	Daily feed intake (kg)	FCR[2] (g:g)
Wheat control	-	62.3	945	1.92	2.03[b]
Wheat +20% millrun	-	61.5	926	2.15	2.33[a]
Wheat +20% millrun	+	63.4	986	2.01	2.04[b]
SED[1]		0.75	14.9	0.033	0.028

[a,b]Means in the same column with different superscripts are significantly different (P≤0.05). [1]SED, standard error of difference between means. [2]FCR, feed conversion ratio.

β-Glucanases

In poultry, β-glucanases were the first enzymes used successfully on a commercial scale. Increases of up to 17% in live weight gain (Broz and Frigg, 1986) and 19% in feed conversion efficiency (Newman and Newman, 1987) have been reported for broiler chickens fed barley diets supplemented with β-glucanases. Barley contains a high level (30-50 g/kg) of β-glucans, which are glucose polymers containing a mixture of β (1-3) and β (1-4) linkages. The physicochemical properties of β-glucans are very different from cellulose, which is a straight-chain glucose polymer with only β (1-4) linkages. Diets high in soluble NSP, such as β-glucans, are in general poorly utilised by pigs (van Barneveld, 1997). In pigs, differences up to 4 MJ in the DE value between barley cultivars have been reported (van Barneveld, 1999). Growing conditions, rather than variety, appear to represent the larger source of variation in the nutritive value of barley for pigs (Fairbairn *et al.*, 1999), and therefore use of appropriate β-glucanases in pig diets containing high levels of barley will be beneficial in reducing this variability in nutritive quality. Partridge (2001) comprehensively reviewed the literature regarding the use of β-glucanases in pig diets. From this review, it is clear that in most cases β-glucanase supplementation can improve the performance of pigs fed diets containing high levels of barley, particularly when the barley is a hull-less variety. This is because the β-glucan in barley is concentrated in the endosperm of the grain. Baidoo *et al.* (1998, cited by Partridge, 2001) demonstrated that β-glucanase supplementation of diets based on hull-less barley increased daily gain by 12% in pigs ranging in body weight between 9-12 kg, and 17% in those ranging in body weight between 20-40 kg. Barley also contains an appreciable amount of soluble NSP other than β-glucans. Barley diets, therefore, generally require supplementation with enzymes having both β-glucanase and xylanase activities.

Mode of action of glycanases to increase pig growth performance

Effect of non-starch polysaccharides on the rate of passage of digesta and water holding capacity

Gastric emptying and distension of the stomach are two factors affecting satiety in the pig (Forbes, 1995). When highly digestible diets are progressively diluted with crude fibre, daily feed intake increases, the DE intake remains relatively constant and pig performance is hardly affected. Beyond a critical level of crude fibre, however, feed intake and digestible energy content will fall and performance will decrease due to a nutrient dilution effect of the fibre both in pigs (Owen and Ridgman, 1967) and poultry (Mraz *et al.*, 1957). The critical point has been assumed to reflect the capacity of the animal for 'bulk' or 'gut fill'. Kyriazakis and Emmans (1995), using experimental diets with graded levels of fibre (obtained by replacing the control diet with wheat bran, with the highest wheat bran control being 96.93% of the diet), reported that voluntary feed intake of young pigs decreased in a quadratic manner as the water holding capacity of the diet increased (Figure 9). It is postulated that the presence of a large amount of soluble NSP in the digesta could trigger a feedback loop for "gut fill". This might occur by one, or both, of the following two mechanisms: (a) high digesta viscosity resists the propulsive actions of the intestinal contractions and thus reduces digesta flow, and (b) increasing the physical bulk of the digesta increases their ability to hold a large amount of water. Both soluble and insoluble NSP hold a large amount of water, although the ability of the soluble fraction to hold water is twice that of the insoluble fraction. For example, each gram of carboxymethylcellulose (soluble) and coarse bran (insoluble) can retain 13.5 g and 6.15 g water, respectively (Kirwan *et al.*, 1974; Bourguin *et al.*, 1993). The relationship between water holding capacity of NSP and feed intake in pigs is suggested by the study of Brouns *et al.* (1991), who found that the depression of voluntary feed intake of sows was greater for diets containing a high level of sugar-beet pulp (largely soluble, pectic polymers) than for those containing straw and rice bran (insoluble).

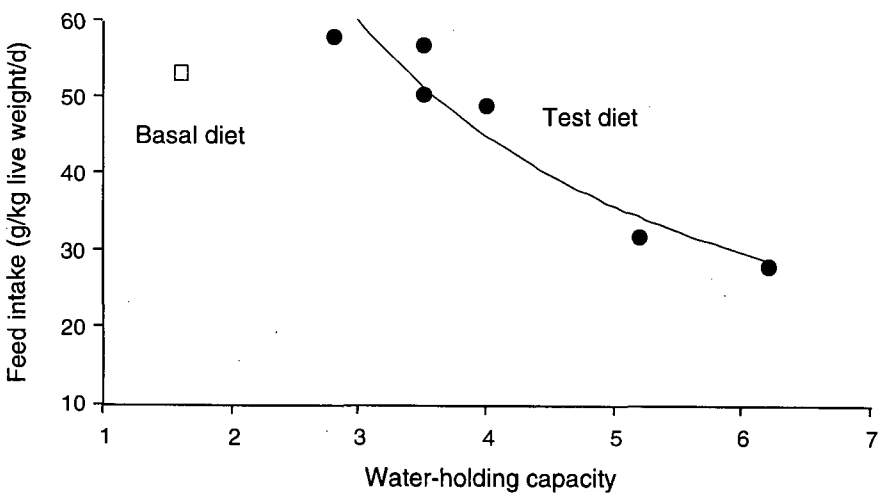

Figure 9. *Relationship between water holding capacity and feed intake in pigs (Kyriazakis and Emmans, 1995).*

The relationship between water-holding capacity of NSP and feed intake in pigs fed experimental diets with high fibre contents, however, may not be the same in pigs fed practical diets. Nevertheless, the dietary fibre content of the diet is probably not the only factor affecting the water-holding capacity of digesta. It is thought that NSP may undergo changes within the gastrointestinal tract of the pig, especially under the acidic conditions of the stomach. For example, some ester linkages may be cleaved, resulting in

solubilization of part of the originally insoluble NSP. Entangling of various carbohydrate molecules in solutions can lead to the formation of highly strengthened gel network (Fincher and Stone, 1986). Such a gel could increase the water holding capacity of NSP in the gut. Enzymes capable of cleaving these polysaccharides can reduce their effect on viscosity and restore normal digesta flow. This is probably one of the reasons why enzyme supplementation increases feed intake of pigs fed poor quality wheats.

The rate of starch digestion may also influence voluntary feed intake. For the amylolytic enzymes to digest starch, not only must the grain be broken down (ground), but it also must be well hydrated. The ability of grains to take up moisture varies widely (Dr Tom Scott, Agriculture Canada, personal communication), which may result in a slow rate of starch digestion in the upper part of the gut. Since starch makes up 40-50% of the diet its rate of disappearance from the lumen would affect the "gut fill" in a given time, and in turn could influence satiety. Selby *et al.* (1999) examined the effects of steeping time and enzyme supplementation on performance of weaner pigs, and demonstrated that the marked effect of the exogenous enzymes on feed intake was totally negated by steeping the feed for 15 hours (Table 15). It was considered that endogenous glycanases were probably activated when the moisture content of the diet was elevated (water to feed ratio, 2:5). However similar diets, both before and after steeping exhibited negligible glycanase activities (K. Chesworth, unpublished data), highlighting the importance of hydration *per se* on the feeding value of wheat for pigs.

Table 15. Effects of mixing time and xylanase supplementation in liquid fed, wheat based diets on weight gain, feed intake and feed conversion ratio of male pigs between 28 and 49 days of age (Selby *et al.*, 1999).

Mixing time (h)	Enzyme addition	Start wt (kg)	21-d wt (kg)	Gain (g/d)	Intake (g/d)	FCR[1] (g:g)
1	-	8.32	14.19	279	310	1.16
1	+	8.28	15.02	321	359	1.14
15	-	8.28	15.42	340	364	1.07
15	+	8.28	15.08	324	388	1.21
P value						
Mixing time (M)		0.91	0.03	0.03	0.01	0.77
Enzyme (E)		0.91	0.35	0.35	0.01	0.18
M x E		0.91	0.05	0.05	0.26	0.06

[1]FCR, feed conversion ratio.

Viscosity

Viscous polysaccharides can increase the viscosity of the gut content that, in poultry, plays a major part in the anti-nutritive effect of NSP (Classen and Bedford, 1999). In the pig, however, the effect of digesta viscosity is not clearly understood. The water content of pig digesta is very high and therefore the effect of soluble NSP on gut viscosity is not of the same magnitude as in poultry (Dänicke *et al.*, 1999). Consequently, a relationship between gut viscosity and feed intake has been difficult to demonstrate (Cadogan, 1999). However, the contrasting effects of glycanases with affinity for insoluble, or both soluble and insoluble NSP (see Tables 12 and 13), on different wheats suggests that soluble NSP have significant negative effects on feed intake in pigs. In addition to viscosity effects, soluble NSP increase the secretion of endogenous protein in chickens (Angkanaporn *et al.*, 1994). The gut secretes some 20 hormones or regulatory peptides (Uvnäs-Moberg 1992), some of which enhance nutrient absorption, and others that depress it. The possible influence of satiety, and hence feed intake by dietary NSP or their intermediate products (from enzymatic digestion by exogenous enzymes in the small intestine or from microbial degradation in the large intestine), has yet to be demonstrated.

