Manipulating Pig Production XII

Proceedings of the Twelfth Biennial Conference of the
Australasian Pig Science Association (APSA)
Cairns, Australia

November 22nd to 25th, 2009

Edited by Dr Robert J. van Barneveld

AUSTRALASIAN PIG SCIENCE ASSOCIATION (INC.)
Werribee, Victoria, Australia

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Australasian Pig Science Association (Inc.)
Conference 12th; 2009: Cairns, Australia.
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Includes bibliographies and index
ISBN: 978-0-9806880-0-9
ISSN: 1324 9177

Printed by: allclear Print+Sign, Brisbane, Queensland.

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The Batterham Memorial Award

The Batterham Memorial Award is a prestigious award conferred by APSA in memory of the late Dr Ted Batterham.

Ted Batterham's love of pigs began at the NSW Agriculture, Wollongbar Research Station in the mid 1960's when he began work with Dr John Holder to solve the problem of variability in the growth of pig fed meat meals. At that time abattoirs in NSW produced meat meals that were very variable because there was little control on either the raw materials used or cooking times and temperatures. Ted soon realized that part of the variability was explained by the content of bone but, something much more fundamental that would keep Ted focused and fascinated for the rest of his professional life, was the variability of available lysine in these meals. Ted knew that if proteins were heated in the presence of carbohydrates and fats, lysine would become unavailable to the pigs own enzymes. Ted went to Melbourne University to commence a PhD with Tony Dunkin to develop an *in vivo* assay in rats and pigs to quantify the available lysine not just on meat meals but in a range of other protein sources and cereals. He returned to Wollongbar and became a world leader in the availability of amino acids in feedstuffs for pigs and poultry. Not content just to solve a problem, Ted wanted to find solutions and reasoned that, if the availability of lysine was known, any shortfall could be remedied by supplementation with synthetic lysine. That idea stimulated research that delved into ways that the biological value of proteins could be enhanced by supplementation with synthetic amino acids.

Ted's research career was always focused on industry issues and driven by a desire to find suitable solutions. He knew that progress was best made by teams of people stimulating and supporting each other, and that investment in young people was essential.

Therefore, the Batterham Memorial Award is made to a young scientist, a person within 10 years of graduation. Its aim is to "stimulate and develop innovation in the pig industry". It is anticipated that the cash award will enable the recipient to broaden his or her exposure to national or international pig science.

Previous winners of the Batterham Memorial Award include:

Robert van Barneveld	(1995)
John Pluske	(1997)
Kaye Coates	(1999)
Darryl D'Souza	(2001)
Patricia Mitchell	(2003)
Eva Ostrowska	(2005)
David Cadogan	(2007)

The APSA Fellow Award

The APSA Fellow Award was first presented in 2007. This prestigious award is offered in recognition of past and present members who have made an outstanding contribution to APSA as well as their contribution and commitment to pig science.

Previous recipients include:

Dr Ray King	(2007)
Dr David Hennessy	(2007)

APSA – Behind the Scenes

APSA has remained a successful and relevant Association through the dedication and commitment of the elected Committees since 1987. The following contributions are gratefully acknowledged by the Australasian pig science community.

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Acknowledgements

The biennial conference of the Australasian Pig Science Association (APSA) conference has gone from strength to strength and is now widely regarded as one of the main international conferences for pig science. From its humble beginnings in Albury, New South Wales in 1987, APSA now represents one of the must attend pig science conferences within the Asia-Pacific region, attracting delegates from all the major pig producing countries globally. This has come about as a consequence of the hard work and dedication of many people over more than twenty years.

As with previous conferences, considerable time and effort by a willing group of scientists and support people has ensured that the 2009 conference reaches the same high standards now expected of APSA. The continued support of members and others associated with pig science and production through submission of papers to these proceedings is acknowledged. Of course no conference is a success without a good number of delegates, and the APSA Committee thanks all those who have attended the 2009 conference and also those who have been instrumental in encouraging others, especially those from overseas, to participate.

Given the number of international delegates now attending APSA and the global nature of pork production, the organising committee aims to invite a number of international speakers to each conference, and the contributions from Jon Ratcliff, Joaquim Segales, Flemming Thorup and Dean Boyd are greatly appreciated. In addition, I acknowledge the following people from Australia who also contributed to the success of the symposia and reviews: Greg Harper, Kim Bunter, Bruce Mullan, David Hennessy and Rob Wilson. The A.C. Dunkin Memorial Lecture is an important part of any APSA conference, and the Committee thanks Robert van Barneveld, Paul Pattison and Brian Luxford for accepting the honour of presenting the 2009 Lecture utilising a new format. APSA also thanks this year's chairpersons and judges for their important contribution to the success of the Conference.

There are very few conferences now held where the proceedings are produced prior to the conference and to such a high editorial and scientific standard. The contribution and dedication of the Editor, Robert van Barneveld, in ensuring this happens is acknowledged. The team from Barneveld Nutrition Pty Ltd and the CHM Alliance Pty Ltd including Kylie Franzmann and Robert Hewitt are also thanked for their on-going support and contribution to this process. I would also like to point out that it is becoming increasingly difficult to find people who are prepared to act as referees, and the contributions of these people (named elsewhere in the proceedings) are gratefully acknowledged.

APSA has always had a strong relationship with Australian Pork Limited, and it is pleasing that they again have agreed to be the Principal sponsor for the event. The partnership with the Pork CRC Ltd has grown significantly and the number of papers supported by the Pork CRC Ltd is a testament to the outcomes that the Pork CRC Ltd is delivering to its core and supporting participants, as well as its outcomes to the pork industry in Australia and New Zealand.

The organising committee has worked hard for the last two years to organise this conference. Accordingly many thanks go to Darryl D'Souza (Vice President), Bruce Mullan (Immediate Past President), Karen Moore (Secretary), Megan Trezona (Treasurer), Heather Channon, Frank Dunshea, Patricia Holyoake and Brian Luxford. The 2009 conference was organised in conjunction with YRD who have acted as the secretariat for the last two conferences, and it has been a pleasure to work with Kate Murphy, Mary Sparksman and Louise Ritchie. In recognition of the contribution that the past APSA Committee's have made to the current success of APSA, the membership of past Committees is now documented in the Proceedings. The current committee is also pleased to be able to award an APSA Fellowship in 2009.

Finally, the XIIth Biennial Conference would not have been possible without the generous support of our many sponsors. The Sponsors are listed on the Sponsors page, and their contribution to the success of the 2009 APSA conference is gratefully acknowledged.

Dr Neil Gannon, President

Message from the Pork CRC Ltd

In 2005, the Cooperative Research Centre for an Internationally Competitive Pork Industry (Pork CRC Ltd) was established. The Pork CRC Ltd is funded by an alliance between the Australian Federal Government, industry and research organisations in Australia and New Zealand.

The outcomes from the Pork CRC will be:

- Reduced production costs for high-quality pork through more reliable and consistent protein and energy supplies via innovative grain production, co-product utilization and quality assurance.
- Reduced production costs for high quality pork through improved herd feed conversion efficiency.
- Increased demand for high-quality, niche Australian pork products as a result of enhanced capacity to deliver nutrients that promote the health and well-being of consumers via consumption of pork and pork products.

An increasing amount of pig research conducted in Australia and New Zealand is being funded under the auspices of the Pork CRC Ltd. Three years of innovative research has seen Pork CRC Ltd outcomes cutting the cost of pork production and enhancing the global competitiveness of Australia's pork industry, according to Pork CRC Chairman, Dr John Keniry.