Non-starch polysaccharides and the gut microflora

There is no doubt that dietary carbohydrates are the main modulator of the gut microflora in monogastric species (Chesson, 1994). Small molecular weight carbohydrates can selectively stimulate the beneficial microflora, such as the *Bifidobacteria* spp. and *Lactobacillus* spp. It is believed that through such an action, these carbohydrates displace the harmful bacteria from the gut. In a production situation, this can mean reduced mortality and morbidity in the herd, an effect that could be exacerbated if antibiotic growth promotants are removed from the feed. Feed enzymes can produce considerable amounts of low molecular weight carbohydrates *in situ* (Austin *et al.*, 1999; Kocher *et al.*, 2001), which may benefit the host by stimulating the beneficial flora. Currently, the commercial enzyme products are not designed to produce the amount and type of oligomers required for establishing specific gut microflora. There is also no control of the "secondary effects" on the host that can be expected from enzyme supplementation of animal diets (Choct and Kocher, 2000). In reality, it will also be some time before enzymes are tailor-made for their effects on the gut microflora because the substrate structure and the physiological conditions of the gut will also influence the type and amount of oligomers that could be produced by a given enzyme. On the other hand, through modulation of the gut microflora and physiology, enzymes can have a partial role in replacing the effect of antibiotics in feed on increasing production efficiency (Chesson and Stewart, 2001) and, in some cases, preventing proliferation of enteric pathogens (e.g., reduction in *Campylobacter jejuni* numbers in broiler chickens; Fernandez *et al.*, 2000).

Conclusion

Although enzymes are used regularly in pig diets, the mechanism(s) of action, apart from that for phytase, are not well elucidated. Also, the aim of using glycanases such as xylanase and β-glucanase is not always clear as many researchers look for an increase in digestibility of nutrients or FCR, whereas feed intake is a crucial parameter for young (weaner) pigs. The possible mechanisms by which NSP influence feed intake may include: reduced passage rate of digesta, a decrease in the rate of starch digestion in the small intestine, and an influence on satiety through changes in secretion of endogenous proteins such as hormones. More research into characterisation of the substrate structure and gut dynamics in relation to glycanase application is required for a clearer understanding of factors that affect grain quality for pigs.

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SYMPOSIUM CONCLUSIONS

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The overriding impetus for this symposium is the realisation that demand for feed grains in the livestock industries is increasing at a faster rate than any increases in supply due to greater yields per hectare. Some reductions in the demand for grain can occur through decreased feed wastage and increased efficiency of grain use through more accurate diet formulation. A better definition of the nutritional quality of grains and factors that influence their utilisation in the pig *in vivo* also has potential to improve the utilisation of grains, as well as to open alternative avenues for grain marketing and price setting. Collectively, these improvements will enhance the productivity, profitability and sustainability of the pig industry.

When examining ways to sustain supply and improve utilisation of feed grains by the pig industry, Black (1997) commented that it was vital to understand the chemical characteristics and nutritional chemistry of feed grains to improve the efficiency of pig production. Consequently, the Premium Feed Grains for Livestock program was established in 1997. The broad objectives of the programme (modified from Black, 1997) were as follows:

1. Identify the reasons and magnitude of differences in the nutritional values of commonly-used feed grains for pigs, poultry and ruminants. Improvements in feed grain quality may then be achieved through strategies such as plant breeding, processing and feed manipulation (e.g., liquid feeding), and strategic enzyme use;

2. Develop and assess the use of rapid tests of nutritional quality; and

3. Develop and upgrade computer simulation models that accurately predict the consequences of grain characteristics, grain processing and storage on animal productivity and profitability.

It is evident from the data presented by van Barneveld *et al.* (2001) that some of these objectives are now being met. A cross-species comparison allied to detailed chemical analyses of grains permitted some conclusions to be made regarding grain quality, with the cell wall quantity, size and structure having a significant influence on the amount of 'available' energy the pig can derive from a given grain. Nevertheless, comparison across grain types indicated that gross chemical composition only partly explains energy digestion in pigs. As such, van Barneveld *et al.* (2001) showed succinctly that determination of energy digestion at the end of the small intestine is a more sensitive indicator of net energy than DE content. The industry must now develop technologies to implement and take advantage of these findings, perhaps using a ratio of ileal to faecal energy digestion. Van Barneveld *et al.* (2001) also demonstrated that cell size in sorghum may be restricting the digestion of energy in the small intestine of pigs presenting opportunities to investigate grind size and the application of proteinases and cellulases with this grain. Nevertheless, an appreciation of the entire system of pig production is required when considering such findings. For example, fine grinding of sorghum might increase the digestibility of energy at the terminal ileum, but what are the consequences for the pig with regard to gastric ulceration?

A key component of enhanced ileal digestibility of energy is the cell wall of the grain, particularly with regard to the starch component. Autio (2001) highlighted the potential of light microscopy and other techniques to study, both before and after feeding, the cell wall structure of grains. These techniques can be harnessed to study, for example, the effects of different processing (e.g., particle size) and feed treatment (e.g., liquid pre-treatment of grain) methodologies on the utilisation of grains. If these *in vitro* methods prove to be sensitive indicators of energy digestibility, particularly at the ileum, then the

logical extension of these techniques is an 'energy yield' prediction of feed grain quality based on histological characterisation of grains.

The paper presented by Choct and Cadogan (2001) in this symposium reviewed current knowledge and understanding of enzyme applications in the pig industry. It is evident that mechanism(s) of action, apart from phytase, are relatively poorly understood and likely to hinder the expansion of enzymes into the pig industry. In the young pig for example, this is related in part to a lack of understanding in basic digestive physiology. The rationale and emphasis for enzyme also requires addressing (or readdressing) since, and as shown in this paper, voluntary food intake is often a better indicator of an enzyme's efficacy than growth rate and FCR. Clearly further research is needed in the area of supplementary enzymes, especially concerning interactions between the substrate, the structure of the substrate and digestive and absorptive physiology. Consideration needs to be extended also to include the effects of agronomic and geographical factors on enzyme usefulness and the potential gut 'health' benefits of oligosaccharides that result from enzyme hydrolysis of feed grains.

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PLASMA UREA N (PUN) – A RAPID METHOD FOR ANALYSES OF PROTEIN QUALITY AND AMINO ACID REQUIREMENTS?

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Plasma urea N (PUN) concentration in monogastric animals has for many years been known to be influenced by the dietary protein supply (Eggum, 1970). Thus, PUN is a direct response to the quantity and quality of the digested protein. Because this method has not been commonly used a standardised method was developed (Pedersen and Boisen, 2001). The purpose of this study was to investigate the agreement between the theoretical biological value (BV) of dietary protein and the response in PUN in growing pigs.

Experimental diets based on single protein sources, i.e., barley, wheat and casein, were prepared. The protein quality of all diets was fortified step-wise by supplementation with amino acids, according to their expected order of limitation of protein utilisation. The improvements in BV were based on standardised ileal digestible amino acids in the protein sources and the ideal protein for slaughter pigs proposed by Boisen (1997).

Five female pigs (Danish Landrace x Yorkshire) of 30 ± 2 kg live weight (mean ± SD, LW) were fitted with a catheter in the jugular vein and used in a Latin square design. The pigs were housed individually in a temperature-controlled room (20-22°C) with free access to water. All pigs were fed the same quantity of feed, about 10 % below *ad libitum* intake to assure a quick and controlled intake. Feed, mixed with water, was provided at 0800 and 1600. Amino acids were added to the mixture immediately before feeding. Blood samples were collected after four feeding periods finishing with the morning feeding on the day of blood sampling. Five ml of blood was sampled in heparinized tubes 30 min before the morning feed and again 2, 4 and 6 hours, after feeding, and PUN was determined in the samples.

From statistical analyses of the response curves of PUN the results were found to generally correlate well with the theoretical BV (Table 1). The results indicate that an amino acid in the EAA mixture is co-limiting with threonine in barley protein.

Table 1. Response in plasma urea N (PUN) after feeding experimental diets based on wheat, barley and casein, all stepwise fortified with limiting essential amino acids.

	Wheat		Barley		Casein	
Amino acid supply	BV[1] (%)	PUN (mg/dl)	BV (%)	PUN (mg/dl)	BV (%)	PUN (mg/dl)
-	44	25.5 ± 1.3	48	22.1 ± 1.1	-	-
Lys	60	16.5 ± 1.3	60	14.6 ± 1.1	-	-
Lys, Thr	87	13.0 ± 1.3	82	15.1 ± 1.6	-	-
EAA mixture[2]	92	11.6 ± 2.3	94	8.8 ± 1.9	-	-
Met, Thr	-	-	-	-	99	4.4 ± 0.9

Abbreviations: Lys: lysine; Thr: threonine; EAA: essential amino acids; Met: methionine. [1]BV, theoretical biological value. [2]EAA mixture, lysine, threonine, tryptophan, isoleucine, leucine, valine and histidine.

It was concluded that PUN responses, with the developed procedure, are very sensitive and give a reliable measure of protein imbalance in pigs. Hence, the method has the potential for proper and fast analyses of protein quality. Furthermore, the procedure can be used, for a more direct response than growth and feed utilisation, in studies on the requirements of individual essential amino acids.

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IMMUNOHISTOCHEMICAL LOCALIZATION OF TRANSFORMING GROWTH FACTOR RECEPTORS IN THE SMALL INTESTINE OF NEONATAL PIGS

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Transforming growth factor-β (TGF-β) is a multifunctional cytokine involved in regulation of immune cell activity and epithelial cell proliferation and differentiation (Roberts and Sporn, 1993). This cytokine has been detected in milk of various species including the pig (Xu *et al.*, 1999), and may play an important role in postnatal adaptation of the intestine in neonatal animals (Xu *et al.*, 2000). Transforming growth factor-β exerts its multiple functions through interaction with two types of transmembrane receptors (type I and type II). The type II receptor (RII) is an active serine/threonine kinase and determines the ligand specificity. After the initial binding of TGF-β to RII, the ligand and RII complex activates the type I receptor (RI) through phosphorylation; the latter then propagates the signal. There is also a third transmembrane protein molecule, known as betaglycan, which binds and presents TGF-β to signaling receptors. All the TGF-β receptors have been found in the intestinal mucosa in neonatal rats (Zhang *et al.*, 1999), but existence of the receptors in the neonatal pig intestine has not been reported. The aim of this study was to localize TGF-β receptors in the small intestine (SI) of neonatal pigs.

Fresh jejunal and ileal tissue specimens were collected from four newborn-unsuckled, and four 1-day-old, four 3-day-old and one 7-day-old sucking, Landrace x Large White, piglets. Tissue samples were fixed in Bouin's fluid, dehydrated in a series of alcohol solutions and embedded in paraffin wax. Cross sections of tissue were deparaffinized in xylene, rehydrated in increasing dilutions of alcohol, and were then immersed in phosphate buffered saline. Endogenous peroxidase activity was blocked by incubation in 1% H_2O_2 for 30 min and nonspecific binding was blocked by incubation in 2% normal goat serum for 30 min. The receptors were detected by incubation with specific antibodies (Santa Cruz Biotech, CA, USA) and visualized using the biotin-streptavidin-peroxidase system (Amersham, Hong Kong).

In newborn unsuckled piglets, TGF-β receptors I and II were localized on apical and basal membranes of villus epithelial cells along the SI. Epithelial cells at the intestinal crypts were largely negative while epithelial cells at the villus tip were intensively stained, particularly at the apical side of the cells. Positively stained individual cells, probably blood leukocytes, were scattered in the lamina propria and submucosa. Numerous lymphocytes in the Peyer's patches in the ileal region of the SI were also positively stained. In 1- and 3-day-old sucking piglets, the staining of villus epithelial cells with RI and RII specific antibodies was much weaker compared with that in newborn unsuckled piglets, possibly due to a down-regulation of RI and RII following exposure to colostrum-borne TGF-β. However, positively stained leukocytes were more abundant in the lamina propria and the submucosa along the SI in 1- and 3-day-old piglets than in the newborn unsuckled piglets. In the 7-day-old sucking piglet, villus epithelial cells were positively stained with RI and RII specific antibodies and the staining was more intensive at the basal membrane of the cell, likely corresponding to a shift of exogenous colostrum-borne TGF-β to endogenous produced ligand. The betaglycan capable of presenting TGF-β to the signaling receptors was broadly located on both villus and crypt epithelial cells with no obvious differences among animals of different ages.

This study demonstrated for the first time the existence of TGF-β receptors on the SI epithelial cells and lymphocytes in neonatal pigs, and that transient changes of receptor density follow the onset of sucking. The findings support the hypothesis of a regulatory role of colostrum-borne TGF-β in postnatal adaptation of the SI in neonatal pigs.

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LIVE PERFORMANCE OF WEANER PIGS FED CANOLA SEED

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Whole canola seed contains up to 40% oil and a reasonable quality protein. Canola seed has potential as an alternative energy and protein source in pig diets depending on price and availability of traditional ingredients. However, canola seed contains small amounts of anti-nutritional factors (e.g., glucosinolates and sinapine) that may depress thyroid function and/or affect food intake in pigs. This study was designed to assess the growth and metabolic implications of using milled canola seed in weaner pig diets.

Thirty male Large White x Landrace crossbred piglets, 8.5 ± 0.30 kg live weight (mean ± SEM), were allocated to a randomised block experiment consisting of three dietary treatments each containing 0.8 g available lysine and 15 MJ DE per kg. The three diets included a). a triticale-based diet supplemented with a solvent extracted canola meal (64.2 g/kg) and canola oil (30 g/kg); b). a triticale-based diet supplemented with milled canola seed (100 g/kg); and c). a commercial diet (Eziwean; Ridley AgriProducts) that contained no canola ingredients. Levels of protein (215 g/kg), oil (400 g/kg) and glucosinolates (7 mmol/kg) were estimated in the whole canola seed using near-infrared reflectance and used in diet formulation.

The pigs were housed in individual weaner cages. Food and water was available *ad libitum* and room temperature was maintained at 27°C. The experiment was conducted for 21 days. Measurements included food intake and live weight at the start and finish of the experiment. At the end of the experiment a blood sample (8 ml) was collected from each pig to assess thyroid activity (T3, tri-iodothyroxine and T4, thyroxine).

Table 1. Mean (± SEM) live performance[1], and serum concentrations of tri-iodothyroxine (T3) and thyroxine (T4) for piglets offered diets containing either canola meal + canola oil, milled canola seed or a commercial diet containing no canola.

Treatment	Canola meal + oil	Milled canola	No canola	SEM	Sig[2]
Daily intake (g)	638[a]	644[a]	767[b]	29.0	**
Daily gain (g)	462[a]	462[a]	568[b]	17.0	**
Feed:gain (g/g)	1.46	1.47	1.41	0.040	NS
T3 (ng/ml)	1.1[a]	1.0[a]	1.3[b]	0.05	**
T4 (ng/ml)	43.4[a]	34.6[b]	59.6[c]	2.30	*

[1]Mean live performance adjusted for initial live weight. [2]Significance. [a,b,c]Means in rows with different superscripts differ significantly at *P≤0.05 or **P<0.01.

There was no significant difference in daily gain or feed:gain between pigs fed diets containing either canola meal plus canola oil or milled canola seed. However, daily feed intakes, and consequently growth rates were depressed by 20% in pigs fed diets containing canola ingredients compared to the commercial diet with no canola ingredients. Pigs fed diets containing canola ingredients also exhibited a significant decline in serum T3 and T4 concentration compared to pigs fed the commercial diet. Further research is required to establish the significance of thyroid function on feed intake and growth in pigs fed diets containing canola meal and/or canola seed.

Canola seed is an acceptable alternative energy and protein source for pig diets. However, the results suggest that anti-nutritional factors in canola affect thyroid function in weaner pigs, reducing serum T3 and T4 concentrations, which in turn may affect food intake. Nutritionists need to consider the metabolic and growth implications of including canola meal and/or canola seed in weaner pig diets.

GROWTH PERFORMANCE AND FEED INTAKE OF MALE PIGS (8-10 KG LIVE WEIGHT) FED AUSTRALIAN WHEAT CULTIVARS

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Wheat cultivar has been shown to influence the voluntary feed intake and daily gain of young male pigs when included at rates of 650 g/kg in balanced diets (14.5 MJ digestible energy (DE)/kg; 0.8 g available lysine/MJ DE), but with no effect on feed:gain (Cadogan *et al.*, 1999). The variation among cultivars has been attributed to cell wall characteristics and the quantity and structure of non-starch polysaccharides in the grain (Choct *et al.*, 1999). To further explore the influence of wheat cultivar on the performance and feed intake of young pigs, four cultivars of wheat grown at different sites and in variable conditions were examined.

Ten samples of wheat were obtained from across Australia representing four cultivars: Currawong, Janz, Kukari and Sunstate. One of the samples of Janz was severely frost affected and hence was considered separately. Experimental diets were formulated to contain 940 g/kg of the test grains, the remainder consisting of dicalcium phosphate, salt, minerals, vitamins and choline chloride. Celite® was included as an indigestible marker. One hundred and twenty male pigs with an average live weight (LW) of 8.0 kg were selected and placed in individual pens. Pigs were fed a nursery diet for 3 days prior to experimentation and were then reweighed and allocated to one of 10 experimental diets based on a randomised block design with 12 pigs/diet. The pigs were fed *ad libitum* and water was available without restriction over a period of 21 days. The data were statistically analysed using an analysis of variance.

Table 1. Average daily gain (g), feed conversion ratio (FCR) and average feed intake (g/d) of male pigs (8-10 kg LW) fed different wheat varieties for 21 days.

Wheat cultivar	n	Average daily gain (g)	FCR	Feed intake (g/d)
Currawong	3	58^{a}	4.6^{ab}	253^{ac}
Janz	3	52^{ac}	4.7^{ab}	235^{a}
Janz (frosted)	1	100^{b}	3.0^{c}	272^{bc}
Kukari	1	50^{ac}	4.1^{ac}	225^{a}
Sunstate	2	43^{c}	5.4^{b}	230^{a}
Statistics				
SEM[1]		2.7	0.156	4.7
P		0.001	0.001	0.035

[a,b,c]Values in a column with different superscripts are significantly different (P≤0.05).
[1]SEM, standard error of mean.

No significant difference (P>0.05) in the measured parameters existed among samples within a cultivar, so the data were pooled to facilitate a comparison among cultivars. Contrary to expectations the average daily gain, feed conversion ratio and feed intake of pigs fed the frosted sample of Janz was superior. Increased feed intake may have resulted from lower net energy contributions from this sample, due to reduced starch content, while growth rate and feed conversion ratio may have been significantly influenced by gut fill. This is supported by the apparently poor growth performance of pigs fed Sunstate, which had the highest starch content.

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COMPARISON OF CHICKPEA (*CICER ARIETINUM*) VARIETIES IN DIETS OF GROWING PIGS

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The increase in chickpea (CP) cultivation in Queensland will provide pig growers with additional opportunities to use CP in pig diets. However, feeding high levels of CP is not practiced because they contain high concentrations of protease inhibitors. Trypsin and chymotrypsin inhibitor activity (TIA and CTIA) of current varieties of CP were determined. The TIA of Amethyst chickpea (CPA) and Barwon chickpea (CPB) were 6.9 and 4.1 mg/g respectively (D.N. Singh, unpublished results). Chymotrypsin inhibitor activity was not detected in either of the varieties. However, mean TIA and CTIA in CP (4.79 and 7.72 mg/g respectively) were reported by Petterson and Mackintosh (1994).