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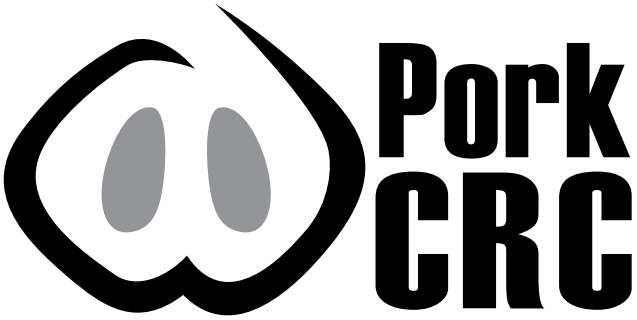

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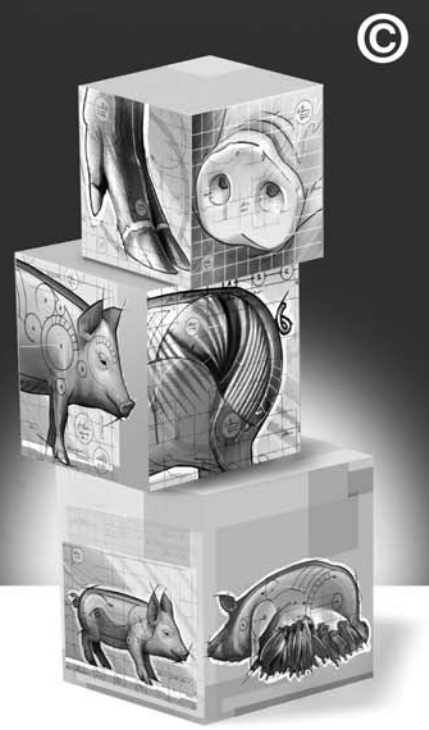

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Preface

The global pork industry is subject to many factors that ultimately contribute to significant pork supply and demand volatility with often severe consequences for regional and national pork producers in many countries around the world, Australia included. Relative to the situation that prevailed at the last Australasian Pig Science Association (APSA) conference in 2007, the Australian pork industry is fortunately in a much better position, but this is not necessarily the case in other pork producing countries. The increased cost pressure on inputs, downward pressure on pork prices and challenges with environmental sustainability, disease control and identifying skilled labour make the information transfer that occurs at APSA as critical as ever.

On top of the industry challenges above, during 2008-2009 the pork industry faced two additional challenges which are still ongoing and will forever change the way we operate. The first was the Global Financial Crisis and the second was the emergence of Influenza A H1N1(2009), unfortunately commonly referred to as 'Swine flu'. On top of these challenges, governments around the world are debating the merits of greenhouse gas emissions and their impact on climate change. The resulting policies to reduce greenhouse gas emissions will have major ramifications for agricultural production, including pork. With this backdrop, the issues discussed by the presenters of the A.C. Dunkin Memorial Lecture will provide some very prudent messages for our industry's future survival. The many other papers in these proceedings and resulting discussions they stimulate, while not necessarily specifically addressing the above challenges, nevertheless will provide valuable opportunities for improving the productivity, profitability, sustainability and welfare aspects of pork production. There is something in each paper for every reader and I commend you to read these papers and to fully appreciate the multi-disciplinary benefits that APSA provides.

By providing a forum for people from a wide range of backgrounds and interests to meet and share ideas, APSA provides a real opportunity for important changes in pork production to occur. An equally important role of APSA is to facilitate the transfer of knowledge and experience from the senior scientists to the junior scientists and it is encouraging to see the number of new gradates attending and presenting at APSA and being well supported by private and publicly funded research programs. I hope that in the current financial situation organizations recognize the value of research and continue to invest.

It has been an honour and a pleasure to preside over APSA for the last two years and to have contributed in facilitating the networking of many of those involved in pork production and the exchange of ideas that APSA has a well deserved reputation for. The future challenges for our industry will require an expansion in the role for APSA and I hope you will continue to be part of the future success of the Association.

Dr Neil Gannon, President

CHAPTER 1

Nutrigenomics and Gut Physiology

Targets for Nutrigenomics and Nutrigenetics in Pig Production Research

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Nutritional genomics applied to pigs is discussed for its potential to deliver novel and relevant information about the response of animals with particular genotypes to the nutrients in their diet. Dietary formulations that are specific for particular genotypes and optimized for critical developmental windows in terms of feed efficiency are likely outcomes of the research. This paper surveys recently published articles and web releases concerning livestock production efficiency and particularly postnatal liveweight gain trait(s). It seeks to capitalize on the knowledge gained from large global investments made in human and model-animal nutritional genomics, in both the private and public sectors, to foresee production benefits that will address the challenges of the "livestock revolution". The Australian pig science community cannot afford to rely on spill-over of information from these larger studies, as intellectual property is being secured, rights exercised and understanding moving forward at an accelerating pace.

Introduction

Genomics is the molecular characterisation of all of the genetic material of a particular organism (its "genome"), which by necessity utilises high throughput technologies. Nutritional genomics is the study of nutrition, in this case animal nutrition, using genomics. Practically, the field encompasses aspects of nutrigenomics (the influence of common dietary ingredients on the expression of the genome), nutrigenetics (the effects of an individual's genotype on the response to nutrition), and nutritional epigenetics (the effects of epigenetic chromosomal modifications on the response to nutrition, and *visa versa*). Unlike genetics which can be reductionist in its approach (down to single genes), nutritional sciences are more integrative and encompass effects on the entire animal, probably because all of an animal's physiological systems can be affected by nutrition: though to different degrees and with different time-scales. Of interest is the extent to which knowledge of the genome, and the genotypes of a particular individual animal, can inform the optimisation of its nutrient requirements.

Animal nutritionists seek to understand enough about the networks of gene regulation and expression to ultimately influence growth, development, performance and health of animals. In food production animals, a priority would be optimisation of diets for energetically efficient deposition of muscle and development of eating quality-related traits, such as tenderness in pork. In seedstock animals, diets that optimize reproductive performance and wellbeing of the animals are likely to be of most interest.

In this paper, we propose to focus our discussions on pigs, and post weaning growth (or more specifically liveweight gain) as a trait influencing both on the profitability and sustainability of pork production enterprises.

The global context

Pig production is a major international enterprise, and it is likely to become bigger as a consequence of the "livestock revolution". This trend was described by Delgado *et al.* (1999) and represents a raft of consequences around the propensity of consumer populations in the developing world to favour animal protein over plant protein for their base nutrition, as their living standards rise and aspirations for themselves and their families change (Table 1).

The long-term downward trend in the market price for commodities such as pork has contributed to the increase in meat consumption, but urbanisation has also been a significant driver based on transport, storage and distribution issues. Urban consumers often prefer foods that offer variety and convenience rather than seeking caloric content *per se*. While poultry, meat and eggs are the most acceptable livestock products throughout the world, pork is particularly valued by consumers in the large population centres of East Asia and peoples of European descent. It is of course largely excluded from the diet of a large proportion of the world's population, especially Moslems in the Near East, Asia, and Sub-Saharan Africa. On the supply side, global pork production is estimated to be 100tonnes, of which 68 percent is produced by the top five countries: China, USA, Germany, Spain and Brazil. Excluding China, the developing countries as a group only produce about 12tonnes or about 12 percent of global production (Anon, 2007). Output of globally traded products, namely beef, pork, poultry, sheep meat and milk, grew at about 10 percent per annum between 2003–2007 driven primarily by the developing countries, far outstripping the equivalent growth in the developed world, which is at greatest two percent per annum (Anon, 2008).