An experiment was conducted to evaluate inclusion level of two CP varieties in diets for both male and female grower (20-50 kg live weight, LW) and finisher pigs (50-90 kg LW). Individually housed pigs were fed diets containing 0, 10, 20, 30 and 40% of CP varieties. All 18 factorial treatments were replicated 3 times in a randomised complete block design. A total number of 54 Large White pigs were used. Diets were formulated to 14 and 13 MJ DE/kg and 0.63g and 0.55 g available lysine/MJ DE for growers and finishers respectively. Chickpea was added at the expense of sorghum and plant and animal protein meals.

Results indicated that there were no significant difference among the diets in terms of growth rate (kg/d) and feed:gain ratio in grower and finisher phases and the P2 measurement taken at 90 kg LW (Table 1). There were no significant variety main effects or variety interactions with inclusion level or sex. There were significant sex main effects for growth rate in the finisher phase and feed:gain ratio in both growers and finishers. Growth rate of males (1.135 kg/d) was significantly greater ($P<0.05$, $LSD_{0.05} = 0.067$) than females (1.046 kg/d) in the finisher period. Feed:gain ratios for males and females were 2.08 vs 2.32 ($P<0.05$, $LSD_{0.05} = 0.18$) and 2.43 vs 2.70 ($P<0.05$, $LSD_{0.05} = 0.14$) in growers and finishers, respectively.

Table 1. Effect of feeding graded levels of Barwon and Amethyst chick peas in diets for pigs growing from 20 to 90 kg live weight (LW).

Diet	Grower (20-50 kg LW)		Finisher (50-90 kg LW)		
	Growth rate (kg/d)	Feed:gain	Growth rate (kg/d)	Feed:gain	P2 (mm)
Control	1.036	2.35	1.040	2.65	13.5
Barwon 10	1.039	2.08	1.107	2.58	14.7
Barwon 20	1.079	2.25	1.057	2.44	13.5
Barwon 30	1.073	2.34	1.083	2.55	14.5
Barwon 40	1.007	2.19	1.138	2.57	15.2
Amethyst 10	1.070	2.27	1.083	2.58	13.9
Amethyst 20	1.060	2.29	1.119	2.54	14.7
Amethyst 30	0.983	2.27	1.040	2.63	15.5
Amethyst 40	0.974	1.78	1.150	2.59	13.3
Significance	NS[1]	NS	NS	NS	NS

[1]NS = Not Significant

There is a tendency for growth depression in the grower phase as the inclusion level of CPA increased, although this was not significant. This could be due to higher anti-nutritional factors in CPA. Diets containing up to 400g/kg CP has no deleterious effect on pig performance.

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VARIABILITY OF WATER INTAKE IN GROWING PIGS

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Water medication is promoted as an efficient means of delivering mass-medication to growing pigs and reducing the risk of residues in pork (Pointon *et al.*, 1995). However, recent studies in sows have demonstrated a wide variation in daily water intakes that are unrelated to body weight (Cargill *et al* 1999). The study was designed to determine if variations in water consumption, similar to those recorded in sows, occur in growing pigs. Such a finding would increase the risk of antibiotic residues in pork when pigs are being medicated via the water.

Water consumption was measured over a 24-hour period for five consecutive days in three experiments. Three groups of 10 Large White cross pigs, with a mean body weight (BW) of 50 kg (range 48 to 55kg), were used in the first experiment. Pigs with mean body weights of 70 kg (range 67 to 73 kg) and 90 kg (range 86 to 93 kg) were used in the second and third experiments respectively.

Pigs were offered a standard commercial diet *ad libitum* and were housed in individual pens. Each pen was fitted with one mono-flow® nipple drinker attached to an individual overhead tank. Flow rates were checked daily. A curved metal plate was placed below the nipple to collect all water that was spilt. The amount of spilt water was measured and deducted from the total water used to obtain the daily consumption for each pig. The quantity of water consumed during each 24 hour period was recorded and the group mean (± SE) for water consumption for a five day period calculated (Table 1).

Table 1. The group mean (± SE) of the mean daily (24 h) water consumption and water wastage for each pig over a period of 5 days and the mean (± SD) for daily water consumption for pigs with the 10% lowest and 10% highest consumption levels.

Experiment	50 kg pigs (BW[1]) (Experiment 1)	70 kg pigs (BW) (Experiment 2)	90 kg pigs (BW) (Experiment 3)
Water consumed (l)	3.94 ± 0.13	5.74 ± 0.37	5.92 ± 0.29
Range (l)	0.50–11.75	1.00–13.50	2.25–11.75
Water wasted (l)	3.06 ± 0.29	4.54 ± 0.64	2.47 ± 0.37
Range (l)	0.98–8.25	0.60–11.95	0.85–3.85
Lowest 10% consumption (mean ± SD)	2.81 ± 0.25	3.98 ± 1.88	4.05 ± 1.05
Highest 10% consumption (mean ± SD)	6.10 ± 0.62	10.75 ± 1.88	8.10 ± 2.35

[1]BW, Bodyweight.

The mean water consumption by growing pigs was less than that recorded for sows (Madec *et al.*, 1986, Cargill *et al.*, 1999) and the day to day variation for individual animals was also smaller. However, the 10% of pigs with the highest water intake consumed 2.09, 2.70, and 2.00 times as much water as the 10% of pigs with the lowest intake respectively at 50 kg, 70 kg, and 90 kg BW. Hence, in a pen of 30 pigs (70 kg BW) being medicated for the mean weight of the group, three pigs will receive less than 70% of the required dose, while three pigs will receive 1.5 times the required dose. In the latter case, withholding periods may become invalid and the risk of residues will be increased.

The results also confirm that water wastage is a significant problem with growing pigs using nipple drinkers. In these experiments, pigs wasted from 30% to 44% of water used.

The results indicate that caution needs to be exercised when medicating pigs via drinking water to avoid over and under dosing animals.

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EFFECT OF XYLANASE IN DIETS CONTAINING PRE-CHARACTERIZED WHEAT VARIETIES ON THE PERFORMANCE OF WEANER PIGS

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Previous studies (Partridge *et al.*, 1999) have shown that the level of improvement in voluntary feed intake of pigs fed xylanase-supplemented wheat-based diets was dependent on the initial quality of the wheat. Two wheat cultivars (Stiletto and Currawong) were chosen which had similar digestible energy (DE) values (13.3 and 13.4 MJ/kg DE, respectively; Kim *et al.*, 2001), but different feed intake responses in weaner pigs when included at 90% in the feed (higher with Currawong). In this study the two cultivars were compared in a performance trial using conventional wheat-based diets that were titrated with multiple levels of a xylanase-based product.

Sixty, 21-day-old male pigs (Large White x Landrace) averaging 5.9 kg live weight were stratified on the basis of weight at weaning. Two wheat-based weaner diets, with Stiletto and Currawong included at 650 g/kg, were formulated to contain 14.5 MJ DE/kg and 0.85 g lysine/MJ DE. Porzyme® 9300, containing 4000 U/g xylanase, was added at 0, 0.25, 0.50, 0.75 and 1.00 kg/t to each diet. Pigs were housed individually and offered the diets *ad libitum* for 27 days. Feed intake, growth and feed conversion ratio (FCR) were measured. Analysis of variance was used to analyse the results (Table 1).

Table 1. Effect of xylanase on performance of weaner pigs fed the experimental diets.

	Stiletto			Currawong		
Treatment	Feed intake (g/d)	Daily gain (g)	Feed:gain	Feed intake (g/d)	Daily gain (g)	Feed:gain
Control	594[a]	390[a]	1.5	660	485	1.4
0.25 kg/t	731[b]	505[b]	1.5	764	504	1.5
0.5 kg/t	749[b]	505[b]	1.5	705	477	1.5
0.75 kg/t	752[b]	528[b]	1.4	778	488	1.6
1.00 kg/t	758[b]	522[b]	1.5	764	509	1.5
SED	66.3*	42.0**	0.10 (NS)	70.8 (NS)	54.4 (NS)	0.14 (NS)

[a,b]Values in the same column with different superscripts were significantly different ($P \leq 0.05$). *$P \leq 0.05$; **$P < 0.01$; NS $P > 0.05$.

Pigs fed the diet containing Stiletto increased their voluntary feed intake and growth rate following enzyme supplementation. The pigs' responses to xylanase supplementation were observed at the lowest enzyme inclusion level. The use of xylanase ameliorated anti-nutritional factors in wheat-based diets associated with reduced feed intakes that were not related to the DE assessments of the two cultivars. Parallel work with a multi-enzyme complex having also 4000 U/g xylanase as well as β-glucanase, α-amylase, pectinase and protease (Porzyme® TP 100HP) gave similar results with both wheat cultivars, indicating that the main response was associated with xylanase supplementation in high wheat diets.

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BARLEY ARABINOXYLAN, CELLULOSE AND EXTRACT VISCOSITY ACCOUNTS FOR MOST OF THE VARIATION IN ENERGY DIGESTION IN PIGS

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Development of techniques for the rapid assessment of the nutritional quality of grain requires a fundamental understanding of those factors responsible for variation in nutrient supply (van Barneveld, 1999). These factors may include gross chemical components that influence the supply of nutrients to the pig, but also those grain characteristics that influence the digestive processes. The aim of this experiment was to identify physical and chemical characteristics of barley that influence the ileal and faecal digestion of energy in growing pigs.

Eleven samples of barley were collected from across Australia representing 10 different cultivars. Samples were subjected to chemical analyses and *in vivo* assessment. Chemical analyses included all proximates, amino acids, non-starch polysaccharides, fatty acids, anti-nutritional factors, physical grain characteristics and viscosity measurements on acid and water extracts of the test grain. The ileal and faecal digestion of energy from the barley samples was determined in four separate experiments (2-3 test grains/experiment) using Large White male pigs (35-40 kg live weight, LW) fitted with simple T-piece ileal cannulas. A common control sample was used in each experiment and diets were provided based on a 5 x 5 Latin square design. Diets were formulated to contain 940 g/kg of the test grains, the remainder consisting of dicalcium phosphate, salt, minerals, vitamins, choline chloride and Celite® as an indigestible marker for digestibility calculations. Diets were fed for 7 d (3 x maintenance i.e., 0.5 x $LW^{0.75}$) prior to 8 h digesta collections over 2 consecutive days. Partial samples of faeces were collected simultaneously during the digesta collection period. Following principal component analyses of the chemical variables, stepwise regression analysis was used to establish those chemical variables responsible for any variation observed in ileal and faecal digestible energy (DE) content.

Table 1. Chemical variables accounting for differences in ileal and faecal digestion of energy from barley fed to growing pigs determined using stepwise regression analysis.

Ileal diet DE[a]			Faecal DE		
Variable	Partial R^2	P>F	Variable	Partial R^2	P>F
Total arabinoxylose	0.68	0.002	Total cellulose	0.82	0.000
Acid extract viscosity	0.17	0.019	SP[b] viscosity extract	0.10	0.013

[a]DE, Digestible energy. [b]SP, Slow profile.

Ileal diet DE measurements ranged from 7.7–11.3 MJ/kg, as received, while faecal DE content of the barley samples ranged from 11.3-13.4 MJ/kg, as received. Up to 85% of the variation in the ileal diet DE measurements could be explained by variation in the total arabinoxylose content and an acid extract viscosity measurement on the grain (Table 1). In contrast, variation in the faecal digestible DE content of the barley was influenced by the total cellulose content and a modified slow profile extract viscosity measurement of the grain. The results support the suggestion by Black (2001) that gross chemical composition of grain accounts for the bulk of variation in nutritional quality variables such as DE. However, total cellulose and total arabinoxylose are unlikely to contribute significantly to digesta viscosity given the small soluble fractions. Hence, other barley components such as β-glucans may be influencing digesta viscosity in the small intestine and fermentation rate in the hind gut.

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A REVIEW - LUMINAL BACTERIA AND REGULATION OF GUT FUNCTION AND IMMUNITY

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Abstract

This review paper describes the importance of intestinal bacteria to the function of the pig gut and its associated immune system. Extensive colonization with a diverse range of microbes occurs soon after birth and eventually stabilises to resemble an adult intestinal flora. Current molecular methods show that approximately 60% of the microflora associated with the pig gut wall remains uncharacterised. This may reflect the fact that much earlier work on intestinal bacteria was dedicated to the study of enteropathogens and their effects on host physiology. Whilst this continues to be an important area, evidence is now emerging which highlights the impact of the indigenous non-pathogenic flora on both innate and adaptive immunity. Within the gut microflora, diverse biological activities have been identified and these have important implications in relation to gut health and lifetime performance of pigs. The study of the mechanisms of interaction between bacteria and the gut mucosa is emerging as a highly important research theme in both the fields of human and animal health. Unravelling the cellular and molecular basis of bacterial colonization, host recognition and the modulatory effects of bacteria on intestinal cell signalling and gene expression will provide the platform for the development of safer therapeutics to prevent disease and promote intestinal health.

Introduction

The intestinal tract, which provides a complex interface between the animal and its environment, is continuously bombarded with a diverse array of dietary and microbial antigens. These antigens play a critical role in moulding both the morphology and function of the intestine and its associated immune system. Some of the major changes in intestinal biology are coincident with the abrupt dietary changes brought about by birth and weaning. These periods are associated with heightened susceptibility to disease but importantly, are also recognised as critical periods during which immune defence mechanisms essential to the survival and performance of animals, are both primed and activated. There is now a real appreciation among those with a vested interest in pig production and welfare that, fundamental to improving life-time performance of the pig, are multi-disciplinary investigations to address the interactions between nutrition, gut physiology and immunity particularly during early neonatal and post-natal life.

The early weeks of neonatal life see extensive changes in gut morphology, transiently elevated protein transcytosis, sustained increases in *de novo* protein synthesis and both age-related and diet-induced changes in brush border membrane digestive and transporter functions. During the same period, the rapidly changing mucosal surface becomes colonized by successions of gut bacterial groups. In the majority of animals, the dynamic balance between host physiology, diet and the gastrointestinal microbiota leads to the establishment of a stable microbial ecology characterised by the presence of commensal organisms that exert a positive influence in maintaining and establishing a healthy gut immune system. However, perturbation of the gut ecosystem often occurs in neonates and the pre-/post-weaning period still represents the time of greatest pig morbidity and mortality.

Over the past 50 years, the weaning age of piglets has been decreased from ten to twelve weeks to current ages of three to five weeks (Nabuurs, 1998). Weaning is clearly a stressful time in a pig's life; it has to rapidly adapt to major changes in environment and nutrition and in addition, to the withdrawal of passive immunity. The weaning transition is also accompanied by adverse changes in intestinal morphology and reduced absorptive capacity (McCracken *et al.*, 1999). A major challenge for the pig industry is to formulate

economically viable, growth promoting diets that ease the transition from sow's milk to nursery diets (Thacker, 1999). Importantly, in addition to satisfying the nutritional requirements of weaned pigs, the likely withdrawal of antibiotic growth promoters means that such diets are increasingly assessed for their ability to modulate microbial succession, stabilise the commensal microbiota, improve immune function and enhance disease resistance in the young animal.

The gut as a bacterial habitat

The newborn and pre-weaned gut

Several hundred microbial species have been documented as components of the indigenous intestinal microflora and their origin appears to be maternal and environmental (Conway, 1997). However, recent molecular analysis describing the microbial diversity of the pig gut has indicated that many of the bacteria present are currently unknown (Pryde *et al.*, 1999). Based on conventional culturing techniques, it can be said that the pattern of colonization in pre-weaned pigs is similar for most animals, with lactic acid bacteria, enterobacteria and streptococci appearing first, followed by obligate anaerobes (Conway, 1997). Microbial colonization is a complex process of natural selection and ecological succession (Rolf, 1996) and is influenced by numerous regulatory factors of both bacterial and host origin including bacterial antagonisms, animal genotype and physiology, and importantly, nutrition (Kelly *et al.*, 1994; Conway, 1997). Several microhabitats exist within the intestine, which exert a selective influence on the local composition and metabolic activity of the microflora. These microniches are found in the proximal and distal intestine associated with the villus surface, crypts, epithelial associated mucins and luminal mucus. Variables that contribute to the regional compositional diversity include immune reactivity, the presence of gut receptors, nutrient availability and composition, the flow of digesta, pH and Eh (oxidation/reduction potential) and available molecular oxygen (Stewart *et al.*, 2001).

For growth, bacteria require energy sources and nutrients, derived either exogenously from the host diet or endogenously from sloughed-off epithelial cells, and cell secretions from the mucus blanket that coats much of the inner surface of the gut (Stewart et *al.*, 2001). Competition for substrates is a major determining factor in the composition of the intestinal microbial population. Dietary residues influence the composition and metabolic activities of gut microorganisms (Gibson and McCartney, 1998). During post-natal development, alterations in diet are believed to induce a succession of related changes in the gut microbial ecosystem (Conway, 1997).

Enterotoxigenic *Escherichia coli* and rotavirus infections are common causes of scours, or diarrhoea, in pre-weaned pigs. Possibly the most important predisposing factor in susceptibility of piglets to infections is insufficient uptake of colostrum in the first hours of sucking. Weak, undersized, chilled or injured piglets often have difficulty in competing for functioning teats. Sows with mastitis or other infections and injuries, may be unable to produce sufficient colostrum for transfer of passive immunity to the sucking piglets. A second important predisposing factor to enteric infections is the prevalence of binding sites for pathogens on the intestinal surfaces of the sucking pig. The chemistry and distribution of bacterial and viral binding sites on gut mucosal surfaces play important roles in determining host and tissue susceptibility and in triggering host responses. This is particularly noticeable in neonates where both beneficial and harmful swings in microbial balance can accompany epithelial differentiation (Kelly *et al.*, 1994; King, 1995; King and Kelly, 2001; Stewart *et al.*, 2001). Enteric bacterial strains that cause diarrhoea in sucking pigs have been partially classified according to the nature of their fimbrial adhesins or lectins. These lectins are constituents of proteinaceous appendages that protrude from surfaces of bacteria and recognize sugar moieties of glycoproteins and/or glycolipids on intestinal surfaces. The synthesis of these appendages and the production of enterotoxins are essential virulence factors that enable pathogens to compete successfully with commensals in the intestine.

The post-weaned gut

Microbial succession in the intestine of the weaned pig is influenced by the interplay of environmental factors, dietary change, intrinsic variations in host physiology, endogenous nutrients and the composition of the microbiota (Mackie *et al.*, 1999; Stewart *et al.*, 2001). As the young animal is weaned, the obligate anaerobic bacteria become numerically dominant and *E. coli* and enterococci decrease in numbers (Conway, 1997). In the mature gut the number of anaerobes is approximately 100-1000 fold greater than aerobic bacteria and the most prevalent species are *Bacteroides, Eubacterium, Clostridium, Peptococcus, Peptostreptococcus, Bifidobacterium* and *Fusobacterium.* The increase in anaerobes is particularly marked in the hindgut of the pig but high levels of such bacteria are also found in the ileum. The microbiota in the small intestine compete with the host animal for easily digestible nutrients. As much as 6% of the net energy in the pig diet can be lost due to microbial fermentation in the stomach and small intestine (Jensen, 1998). However from 5-20% of the total energy supply in the adult pig is achieved from microbial fermentation in the large intestine (Jensen, 1998; Anderson *et al.*, 2000).