Table 1. *Increase in food consumption of meat, milk, fish and major cereals 1971–95*[a]

Commodity	Developed countries (million metric tons)	Developing countries (million metric tons)
Meat[b]	26	70
Milk	50	105
Fish[c]	5	34
Major cereals[d]	25	335

[a]Source: Delgado *et al.*, 1999 and associated Food and Agriculture Organisation (FAO) publications; [b]Beef, sheep and goat meat, pork, and poultry; [c]Marine and fresh water fin fish, cephalopods, crustaceans, molluscs, and other marine fish; [d]Wheat, rice, and maize used directly as human food.

The resource use challenge

Seen from the global environmental perspective, large scale shifts in animal production to meet heightened human demand raises concerns about the costs to the resource base as well as the impacts on food security (Steinfeld *et al.*, 2006), given the likelihood of other intervening factors. Such factors might include seasonally-related production shortfalls, political and social unrest, feed crop and animal disease, land-use competition, and most recently, the food versus biofuel trade-off. Pingali (2007) suggests that a systemic implication of the changes in diet will be greater commercialisation of food production in developing countries and the gradual decline of the small landholder/producer, in the absence of specific policy interventions to maintain this group. The Food and Agriculture Organisation (FAO) now shows the food price, and real food price indices increasing for the first time since 1974, to some extent following the Reuters-CRB Energy Index (Anon, 2008). The global stores of wheat, including feedgrains, have gradually declined since the mid 1980s with some grains now stored at levels (relative to use) not seen since the 1970s. While we haven't been able to source reliable information about the total feed consumed by pigs themselves destined for human consumption, it is clear from derived parameters such as the above, and concerns raised in the context of food security, that animal feed demand competes with human food demand (Steinfeld *et al.*, 2006).

The inherently low efficiency of assimilation of nitrogen (N) by livestock is a major theoretical and practical problem for livestock production, though to be fair, more so for ruminant species than for monogastrics such as pigs and chickens. This inefficiency could have significant consequences, and is a topical issue at present, given the community's concerns about catastrophic climate change, and the role livestock might have in greenhouse gas accumulation. Here are some calculations to illustrate the scale of the problem. N enters an individual livestock animal as protein, amino acids or urea in the feed, which is likely to contain between 10 and 40 g of N per kg of dry matter. Averaging across all species and extrapolating to the global scale, Smil (1999) estimated that in the mid-1990s livestock excreted in the order of 75tonnes of N per annum, while the global production of animal products at about that time was estimated to be 12tonnes (Van der Hoek, 1998). This suggests an integrated efficiency of about 14 percent. One of these authors later estimated only maginally better efficiency, 15 percent, for crop-fed animal production (Sim, 2002). There is general agreement amongst estimates in the literature (eg. Steinfeld *et al.*, 2006), demonstrating that more that 80 percent of the N taken into livestock animals as feed is returned to the environment through excretion, although monogastrics may be higher. Given the locations of many production enterprises around the world, and the lack of technological solutions for dealing with the waste, notwithstanding the reuse of some wastes as fertilizer, much remains to pollute and otherwise degrade the local and global environments. The situation is compounded by the proportion of N which is excreted in the urine as urea where it can be a major substrate for denitrification to the potent greenhouse gas, nitrous oxide (N2O). The authors of the seminal FAO report (Steinfeld *et al.*, 2006) estimate the total emissions of N_2O from pig excretion in 2004 to be 0.44tonne which was about 12 percent of the global totals, and regionally more significant in terms of odours and other forms of pollution. In the USA for example, it has been estimated that as much as 51 percent of the N incorporated chemically into fertilizers is used specifically for animal production. This amounted to about 4.7tonnes in 2002/03 (Steinfeld *et al.*, 2006). These are significant contributions to the greenhouse gas accounts for either N or carbon (C), and particularly when the fuel used to prepare the land, drive the tractors and the chemical plants is included.

Taken together these data build a case for the global animal science community to focus on increasing the resource efficiency with which production animals and their associated systems utilise resources and convert feed stuffs into edible protein, to meet the legitimate demands of people to feed themselves and their families.

Approaches to increasing feed conversion efficiency

Food animal production efficiency is fundamentally the growth of livestock through to market weights, in the shortest possible time, and with few as possible inputs. In the poultry industry for example, selection for faster growth over the last 40 years has doubled the rate of broiler growth to market size at 35 days of age (Carre *et al.* 2008). Some of this advance has occurred through genetic improvement in feathering, lipid content of lean growth, basal metabolic rate, homeostatic body temperature, appetite, growth path, digestion efficiency on particular diets (cereal x genotype) and interactions amongst these factors. Looking at this variation from a more mechanistic perspective, those authors (Carre *et al.*, 2008) discussed issues of protein concentration relative to metabolisable energy, energy content *per se*, and specific ingredients (bioactives, contaminants and trace elements) in the feed, as candidates for interactions with genotype, in determination of the performance of chickens.

Selective breeding for faster growing pigs has also led to leaner carcases and this has, we suggest, inescapable consequences in terms of muscle fibre type profile and muscle lipid content (Rehfeldt *et al.*, 2008). Unfortunately this selection pressure has also led to quantifiable deterioration of the eating quality characteristics of pork (Sonesson *et al.*, 1998; Schwab *et al.*, 2006). It seems likely that there will be some trade-offs that are inescapable because of the thermodynamics and metabolic characteristics of mammalian tissues and bodies, and the physicochemical properties of meat as a food material. For example, carcase leanness may always be associated with energetic efficiency, and low fat in meat, always associated with dry mouth feel. These realities can be potentially overlooked during the design phases of animal breeding programs such that the goals of efficiency and simplicity may obscure the complexity of the entire system within a mammalian body. Nonetheless, commercial pressures are powerful drivers of efficiency; which in this context is a good thing. Also, animal breeders have long been aware of the often antagonistic associations between lean growth efficiency and meat quality. One of the roles of the public investments in animal science could be to provide information about the possible negative implications of an unchecked drive towards efficiency. It would be particularly unfortunate if animal breeding went down paths that were ultimately non-productive.

So how might investments in animal science help alleviate such problems, when all of global animal production is being faced by the challenges identified above, and what might be some productive areas for scientific pursuit? For the purposes of this paper, we will focus on the trait of pre-weaning growth rate, and how nutrigenetic and nutrigenomic research approaches might be made to its improvement. There are many production traits that could have been chosen, and could yield to these research approaches, but pre-weaning growth rate has unique strategic value as we will describe.

Firstly, much genetic progress has been made by selecting breeding stock based on easy-to-measure traits, and pre-weaning growth rate requires only a set of scales and a clock. Secondly, the trait has been found to be moderately heritable (Cucco *et al.*, 2009; Huismann and Brown, 2008) suggesting that genetic progress is possible and that other production traits may be improved coincidently. Thirdly, there is evidence for a proportion of phenotypic variance still remaining in the population despite significant effort to minimize genetic variance, through choice of sires with high breeding value, and minimising environmental variance, through controlling diets and ambient atmospheric conditions. On the latter point, Table 2 illustrates the phenotypic variance amongst piglets for pre-weaning growth rate, and was derived from an experiment performed by Hawken *et al.* (pers. comm.) in collaboration with a professional pig production company.