Enterotoxigenic *E. coli* infections are common contributing factors to post-weaning scours in pigs. Predisposing factors in such infections include the removal of protective levels of IgA and other beneficial factors present in sow's milk, inadequate feed and water intake, inadequate gastric acid secretion, unstable microbiota and expression of membrane and mucin glycoconjugates that serve as binding sites for enteropathogens (Kelly *et al.*, 1994; Thacker, 1999; Kelly and Coutts, 2000; Kelly and King, 2001a,b). Post-weaning malnutrition predisposes to infection by compromising the barrier and immune functions of the gut. At the same time, the infections adversely influence dietary intake, absorption and cause loss of endogenous nutrients (Calder and Jackson, 2000). Niewold *et al.* (2000) have proposed that intestinal ischaemia is a key predisposing factor to diarrhoea in post-weaned pigs. Intestinal blood supply may be unable to meet the metabolic demands of the fast growing intestine undergoing hyper-regenerative villus repair. It is suggested that the resultant ischaemia leads to intestinal acidosis and increased permeability for enterotoxigenic *E. coli* toxins (Niewold *et al.*, 2000).

Antibiotics and growth promoters

For several decades, orally administered antibiotics have been used to enhance growth of livestock. Astonishingly, the precise mechanisms underlying the beneficial effects of antibiotics remain unclear. Anderson *et al.* (2000) recently proposed that the benefits of growth promoting antibiotics result from substantial decreases in bacterial populations and consequent alterations in epithelial functions in the pig small intestine, whereas changes in large intestinal microbial populations exert less impact on whole animal growth. The use of avoparcin and virginiamycin as growth promoters in animal feed has been associated with an increase in resistance of bacteria to therapeutic agents and a fear that this could reduce the ability to treat diseased humans (Jensen, 1998). The addition of growth promoting antibiotics to the feed of growing pigs is now banned in many European countries. The removal of such additives will profoundly influence intestinal microbiology and physiology of post-weaned pigs.

Research in several laboratories is directed towards finding alternative methods to sustain growth and health of the animals in pig production. For example, the impact of fermented liquid feed on the activity and composition of the microbiota is one such system that is attracting interest (Mikkelsen and Jensen, 2000; Demeckova *et al.*, 2001). The feed, containing high levels of lactic acid and lactic acid bacteria, reduces gastric pH, lowers microbial activity in the small intestine and reduces the number of enterobacteria (including coliform bacteria) throughout the gastrointestinal tract. When fed directly to sows, fermented liquid feeds also enhance the immunological properties of colostrum (Demeckova *et al.*, 2001). Further research is required to define the mechanisms whereby fermented liquid feed helps prevent coliform scours in small intestine of the post-weaned pig.

Changes in the carbohydrate complexion of the gut surface: implications for bacterial, mucosal interactions.

Gut membranes

An elaborate surface coat or glycocalyx is present on the microvillar surface of the mammalian intestine. Electron microscopy shows that the glycocalyx consists of fine filaments extending in a more or less perpendicular fashion from the outer leaflet of the microvillous membrane. Surprisingly, since its discovery more than twenty years ago, relatively little research has been undertaken on the molecular biology and biochemistry of the intestinal glycocalyx. The most distinctive characteristic of the glycocalyx is its high carbohydrate content. Various functions have been attributed to the glycocalyx, but current thinking is that it helps protect epithelial cells from infection, dehydration and physical or chemical injury (King and Kelly, 2001)

The structural diversity of membrane-associated oligosaccharides that comprise the intestinal glycocalyx is theoretically enormous. Monosaccharides can be combined with each other in a variety of ways that differ not only in sequence and chain length, but also in anomery (α and β), position of links and branching points (Lis and Sharon, 1993). In reality, regions of structural variation are often restricted and the assembly of oligosaccharide chains is at least partially based upon sets of structural rules. Membrane and secretory glycoconjugates are not themselves primary gene products, but are constructed in a stepwise manner as monosaccharides are added to precursor oligosaccharides via several glycosyltransferases coded for by different genes (Roth, 1997). Most glycoproteins carry oligosaccharide side chains N-glycosidically linked to the amide nitrogen of asparagine and/or O-glycosidically linked to the hydroxyl groups of the amino acids serine/threonine. The latter are sometimes referred to as mucin-type O-glycans because of their common location on epithelial surfaces and their structural similarity to glycans present in secreted mucins. A diverse group of bioactive oligosaccharides is also linked to lipids.

Gut mucins

Epithelial mucins are major glycoprotein components of the mucus that coats the mucosal surfaces of the gastrointestinal tract. Like the glycocalyx, they function to protect epithelial cells from infection, dehydration and physical or chemical injury, as well as to aid the passage of materials through the tract (Perez-Vilar and Hill, 1999). Mucin production may therefore be considered a key innate defence mechanism of intestinal epithelial cells. A negative feature of enhanced mucin production is that it may slightly reduce nutrient absorption (Satchithanandam *et al.*, 1990).

Intestinal mucins are an extremely diverse group of structural glycoproteins. The heterogeneity of mucin glycoproteins is based on variations in both protein and carbohydrate moieties. Some apomucin species are small molecules whereas others contain several thousands of residues and are among the largest known proteins. All mucins exhibit domains of tandemly repeated peptides rich in threonine and/or serine whose hydroxyl groups are in O-glycosidic linkage with N-acetylgalactosamine. These moieties form the core structures for carbohydrate chains that may account for as much as 90% of the weight of the mucin glycoproteins.

Bacterial interactions with membrane and mucin glycans

Increased production of intestinal mucins occurs in post-weaned pigs compared to the levels detected in pre-weaned animals (Pestova *et al.*, 2000). The dietary composition, microbial flora, as well as interactions between the dietary constituents and the flora, influence the composition and functional characteristics of intestinal mucins (Sharma *et al.*, 1995). Degradation of the carbohydrate chains of mucin glycoproteins involves glycosidases and glycosulfatases produced by specialized strains of normal enteric bacteria, resulting in the release of component monosaccharides that can be used as a source of nutrition by other, larger populations. Such functional specialization

provides an ecological niche for enzyme-producing specialists and is likely to be a contributing factor to microbial diversity in enteric bacterial ecosystems. Bacterial, mucosal crosstalk may lead to changes in gene expression for mucin peptides. For example, the ability of selected probiotic strains of *Lactobacillus* to inhibit the adherence of attaching and effacing bacteria is mediated through their ability to increase expression of MUC2 and MUC3 intestinal mucins (Mack *et al.*, 1999).

Glycosylation is an important factor governing the adherence of bacteria to intestinal mucins. In weaned pigs, the major glycosylation patterns of secreted mucins vary according to the AO histo-blood group secretor status of the individual animals. Thus, high levels of terminal α-linked fucose characterize mucin oligosaccharides in O-secretor pigs. A-secretor pigs have the same levels of fucose but this sugar is extensively masked by terminal α–linked N-acetylgalactosamine (King, 1995; King *et al.*, 1995; King and Kelly, 2001). Within individuals there are often conspicuous differences in mucin glycosylation in different regions of the small intestine and indeed on the same intestinal villi. Immature goblet cells deep within the crypts produce neutral mucins containing little sialic acid. As they mature and migrate to the villus tip, the mucins become sialylated (King, 1995). It is highly likely that animal-to-animal and site-to-site variation in mucin subtypes is reflected in the composition of the mucin-associated microbiota. In addition to the commensal flora, several enterotoxigenic *E. coli* species are known to adhere to mucin glycoproteins or glycolipids in weaner pigs (Bloomberg *et al.*, 1995; Dean-Nystrom and Samuel 1994). The precise significance of these associations is uncertain, but the emerging view is that the mucus barrier reduces the pathogen colonization of villus membranes (Pestova *et al.*, 2000).

Increased levels of membrane and mucin glycoprotein fucosylation occur in the intestines of pigs and other mammalian species at the time of weaning (King, 1995). Available evidence suggests that such glycosylation events are partly pre-programmed but are also sensitive to changes in dietary regime and to weaning (Kelly and King, 1991; Kelly *et al.*, 1993). Supplementing the diet with galactose results in modification of mucin glycosylation in post-weaned pigs. This change may limit microbial degradation of mucin (Pestova *et al.*, 2000). Experimental evidence from other species suggests that intestinal fucosylation may also be enhanced by the presence of selected commensal bacteria. Bry *et al.* (1996) compared genetically identical germ-free mice with mice reared with a functional microbiota, and determined that the production of fucosylated glycoconjugates, appearing in the intestine and colon after the age of weaning, requires components of the microbiota. Fucoconjugates were largely absent from weaned germfree mice; inoculation with the commensal bacterium *Bacteroides thetaiotaomicron* restored the same fucosylation pattern as in conventional mice and induced the accumulation of α1,2 fucosyltransferase RNA (Bry *et al.*, 1996). Molecular studies on *B. thetaiotaomicron* have identified a transcriptional repressor that serves as a molecular sensor of fucose availability that coordinates bacterial fucose metabolism and host fucosylated glycan production (Hooper *et al.*, 2000). The identity and mode of action of the fucosylation-inducing signal produced by the commensal has not been determined (Hooper *et al.*, 2000). The signals may be polyamines. In the weaned rats *B. thetaiotaomicron* contributes high amounts of putrescine and spermidine in the caecum and ileum of pectin-fed gnotobiotic rats (Noack *et al.*, 2000). Polyamines have recently been shown to be potent maturation factors implicated in the expression of increased α1,2 fucosylation in the rat gut at the time of weaning (Greco *et al.*, 1999, 2000). Endogenous sources of polyamines may also be of importance for maturation of the postweaned intestine. Plasma glucocorticoids are markedly increased in pigs during weaning. This cortisol surge has an essential role in enhancing polyamine synthesis, which may be of physiological importance for intestinal adaptation and remodelling (Wu *et al.*, 2000).

Intestinal glycodiversity and herd immunity

As described earlier, many of the intestinal glycosylation patterns associated with microbial attachment have their basis in only small changes in oligosaccharide chain termination by α-linked sialic acid, galactose, N-acetylgalactosamine or fucose. These relatively simple glycosylation changes may be sufficient to create or mask binding

epitopes for bacterial fimbriae. Glycosylation variation within populations means that individual animals may be more or less susceptible to infection by selected organisms. A pathogen that can recognize glycans on the intestinal cells of only some individuals in a population cannot spread through the population because of the presence of others who express different glycans, and are therefore resistant (Gagneux and Varki, 1999). In the wild, there are advantages to animal herds if some individuals survive epidemics. Similar arguments may hold true in agricultural units, where variations in host susceptibility to pathogens and faecal shedding of commensal and pathogen strains, strongly influence the spread of enteric infections.

The herd immunity effect is experienced in many rearing units when outbreaks of enterotoxigenic *E. coli* occur. For example, within the same unit it is common to find some pigs that are more prone than others to K99 or K88 *E. coli*-associated scours. Jeyasingham *et al.* (1999) investigated this phenomenon in a challenge trial where a litter or eight weaner pigs were orally dosed with *E. coli* K88ac. Six of the pigs developed diarrhoea and 2 were unaffected. Postmortem, biochemical and histochemical analyses of the intestinal tissues showed a strong correlation between disease symptoms and the expression of a glycoprotein receptor complex associated with the brush border membrane. Interestingly, further investigation revealed the presence of an analogous glycoprotein complex in the K88-resistant group, but it lacked the binding epitope for K88-fimbriae. This result suggests that genetic differences in glycosyl moieties of the receptor complex provide the basis for disease susceptibility to *E. coli* K88ac.

There is an oft-repeated adage that 'nothing in biology makes sense, except in the light of evolution' (Dobzhnasky, 1973). A large part of the observed intra- and inter-species glycodiversity on mucosal surfaces may result from selection pressure from enteric microorganisms (Gagneux and Varki, 1999). Large multicellular organisms such as pigs and humans with long life cycles have had to constantly change the molecular complexions of their mucosal surfaces in order to survive the onslaught of faster evolving and often lethal microorganisms. At first glance it may appear that evolutionary reasoning has little practical relevance to modern pig management schemes. However, the paybacks from analysis of intestinal glycodiversity include an increased insight into host susceptibility to infectious disease, perhaps leading to new strategies to enhance enteric health (King and Kelly, 2001).

Uniformity in meat production is increasingly recognised as an economically important factor allowing farmers and processors to efficiently target specific consumer markets (Edwards, 2001). Inevitably, new biotechnologies in the field of animal genetics may be called upon to further diminish variance in pig production. Glycodiversity, driven by natural selection, may be an important genetic trait(s) worth preserving to maintain high health status.

Bacterial exposure and innate immunity: An ancient but vital defence mechanism

The immune systems of both invertebrates and vertebrates evolved under selective pressure imposed by infectious microorganisms. As a result, all multicellular organisms have developed various defence mechanisms that are triggered by infection and that protect the host organism by destroying the invading microbes and neutralizing their virulence factors (Medzhitov and Janeway, 1997). These phylogenetically ancient pathogen control mechanisms are also known as the innate defence system. The major immune cell types involved in mediating innate responses are macrophages, neutrophils and natural killer cells. These cells recognize bacterial antigens, such as lipopolysaccharides, techoic acids and glycolipids via specific cell surface pattern recognition receptors. Recognition of bacterial antigen leads to an effector phase involving activation of the complement system, production of chemokines and cytokines including IL-1, IL-6, IFN-g TNF-a, and reactive oxygen intermediates all of which indirectly or directly exert antimicrobial effects (Morein and Hu, 2001).

The cellular basis of the innate immune system

The innate immune system is the first line defence of the gut, and activation of this system is achieved by selective expression and recognition of host receptor systems. Toll-Like Receptors (TLRs) are an important family of receptors involved in the process of bacterial recognition. The TLRs, mammalian homologues of Toll receptors first discovered in *Drosophila* fruit flies (Imler and Hoffmann, 2001), are recognized to play a central role in anti-microbial defence mechanisms (Lemaitre *et al.*, 1996). Thus far 10 mammalian TLRs have been discovered (Imler and Hoffmann, 2001). The TLRs are transmembrane receptors, which have a large extracellular leucine rich repeat domain and a cytoplasmic domain which is homologous to that of the IL-1 receptor and therefore has been designated Toll/IL-1R (TIR) motif (Zhang and Ghosh, 2001). The intracellular domain of the TLR is responsible for signal transduction which results in the activation of transcription factors, predominantly NF-κB and AP-1 (Kopp and Medzhitov, 1999; Anderson, 2000). The subsequent increase in expression and secretion of pro-inflammatory cytokines regulated by NF-κB, such as IL-1, IL-6 and IL-8, is important for the recruitment and activation of other cells of the mucosal immune system (Medzhitov *et al.*, 1997).

Recent studies have provided insight as to the role of TLRs in monitoring luminal bacteria. It was shown that TLR5, which is expressed on epithelial cells, immature dendritic cells and monocytes, act as a receptor for the bacterial flagellin (Gewirtz *et al.*, 2001a; Hayashi *et al.*, 2001). Flagellin is a major component of bacterial flagella that is produced by both commensal and pathogenic bacteria. It was previously shown that only pathogenic bacteria have the ability to translocate bacterial flagella across the epithelial layer, whereas commensal bacteria lack this function (Gewirtz *et al.*, 2001b). From this initial study it was proposed that translocated flagellin was on receptors expressed on the basolateral surface of epithelial cells (Gewirtz *et al.*, 2001b). The molecular basis by which the gut distinguishes between harmless commensal bacteria and pathogenic bacteria is largely unknown but recent studies, both published and from our own laboratory, show that the mechanisms are complex and involve bi-directional communication between epithelial cells, cells of the immune system, and the bacteria resident in the intestinal lumen. Currently, there is no work on pig TLRs but undoubtedly they play an important role in the protection of the pig gut, particularly in the early period of life preceding the development of the adaptive immune system.

Cytokine networks and antimicrobial peptides

As discussed, the immune system is activated following a process of recognition and signal transduction events. A crucial aspect of the innate immune response to infection is the rapid onset of response. Both NF-κB and AP-1 are rapidly activated by a variety of exogenous signals including bacterial invasion (Karin, 1995; Schmid and Adler, 2000). These transcription factors are activated in intestinal epithelial cells, within 30 minutes of bacterial infection (Gewirtz *et al.*, 2000), triggering an increase in the expression of pro-inflammatory cytokines that modulate both the function of the gut and the immune system. Activation of proinflammatory cytokines such as IL8, leads to recruitment of neutrophils and macrophages to sites of infection. These cells participate in the rapid induction of an acute inflammatory response in an attempt to stem the progression of infection. As part of this response many other factors are produced including an impressive array of antimicrobial peptides. These small, endogenous, polycationic molecules constitute a ubiquitous and significant component of innate immunity and exhibit broad microbicidal activity against various bacteria, fungi and enveloped viruses (Zhang *et al.*, 2000). Much of the work investigating the activation of innate inflammatory responses has been carried out in rodents and *in vitro* cell-based systems. The increased availability of pig-specific antibodies and gene probes will facilitate studies such as these in the young pig. This work will help establish the developmental profiles of these responses and the consequences of aggressive inflammatory responses during early post-natal life on performance and health in later life.

Some gut bacteria may suppress inflammatory responses

Commensal and pathogenic bacteria have evolved a diverse range of mechanisms that promote their survival within the gut ecosystem. Bacteria can produce a vast array of cytokine-inducing or cytokine-modulating molecules that will regulate or direct the host response. Certain of these factors may promote the virulence and pathogenic potential of bacteria but others, paradoxically, may facilitate the maintenance of the indigenous microflora by beneficially regulating the immuno-inflammatory status of the gut (Kelly and King, 2001a,b). There is an emerging view that some enteric bacteria actually also help reduce maintenance costs of the gastrointestinal system (Kelly and King, 2001a,b). Identifying the implications of maintaining specific strains within the gut on parameters such as epithelial turnover, inflammatory status and disease resistance would certainly help the development of novel and efficacious products that may improve life time performance of pigs and provide some alternatives to antibiotic growth promoters. This work requires that bacteria are screened for their effects on specific cell populations and signalling pathways that regulate the genes controlling cell cycle, mucosal barrier function, and those that activate lymphoid cells by paracrine mechanisms.

The adaptive immune system

The adaptive immune system is found only in vertebrates. The system is based on receptors that are generated by somatic mechanisms during the ontogeny of each individual organism. These mechanisms produce a diverse repertoire of antigen receptors with random specificities, which are clonally distributed on two types of lymphocytes, T cells and B cells (Medzhitova and Janeway, 1997). In general, clonal expansion of particular T and B cells requires specific signals from foreign or non-self antigens that are largely derived from pathogens. The consequence of this clonal expansion is the production by lymphocytes of immunoglobulins that specifically neutralize harmful antigens. The adaptive immune system is not a freestanding system unrelated to the innate immune system described earlier. There is increasing evidence that the initial recognition and response systems of the innate system play important roles in directing the adaptive responses to microbial and other foreign antigens.