Table 2. *Variation in preweaning average daily liveweight gain in piglets in a commercial circumstance.*

Herd structure:	8 boars, 200 sows.
Breed:	Large White. Boars chosen on the basis of high breeding value for growth rate in the offspring. Data were collected for each of 2 parities and analysed separately.

Group	Statistic	Average daily liveweight gain (kg)
Parity group 1 (~550 animals)		
	Minimum	0.059
	Maximum	0.454
	Standard deviation	0.064
	Mean	0.254
Parity group 2 (~550 animals)		
	Minimum	0.077
	Maximum	0.468
	Standard deviation	0.064
	Mean	0.254

It is clear that variation in this trait is still large relative to the mean (eg. Coefficient of Variation of 25%). Similar variation has been described by Paszek *et al.* (1999). While a number of extraneous factors other than diet could certainly contribute to this variation (individual health status, herd behavioural characteristics such as shy feeding or aggression), it would be useful to quantify the interaction between animal genotype and nutrients ingested, and further whether this trait teaches us something about the feed efficiency of the animals later on in their productive lives. In the dataset presented in Table 2 for example, the correlation between preweaning average daily liveweight gain and the average daily liveweight gain for all of life is approximately 0.25, which is likely to be statistically and biologically significant.

Pigs have a neonatal growth spurt due to a high fractional protein deposition rate into skeletal muscle that does not persist, decreasing rapidly with advancing age (Davis *et al.*, 1993; Davis *et al.*, 2008). Davis *et al.* (2008) have shown that dietary amino acids, as provided by feeding, and insulin stimulate muscle growth independently during this period. Similar responses have been found in the neonates of other production mammals and mammals of research interest such as the rat. Indeed it has been suggested that the neonatal growth spurt of skeletal muscle might have advantages to the survival of the animal in the wild and hence has remained under positive selection pressure within those populations (Davis *et al.*, 2008).

It is reasonable to suggest that the neonatal growth spurt in general, is an important component of the total productive phase of the pig, given the development of the other organ systems, immune competence and behaviours during that phase of the animal's life, and nutrient utilisation during the neonatal growth spurt is particularly important in the context of resource-use efficiency. A great deal of effort has been expended on understanding the physiology and metabolic biochemistry of the growth spurt in muscle in particular (Denne and Kalhan, 1987) and the understanding developed for skeletal muscle in other species can be utilized to a great extent for understanding the pig (Davis *et al.*, 2008). Figures 1 and 2 demonstrate some of the intermediaries known to be important in the control of muscle growth in mammals, and the particular pathways involved in the stimulation of neonatal muscle growth.

These figures integrate knowledge that has been collected in many experimental systems (whole animal, hindlimb, tissue explants and isolated cells) and illustrate the large number of molecular intermediates that are involved in transduction of a hormonal signal (IGF-1 or insulin) through to the genome and the cellular and tissue responses. Not surprisingly some of the same signalling intermediates (eg. IRS-1, PI3K, p70S6K (S6K1), mTOR) are involved in both neonatal and postnatal growth and other processes. Many questions arise, including "how are these intersecting pathways differentially regulated with age?", "what are the relative effects of genetic polymorphisms in each of the gene products or the genes that regulate their expression?", and "how does the responsiveness to particular amino acids vary with genetic polymorphism?". Finally, "what are the global controllers of these metabolic pathways involved in protein turnover and their regulatory genes, and could they be improved in a production environment?". There is evidence from cattle and sheep that genetic progress can be made in these traits through selection. Hence, some proportion of the variation noted above is potentially due to genetic variation in the amino acid responsiveness of skeletal muscle in terms of protein turnover. However, the studies published so far are confounded. For example, nutritional status could not be held constant within the design because of the complications of the status of the rumen, though animal pedigree as a category could be varied systematically.

As we have seen above (Table 2), even in a non-ruminant production species such as the pig, considerable variation remains amongst animal groups that would be regarded as uniform based on the selection of sires and production conditions. So what other sources of variation might there be, and how do we realistically address these? One source is clearly nutrition and the development of new feeds and improved methods for preparation of existing feeds, a science in itself. Another is the interaction between nutrients and the genotype of the animal: the focus of the fields of nutrigenomics and nutrigenetics.

Mutch *et al.* (2005) noted that "nutrigenomics aims to determine the influence of common dietary ingredients on the genome, and attempts to relate the resulting different phenotypes to differences in the cellular and/or genetic response of the biological system in terms of its gene expression". Nutrigenetics on the other hand, "aims to understand how the genetic makeup of an individual coordinates their response to diet, and thus considers underlying genetic polymorphisms". The final member of this category of science is nutritional epigenetics which aims to understand the effects of nutrition, and particularly past nutrition, on heritable characteristics of the genome, and including gene expression levels.

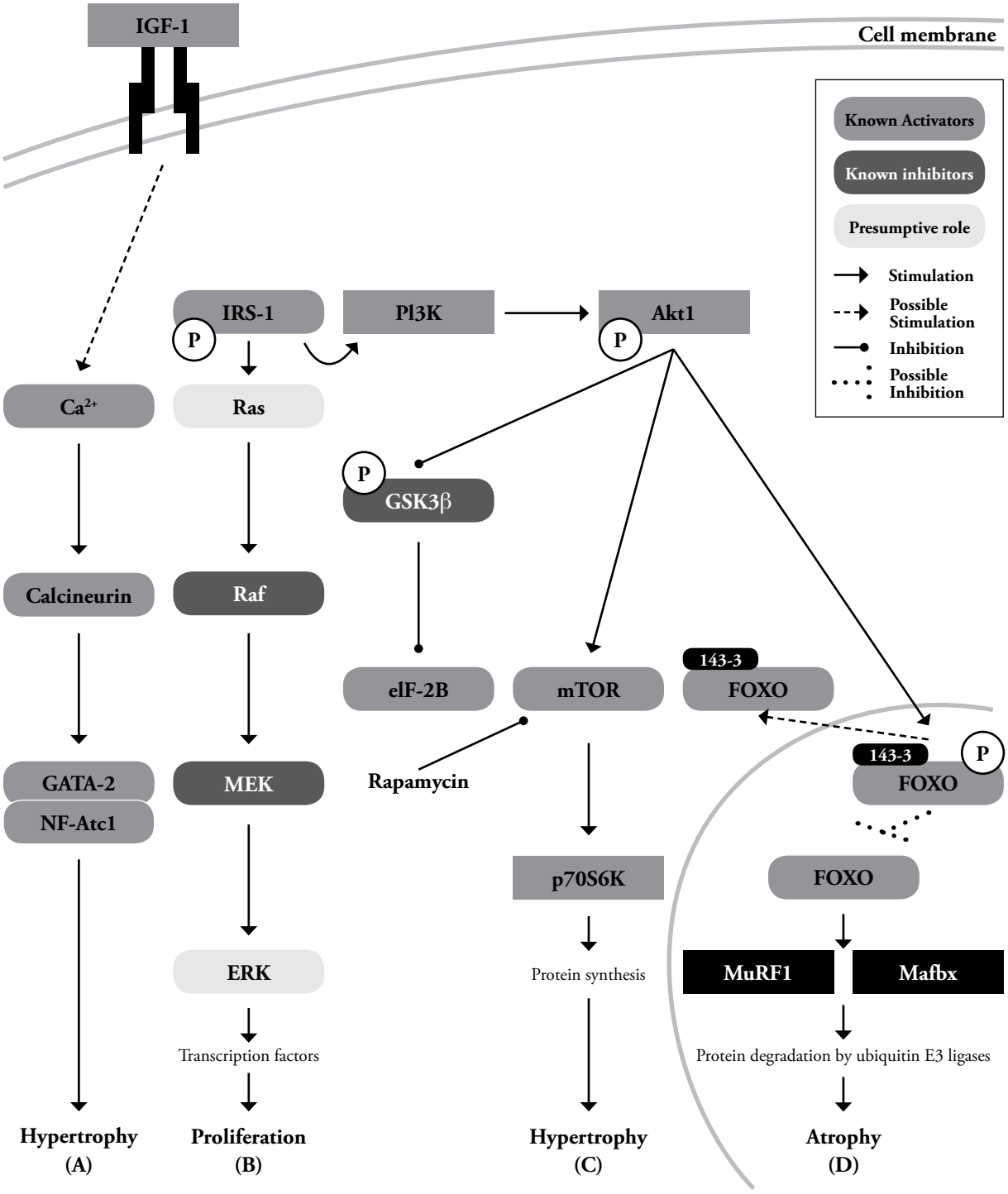

Figure 1. *IGF-1 signalling pathways in skeletal muscle. Pathway "A" results in muscle growth through cellular proliferation, Pathway "B" is associated with cellular differentiation and hypertrophy and "C" with cellular atrophy. This figure has been adapted from that of Glass (2003) and Shavlakadze* et al. *(2006).*

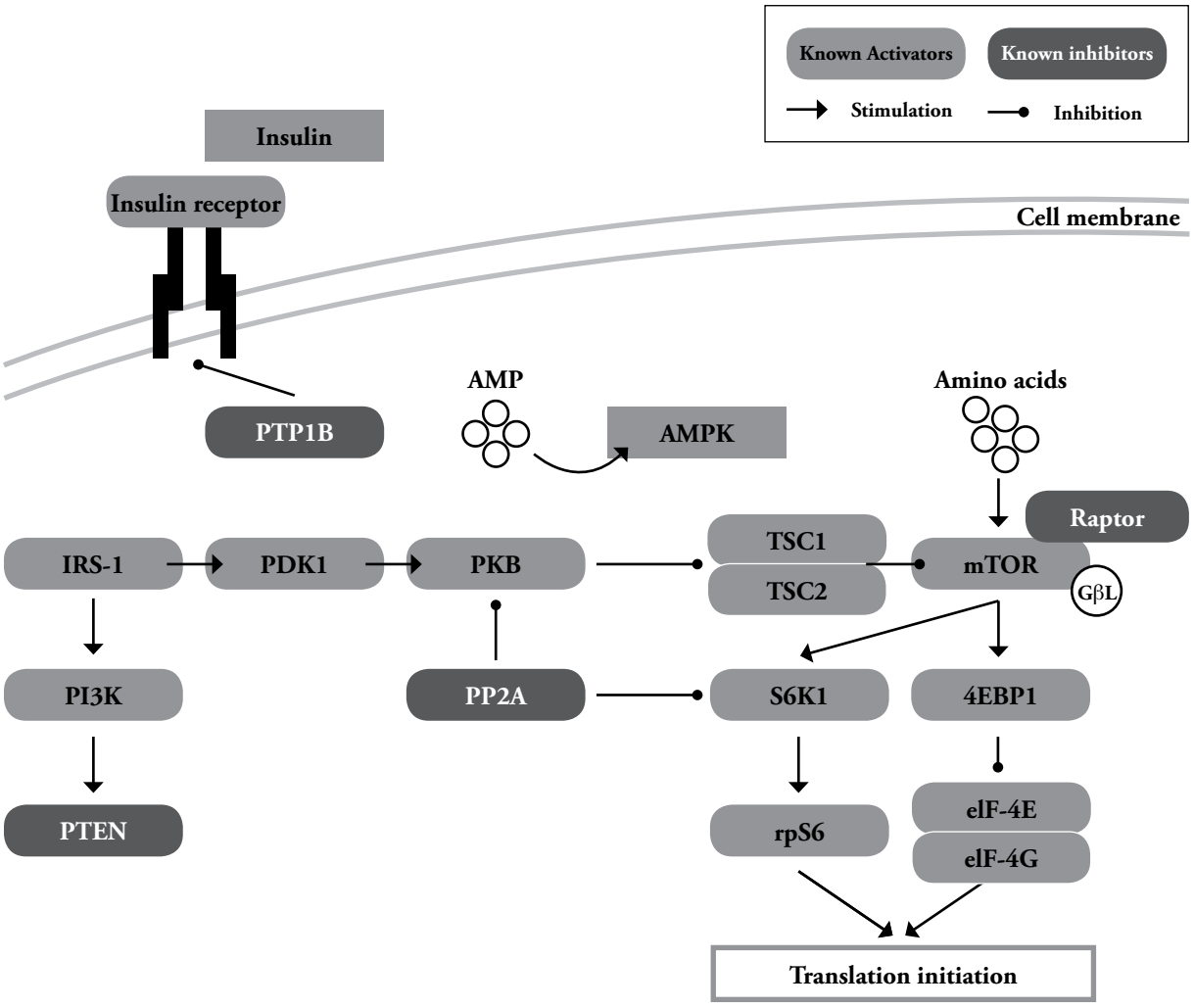

Figure 2. *Insulin and amino acid signalling pathway leading to the stimulation of translational initiation. Adapted from Davis* et al. *(2008).*

Methodologies and their application to the pre-weaning growth rate trait

Animal resources

The goal of a nutrigenomics experiment into this trait would be to identify the key nutrients that are involved in supporting rapid neonatal growth. The following may be one approach to take. The animal resource could be a herd for which the genotypic variation is limited, as might be the case for say two or three sire lines, and sows from one, closely related breed group. Piglets from litters born within a few weeks of one another would be managed as an age-segregated group, to minimise the effects of animal competition. Another important design consideration is the seasonal rhythm *per se* which can influence the growth of piglets (Myer *et al.*, 2008), as can the seasonal challenges of viruses and ambient temperature. Piglets could be hand reared from soon after birth and fed a low protein diet supplemented with amino acids where perhaps the concentration of one or two essential amino acids (eg. lysine, tryptophan, threonine or methionine) within the diet would be varied, based on the rationale that their contents can limit muscle growth. The piglets could be grown for 5 weeks, or 10 kg liveweight, whichever occurs first. A serial slaughter design would allow for sampling of many tissues and comparative gene profiling. Sampling priorities would include skeletal muscle (at least two muscles), intestine (two sites) and perhaps the hypothalamus, because of its known role in controlling body temperature, hunger, thirst, and circadian cycles (Bowen *et al.*, 2009). A serial muscle biopsy design would be more conservative of animal resources, subject to approval by an animal experimental ethics committee, and still give a researcher access to an important tissue. Serial blood sampling would give the researcher access to metabonomic assessments of global changes to the metabolic state of the animal over time. Furthermore, injected treatments of insulin or insulin-like growth factor (IGF)-I might be interesting overlays and provide further experimental contrasts.