Colostral immunoglobulins and passive immunity

The neonatal pig is highly susceptible to infectious diseases. There is a widely held view that the cellular immune system in the young animal is underdeveloped compared to that in the adult. In the first weeks of life, as the piglets expand the cellular machinery required to mount adaptive immune responses, the sucking young receive protective immunoglobulins in maternal colostrum and milk. The level of protection afforded to the sucking animals is limited by the quantity and quality of antibodies in colostrum and by the amount the neonate is able to consume and absorb. At optimal uptake of colostral immunoglobulin, serum antibody titers of the piglet are similar to those of the sow, within twenty-four hours after birth (Holland, 1990). However, the predominant immunoglobulin isotype in colostrum is IgG, and although maternal IgG is protective against many systemic pathogens, most pathogens encountered by the piglet are found at the mucosal surfaces where IgG antibodies are rare and largely ineffective (Gaskins, 1998). A second longer phase of passive protection, occurring as colostrum formation ends and lactation proceeds, sees IgG concentrations decrease quickly as IgA becomes the major immunoglobulin in sow milk (Gaskins, 1998). This maternal IgA provides short-term intestinal protection by neutralizing viruses, inhibiting bacterial attachment and by opsonizing or lysing bacteria (Porter, 1986; Gaskins, 1998). However, although sucking piglets receive partial protection against those antigens to which the sow has previously developed immunity, they have little or no protection against new infectious agents that may be introduced to rearing units.

Development of the gut associated lymphoid tissue

The most abundantly produced immunoglobulin in mammals is IgA, which is secreted mainly across mucous membranes. Conventional immune responses leading to production of IgA involve two principal players, the T- and B-lymphocytes. Immunoglobulin A is synthesised by B (B2 type) lymphocytes that are first exposed to antigens in intestinal Peyer's patches. Luminal antigens are transported through specialized epithelial cells (membranous or M-cells) overlying Peyer's patches, into an interfollicular area where they are presented by resident antigen presenting cells (macrophages and dendritic cells) to helper T (TH) lymphocytes. The TH cells, in turn, secrete cytokines that stimulate B-lymphocytes that produce IgA. After leaving Peyer's patches and passing through the systemic circulation, IgA+ lymphocytes migrate back to the lamina propria where they differentiate into plasma cells capable of secreting large amounts of antibody. Upon reintroduction of the antigen, plasma cells secrete antigen-specific IgA that is then transported back toward the intestinal lumen (see reviews by Gaskins, 1997, 1998).

There is general consensus, albeit based on little quantitative data, that although the newborn and sucking pigs possess some of the effector B-cell machinery to initiate immune responses, they do not develop a fully functioning T-cell repertoire until the late sucking or early weaning periods. Before birth, the spleen, lymph nodes, Peyer's patches and thymus contain detectable levels of immunoglobulin-containing cells. Just after birth, the incidence of IgM+ B cells is increased and this is followed by an increase in either IgG+ or IgA+ B lymphocytes depending on the tissue evaluated (Bianchi *et al.*, 1992). In at least the thymus, this B-cell isotype switching to IgG – and IgA-secreting cells is not influenced by external antigenic stimuli of conventional microflora (Cukrowska *et al.*, 1996). The numbers of both B and T lymphocytes present in the small intestine lamina propria doubles during the first four weeks after birth (Bianchi *et al.*, 1992). Over the same period there occurs a marked change in the differentiation of the T-lymphocyte population; CD4+ T cells increase dramatically in number during the first postnatal week, while the number of CD8+ cells is low at birth and increases only moderately by 5 to 7 weeks (Rothkotter *et al.*, 1991; Stokes *et al.*, 1992; Gaskins 1998).

It has been postulated that transient aberrant immune response to antigens in the post-weaning diet may predispose to bacterial infection and disease (Stokes *et al.*, 2001). Some investigators have suggested that immune responses to dietary antigen, especially those derived from soya protein, are an important cause of local inflammation, which result in villus atrophy (Bailey *et al.*, 1993; Li *et al.*, 1990, 1991; Miller *et al.*, 1994). McCracken *et al.* (1999) concluded that soya-induced inflammation, if present, is likely to compromise intestinal morphology due to local inflammation caused by anorexia in the immediate post-weaning period. Much more research is required into the possible cellular mechanisms linking hypersensivity and the shaping of the villous epithelium at weaning. Although hypersensitivity is a contentious issue, there are good nutritional reasons why soya protein should not be used at too a high concentration in weaner diets. Two- to three-week old pigs cannot effectively utilise bean meal because they lack adequate levels of the digestive enzyme systems needed to break down complex proteins and carbohydrates.

Influence of the bacteria on the mucosal immune system

Very little antigen exposure occurs *in utero*. Hence, at birth the immune system of a healthy neonate, from an immunological standpoint, is naïve. As described earlier, during the birth process and early postnatal life, microbes from the mother and surrounding environment colonize the gastrointestinal tract of the infant. Exposure to this microbiota is a major predisposing factor in the anatomical and functional expansion of the intestinal immune system.

Bacteria stimulate the so-called 'preimmune system' in neonates

Although the T cell machinery in the neonatal pig is functionally underdeveloped it is possible that the young animal can produce some form of defensive intestinal IgA barrier. Recent investigations in mice have shown that a large proportion of the intestinal IgA against cell wall antigens and proteins of commensal bacteria is specifically induced in response to their presence in the microflora, but independently of T cells or germinal centre formation (Macpherson *et al.*, 2000). The cells responsible for producing this often limited immunoglobulin repertoire originate from so-called B-1 lymphocytes found in the peritoneal and pleural cavities. These B-1 derived cells recognize ubiquitous bacterial antigens such as phosphoryl choline as well as self-antigens such as Ig, DNA and membrane proteins on erythrocytes and thymocytes (Bao *et al.*, 1998; Fagarasan and Honjo, 2000). Immunoglobulin A antibodies produced by B-1 cells prevent systemic penetration of commensal bacteria (Fagarasan and Honjo, 2000). Porcine B-1 cells have many characteristics in common with those of other mammalian species, including the expression of the transmembrane glycoprotein CD5, which mediates in intracellular signalling events (Appleyard and Wilkie, 1998). The B-1 system therefore constitutes a primitive form of specific immune defence that evolved before the T-cell dependent B-cell (B-2) systems. The B-1 subset of lymphocytes (the so-called preimmune repertoire) arises early in ontogeny and is a major component of the neonatal B-cell system (Wuttke *et al.*, 1997). Bacterial colonization of the gastrointestinal tract results in selective diversification and expansion of the preimmune repertoire in piglet mucosal lymphoid tissues (Butler *et al.*, 2000).

Bacteria stimulate development of the gut associated lymphoid tissue

Bacterial antigens play a very significant role in the proliferation and development of the gut associated lymphoid tissue (Brandtzaeg, 1996; Helgeland *et al.*, 1996). This feature has been highlighted by comparative investigations on gnotobiotics and animals harbouring a conventional flora. It is noteworthy that germ-free animals, exposed to only dietary antigens but not bacterial antigens, possess only a rudimentary immune system. In the developing gut the immunological outcome following exposure to antigen is determined by variables such as genetic background, the nature, timing and dose of administered antigen (Strobel and Mowat, 1998). Immune response will also be especially dependent on a maintained balance between the developing regulatory and effector functions of the mucosal immune system (Bailey *et al.*, 2001). In the pig there are approximately 30 discrete Peyer's patches in the jejunum and upper ileum and one long continuous patch in the terminal ileum (Binns, 1982). The long ileal Peyer's patch is a major antigen-independent site for the generation of the repertoire of primary immunoglobulins and consequent production of the systemic B-cell pool (Andersen *et al.*, 1999).

The organized germinal centres of jejunal and upper ileal Peyer's patches are important sites of antigen-specific B cell production where the collaboration of epithelial cells with antigen-presenting and lymphoid cells is highly developed. The postnatal development of these two components of the Peyer's patch system is variably influenced by the presence of live microbial antigens. The jejunal patches were found to be significantly larger in specified pathogen free (SPF) and conventional pigs than in germ-free animals (Barman *et al.*, 1997). The same study showed that ileal Peyer's patch follicles in germ-free pigs increased in size between the first and second month, whereas the equivalent follicles in SPF and conventional pigs remained the same size.

Exposure to bacterial antigen is now recognized to be of immense importance, both in early life, in order to prime the immune system in the correct way and throughout life, to maintain a functional immune system (Kelly and Coutts, 2000; Kelly and King, 2001ab.). Disruption of the flora and the immune system at weaning may have long-lasting effects on mucosal function. Bailey *et al.* (2001) suggest that the development of excessive regulatory or effector functions as a result of insults at weaning leaves the pig with a long-term inability to mount appropriate responses to mucosal antigens. Of equal importance is the type of bacteria that the intestine is exposed to, as different species and

strains can exert very diverse effects on the gut, that range from beneficial to harmful (Umesaki *et al.*, 1999).

The mechanisms by which microbes influence the phenotype and function of lymphoid cells are largely unknown but are likely to involve complex events that are probably triggered following the "normal" route of antigen uptake and processing. As described above, commensal bacteria and pathogens can also directly influence cytokine profiles following direct stimulation of epithelial cells (Kelly and Conway, 2001; Wilson *et al.*, 1998). These signalling molecules can have very dramatic effects on immune parameters such as the polarization of the immune response and TH cell subset development (Delespesse *et al.*, 1998).

Conclusion

In the early life of the pig the interplay between luminal bacteria and the intestine is crucial for the development and expansion of the gut immune system and is therefore extremely important to whole body health and the lifetime performance. Changes in diet associated with weaning create disturbances in the gut that undoubtedly alter how the immune system subsequently processes bacterial and dietary antigens. The impact of these 'decisions' are difficult to assess but considerable evidence is accumulating to suggest that inappropriate immune responses established during the development of immune function can lead to immune dysfunction at a later stage. The increasing prevalence of non-specific colitis in pigs may reflect immunological problems associated with early-weaning and the use of in-door rearing systems. Currently, a major issue associated with pig production is the removal of antibiotic growth promoters. Without these agents it will be necessary to use alternative means to enhance performance and provide protection from disease. The deployment of therapeutic agents that target specific pathogens is obviously one way forward but, given the rapid evolutionary strides of microbial pathogens, enhancing the immune status and defence mechanisms of pigs would be a better ideal. This would permit the acquisition of 'natural' immunity and provide global protection.

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