The goal of a nutrigenetic experiment into this trait would be to identify the effects of one or several genetic polymorphisms within newborn pigs, when all other production variables are held constant, or vary insignificantly. The animal resource could be a herd for which the genetic background variation is limited, as might be the case for straight-bred boars and sows, but where sire and dam genotyping has identified the range of genetic variations likely to be found in the progeny. Genetic variants of interest might be, for example, myostatin (MSTN; Jiang *et al.*, 2002); growth hormone releasing hormone (GHRH; Cho *et al.*, 2009); heart-type fatty acid binding proteins (H-FABP; Cho *et al.*, 2009); ryanodine receptor-1 (RYR1; Stinckens *et al.*, 2007) or IGF-II (Maagdenberg *et al.*, 2008). Piglets should be from litters born within a few weeks of one another and managed as an age-segregated group as above. The piglets should be fed by the sow and her nutritional requirements should be exceeded during the lactation period. Again, a serial slaughter design would allow for sampling of many tissues and comparative profiling of each, and the same tissues as noted above would be of interest. Serial blood sampling would again be valuable. Injected treatments of insulin or IGF-I for the piglets might be interesting overlays. The piglets could be grown for 5 weeks, or to 10 kg liveweight, whichever happens first.

The goal of a nutritional epigenetics experiment is to demonstrate transgeneration inheritance of a trait that was influenced nutritionally in one of the parents' or earlier generations. Whilst this phenomenon is of significant scientific interest (Chong *et al.*, 2007), there is evidence to suggest that it accounts for only a minor proportion of the variation in growth traits in mammals (Hager *et al.*, 2009): it certainly contributes in some pigs which have a specific polymorphisms in the IGF-II gene (Maagdenberg *et al.*, 2008). The experiments are likely to be long (at least 1.5 pig generations) and complex and so the features of the design will not be covered here.

Transcriptional profiling and biostatistics

The tissue samples taken from the animal experiments would be stored in liquid N_2 before being thawed and extracted for total RNA following procedures our colleagues have previously described (Lehnert *et al.*, 2004). Given thousands of genes in the porcine genome are expressed at a low level throughout postnatal life, the relative concentration of any particular mRNA compared to the average concentration of most mRNAs directly reflects the level of expression of the particular gene. The concentration of mRNA is measured indirectly in the particular extracts of a tissue, by creation of a complimentary labelled strand of DNA in a micro test tube. This labelled strand of DNA can then be hybridized with complimentary DNA in an array containing a known set of gene sequences that are attached to a solid substrate: often glass. The intensity of signal that results from this hybridisation process is directly related to the amount of specific mRNA present in the original tissue extract, and hence the level of gene expression. Good examples of commercial arrays include the Open Genomics (40K microarray; Agilent Technologies Inc., Santa Clara, Calaifornia, USA) or the Affymetrix Genechip Porcine Genome Array (Affymetrix Inc., Santa Clara, California, USA). At the simplest level, the analyst can determine which genes are expressed more in response to some specific treatment, and which are expressed less. Unfortunately, however, this simplest level of analysis can give misleading conclusions and a number of studies have suggested more sophisticated ways to interpret the data to minimize false positives. These false positives represent genes that appear to be differentially expressed due to factors other than the fixed effects of treatment (Reverter *et al.* 2003, Reverter *et al.* 2004). The bioinformatics and biostatistics that underpin nutrigenomics and nutrigenetics experiments are not trivial and at the research group level, this leads to markedly different structures and collaborative arrangements than previously existed within animal nutrition science.

Differentially expressed (DE) genes are one clue as to how a particular nutrient might be influencing animal metabolism, in the case of a nutrigenomics experiment, or how a particular polymorphism might be influencing the metabolic fate of particular nutrients, in the case of a nutrigenetics experiment. Reverter *et al.* (2004) developed a suite of methodologies with which to analyse DE gene lists in order to reconstruct gene regulatory networks and cross-reference them against the well-characterized pathways of intermediary metabolism, or higher levels of regulation as might occur through networks of transcriptional factors (Hudson *et al.*, 2009).

Many functional genomic laboratories are now active around the world, and their work is based on similar techniques, common microarray platform and comparable nutritional treatments in different species. This provides an unprecedented opportunity to address questions of basic scientific interest that may have a medical application in humans, and an industrial application in production animals. A good example is muscle turnover, which has the obvious commercial application in pigs, but also is relevant to the treatment of sarcopenia in humans. Many of these datasets are available for large scale analysis, and the computation power exists to deliver results that would have been impossible even 3 years ago (Reverter *et al.* 2006). These types of insight are beyond the capacity of any single researcher to develop and are a tangible outcome of the development of high-throughput methodologies and larger collaborative networks.

The importance of these examples is that they show how nutritional genomic approaches allow us to work at levels of abstraction well above where we have previously worked. Previously, many workers including ourselves have relied on a "gene by gene" approach to nutritional research. Researchers identify some gene or small family of genes for particular focus through some mixture of candidate gene analysis, historical precedent, or other factors. They then gather the tools for the analysis of that gene (DNA probes, antibodies, knockout mice, cells in culture, molecular effectors of that gene etc.) and proceed to dissect its properties and the properties of the genes closely associated with it. The strategic challenge for us as animal scientists, is that the gene by gene approach, whilst being effective in uncovering molecular detail, is too slow to work through the multitude of interactions involved in regulation of mammalian growth and development. Genomic and bioinformatic approaches go some way to reducing the dimensions of space and time we need to cover in order to make our next discoveries and see them applied in for example, the efficient production of pork.

Nutrient and species diversity

During the evolutionary development of our current pig breeds, populations were exposed to an enormously diverse range of nutrients, non-nutrients and anti-nutrients through their diets. Scavenging and foraging species face particular challenges as the whole diversity of the plant kingdom can potentially be presented to the gut wall (Rochfort *et al.*, 2008) and ecological evidence suggests pigs in the wild browse widely (Thomson and Challies, 1988). At one level, this diversity can be reduced by assessing each new compound as part of a whole diet and in terms of the amount of energy liberated through its metabolism and the chemical form of the metabolites. At the next level of complexity however, there is the bioactive effect of each compound, that is, the physiological effect of a compound over and above its nutritional value. In nutrigenomics, essential nutrients such as Ca, Zn, Se, and folate, and non-essential nutrients such as phytochemicals (carotenoids, flavonoids, indoles), zoochemicals (conjugated linoleic acid, n-3 fatty acids), fungochemicals (such as mushroom products) and bacteriochemicals (such as those formed from fermentation) are of interest. Groups of people with specific genotypes have requirements for essential nutrients that are significantly different from the broader population, and react to non-essential nutrients in unique ways. This raises questions about the appropriateness and generality of simple public health messages like the "recommended daily allowance". In production animals like pigs, where we lack the scale for epidemiological studies, we need to focus on large nutrient x gene effects, as opposed to those effects that are (simply) of mechanistic interest. We do have populations of animals on which phenotypes have been carefully recorded and some degree of phenotype-genotype association has been achieved (for example, the Large White and Meishan pigs). Chen *et al.* (2007) recently documented the breadth of these global resources, and noted the geographic and phenotypic spread of this species. The next phase of this work should include controlled nutrient intakes in experimental populations for which genetic variance is either controlled experimentally, or at least defined accurately. These are the larger scale versions of the experimental designs described above.

Strategic considerations

The techniques described above have several disadvantages when compared to the set of approaches currently being applied in industry. What then, are the arguments for investing more in the area of nutritional genomics?

It is true that animal scientists have been working with pigs for many decades now (eg. Lusk, 1926) and hence the macronutrient and many micronutrient requirements of these animals should be known with confidence. However as noted above, production animals like chickens and pigs have been driven by genetic selection pressure to levels of feed conversion efficiency that have not been observed before in human experience. Likewise, human research has led to the re-evaluation of the concept of "recommended daily allowances" and it is entirely reasonable that re-evaluation of similar concepts in pigs is warranted given genetic improvement, and the drive to feed animals ethically, safely and ever more cheaply. Finally, the issues of global food security challenge us to find ways of feeding pig breeds that are indigenously grown, and on feedstuffs that can be sustainably produced in regional areas of the developing world.

It is also true that animal and human nutritional science uncovered a broad range of valuable molecules from the early research: hormones, growth factors, bioactives, synthetic amino acids and vitamins. Some may be concerned that nutritional genomics will simply "reinvent the wheel" by identifying genes, and regulatory elements with exquisite sophistication but without novelty. Again, experience in the last five years has reinforced the view that higher levels of organisation, control and integration are still to be discovered and integrated into our understanding of mammalian metabolism (eg. long non-coding RNA, Mercer *et al.*, 2009). It is important in our view, to continue to drive this deeper understanding on the premise that it will uncover new ways of reducing the resource-use footprint of pork production through hitherto undiscovered efficiencies.

There is a view that the challenges of pig feed efficiency can be met effectively through genetic selection within environmental constraints, and more particularly using Genome-Wide Selection (Meuwissen *et al.*, 2001). Given the observation that pre- and post-weaning growth rate in pigs has a genetic component (Paszek *et al.*, 1999), this is not an unreasonable view. Such selection programs are, however, proving to be expensive in terms of financial and human resources, and while they might be feasible in developed world economies and with multinational corporations, large scale breeding programs are unlikely to be feasible for all the breeds of indigenous interest, for all the environments in which pigs are produced, and with all the nutritional interactions likely to arise in these environments. It seems likely to us that nutritional knowledge developed through nutrigenomic studies in particular will be applicable across breeds and that the existing knowledge of pig nutrition will allow reasonable approximations of feeds that will be applicable to indigenous breeds to achieve optimal production. An additional potential pay-off from this type of research is that it might uncover biomarkers – molecules that are present in readily accessible animal products like blood, saliva, faeces or urine, that are strongly correlated to other animal phenotypes – that can be used to optimize production through non-genetic means. An example here may be feeding an Mg supplemented diet for the last few days before slaughter to pigs that have been identified as carrying the halothane gene or that are otherwise susceptible to stress around slaughter and present with resultant pale, soft and exudative pork (D'Souza *et al.*, 1998). Those that do not carry the halothane gene or that have been identified as not having a genetic predisposition towards pre-slaughter stress would receive the non-supplemented diet. Another example from pharmacology is the identification of humans with a SNP in the beta2-adrenergic receptor codon that confers different responses to bronchodilator responses to albuterol (Israel *et al.*, 2001). Such a SNP in pigs may see animals being targeted with different doses or types of dietary beta-agonists. On a background of continual genetic improvement, such non-genetic complementary dietary approaches can significantly enhance the efficiency of a pig production system. The challenge is to keep genetic and non-genetic approaches developing in parallel and in collaboration.

It is also the case that some products of previous nutritional and genetic research have not found favour with the public and hence have not delivered their full potential to the industry – a fate not shared with genetic selection technologies. Good examples include the use of hormonal growth promotants such as growth hormone (Dunshea *et al.*, 2005) and the use of animal transgenesis to significantly enhance the physiological capacity of the pig (Golovan *et al.*, 2008). It is important to take these examples into account when considering the likelihood of industrial success resulting from an investment in an early stage, prototype technology.

There are certainly significant private and commercial resources being invested at present in the development of pigs with improved characteristics, including improved feed efficiency. For example, the UK breeding company Genus PLC (Basingstoke, Hampshire, UK), invested £5.9 million in pig breeding in the last six months of 2008 utilising leading edge genomic technologies. While this is ultimately a good trend for pig production science, there are significant concerns now being raised globally about the ethics and social consequences of corporate ownership and control of the genetic bases of our food production systems. Community reactions to the ownership of pig genetic resources are a case in point (see the case of EP 1651777).

Conclusion

When it comes to planning animal production practices of the future, the scales of the genome and the global production systems are daunting, and the paths to product delivery clouded by inconsistent public policy. Our challenge now is to harness the power of the 'omics' technologies coupled with bioinformatics and biostatistics for discovery of novel pathways, genes and single nucleotide polymorphisms. The targets, however, have not changed. Animal production scientists are still seeking animals that grow efficiently within our production constraints which leave minimum resource-use foot prints and produce high quality products that meet market demands. More than likely, the new technologies will be catalysts for incremental delivery against known targets rather than harbingers of radical change. It is important to remember that genetics and nutrition work together to mould the mature production animal, so to some degree investments in genetics and nutrition need to be balanced and coincident. One without the other is unlikely to uncover the global solutions required to meet current food production challenges.

Acknowledgements

The authors wish to thank Professor Miranda Grounds of the University of Western Australia, Dr Nick Hudson, and Mr Peter Allingham from CSIRO, for many stimulating discussions about fundamental muscle biology and its relevance to animal production.

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Offering Creep Feed to Piglets During Lactation Influences Post-Weaning Feed Intake and Body Weight Homogeneity Out of the Nursery

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An area that has received little investigation with respect to creep feeding is the influence of creep feed familiarisation during lactation on feed intake behaviour by piglets after weaning. The hypothesis tested in this experiment was a qualitative estimate of individual piglet creep feed intake during lactation would be an indicator of the piglets ability to eat in the period immediately after weaning, subsequently related to growth performance.

A commercial piglet feed (12.70 MJ net energy (NE) and 1.21 g standardised ileal digestible (SID) lysine/kg) was fortified with 2kg tri-chromic oxide per tonne of feed to stain the faeces of piglets if ingested (Bruininx *et al.*, 2002). Piglets from 8 litters (commercial cross, mean parity 3.3, 12-13 piglets per litter) were offered this feed from d 10 of lactation until weaning at 28 d. Eating status was assessed individually by faecal colour examination at days 19 and 26 to differentiate 'early', 'late' and 'non' eaters. After weaning, a pre-starter feed (10.46 MJ NE and 1.25 g SID lysine/kg) was offered for 14 d, followed by a commercial starter diet (9.60 MJ NE and 1.05 g SID lysine/kg) up to 69 d of age. Six litters from the same group of sows (mean parity 2.8) did not receive any creep feed during lactation ('naïve' piglets). At weaning, piglets were housed in 32 pens of four piglets based on the eating status ('early', 'late' and 'non' eaters and 'naïve'), sex and weight, taking care not to allocate pigs from the same litter in the same pen. Piglets were individually weighed at birth, d 10, and d 28 and weekly thereafter to 69 d of age. Creep feed disappearance was measured per litter. After weaning, feed disappearance per pen was assessed daily for the first 3 weeks and weekly thereafter. Post-weaning growth and feed intake data on a pen basis were analysed as a randomised block design using a mixed model of repeated measures (MIXED procedure SAS V8). Chi-square statistics were used on categorical data.

Table 1. *Influence of pre-weaning eating status on post-weaning piglet performance.*

Treatment in lactation…	Creep feed		No creep feed			
Eating status…	Early-eaters	Late-eaters	Non-eaters	Naïve	SEM	P value
Number of pens	5	12	3	12		
BW wean (kg)	8.34	8.07	8.12	7.90	0.23	NS
BW 69 d (kg)	32.27^{a}	31.04^{a}	29.30^{b}	31.02^{a}	0.67	P < 0.05
ADFI 0-21[1] (g)	447^{a}	393^{a}	316^{b}	393^{a}	35	P < 0.05
ADFI 0-41[2] (g)	923	872	785	852	19	NS
% piglets within range mean BW± S.D. at d 69		74%		58%	-	P = 0.056

[1]0-21 represents the first 3 weeks post-weaning. [2]0-41 represents the 6 weeks in the nursery, until 69 d of age. SEM, standard error of mean; BW, bodyweight; NS, not significant; [ab]Means in a row with different superscripts differ significantly (P<0.05).

Creep feed intake per litter averaged 72 g/day, with 28% of 'early-eaters' piglets, 61% 'late-eaters' and 11% 'non-eaters'. These data are comparable to those in the literature (Bruininx *et al.*, 2002; Pluske *et al.*, 2007). Contrary to weaning weight, post-weaning ADFI was significantly affected by eating status, (Table 1). 'Early' and 'late' eaters ate more than 'non-eaters' (P<0.05). However, the comparison between piglets offered creep feed in lactation and 'naïve' piglets did not show any difference. The same pattern was observed for growth data. 74 % of piglets offered creep feed were within one standard deviation of the mean when weigted at 69 d of age versus 58% for 'naïve' piglets (P Chi-square=0.056). Improved homogeneity out of the nursery was not expected but looks promising. These results support our hypothesis, indicating that most piglets developed some eating ability before weaning at 28 d.

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Potential for an Extruded Semi-Moist Creep Feed to Improve Pre-Weaning Growth Performance of Pigs

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The effectiveness of dry creep feeding on pre-weaning weight gain is equivocal (Pluske *et al.*, 1995). An alternative feed processing method could be extrusion, which uses heat, pressure and steam to process feed ingredients. An extruded creep feed with relatively high moisture content may assist the piglet in the transition from liquid to solid feed. The aim of this experiment was to examine the potential for an extruded semi-moist creep feed (SMCF) to enhance the pre-weaning performance of piglets in a commercial herd compared with standard medicated or un-medicated creep feeding programs.

The pre-weaning growth performance and mortality of 66 litters (690 piglets) was examined from d 7 to 28 post-parturition. Three dietary treatments were compared based on a randomised block design with treatments comprising 1) a non-medicated commercial creep (NC, 15.7 MJ digestible energy (DE)/kg), 2) a medicated commercial creep (PC, 15.7 MJ DE/kg, 400ppm Amoxicillin and 60 ppm Salinomycin), and 3) a non-medicated extruded SMCF (15.0 MJ DE/kg), with all diets formulated to contain 0.9 g available lysine/MJ DE. The NC and PC feeds were presented as solid 2 mm pellets while the SMCF was a soft pellet. Each treatment contained 22 litters and the distribution of sow parities was even between treatments, and representative of a commercial herd. Diets were offered from d 8 to weaning with piglets weaned at 28 (±2) days of age. Individual body weights were recorded at d 7, 14, 21 and 28. Litter was used as the experimental unit and the data were subject to analysis of variance with means separated by least significant difference.

Table 1. *Growth performance of piglets offered non-medicated (NC) or medicated (PC) commercial creep diets or extruded semi-moist creep feed (SMCF).*

	Mean piglet bodyweight (kg)				Mean bodyweight gain (kg)			
Dietary treatment	D7	D14	D21	D28	D7-14	D14-21	D21-28	D7-28
NC	2.56	4.05	5.71	7.32	1.48	1.70	1.61[ab]	4.76
PC	2.67	4.17	5.86	7.31	1.50	1.75	1.44[a]	4.63
SMCF	2.62	4.16	5.89	7.56	1.54	1.88	1.69[b]	4.94
SEM	0.063	0.086	0.110	0.110	0.033	0.050	0.040	0.078
P Value	NS	NS	NS	NS	NS	NS	0.05	NS

[ab]Means in a column with different superscripts differ significantly (P<0.05); D, day; NS, not significant; SEM, standard error of mean.

Mortality was not different between treatments. Creep feed disappearance from d 8 to 28 was greater (P<0.001) in pigs offered the SMCF compared to pigs offered NC and PC. Piglets offered SMCF gained 0.25 kg more (P<0.05) in the week prior to weaning compared to pigs offered PC creep (Table 1). The results from this experiment suggest creep feed medication and diet form influence the growth performance of litters within a commercial herd. The influence of diet composition alone cannot be assessed in this experiment due to the differences in the milling processes. Medication may limit growth performance through reduced feed palatability. SMCF has the potential to promote higher pre-weaning creep feed intake, and subsequently improve weight gain of piglets from d 21 to 28 (the period of declining sow milk output) in a commercial herd.

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Supported in part by Australian Pork Ltd and the Pork CRC Ltd

The Choice Behaviour of Pigs in a Y Maze: Effects of Deprivation of Food, Social Contact or Bedding

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Preference tests, in which animals are offered choices, have been used to examine the relative importance of environmental features or resources for animals. The hypothesis tested in the present experiments was that food is a highly preferred resource relative to social contact and bedding.

In three experiments, we examined the effects of deprivation of the resources, food, social contact and bedding, on the choice behaviour of pigs for these resources in 12 daily Y maze trials. Eighty female Large White × Landrace pigs aged between 10 and 14 weeks were used. Two main effects in each experiment were studied: Experiment 1 - food (voluntary feed intake (VFI, estimated in two 15 min feeding bouts per day) vs 70% VFI) and bedding in the home pen (presence vs absence); Experiment 2 - social contact in the home pen (full vs restricted in which visual and tactile contact were eliminated) and bedding in the home pen (presence vs absence); and Experiment 3 - food (VFI vs 70% VFI, as in Experiment 1) and social contact in the home pen (full vs restricted, as in Experiment 2). In each of the 12 trials in each experiment, individual pigs could choose between the two resources under investigation; Experiment 1, food vs bedding; Experiment 2, social contact vs bedding; and Experiment 3, food vs social contact. Following training in which pigs were exposed to the two resources in the arms of the Y maze, pigs were tested in a random order once daily for 12 d and allowed 2 minutes with the resource once the choice had been made. Liveweight was only monitored in Experiment 3.

Overall pigs consistently chose food over bedding (94% of trials, Experiment 1) and social contact over bedding (91% of trials, Experiment 2). While there were no main effects or interactions on choice behaviour in Experiment 1, restriction of bedding reduced choice of social contact in Experiment 2 (87 vs 99% of trials, P=0.032). In Experiment 3, pigs on average chose food over social contact in only 37% of the trials. While feed restriction increased choice of feed (46 vs 28 % of trials, P=0.038), there was substantial variation between pigs in their choice behaviour irrespective of the deprivations studied. While further research is required, this apparent difference between individual pigs in their preference for food or social contact is unexpected. Thirty-one percent of the 48 pigs in Experiment 3 chose food in 50% or more of the trials (average food choice of 78%), while 69% of the pigs chose social contact in more than 50% of trials (average social choice of 81%). If this is a real effect, these results have important implications for animal welfare. One interpretation is that pigs may differ in their long-term choice behaviour for food or social contact and thus may also differ in their welfare requirements in relation to these two resources. Furthermore, if this difference in choice behaviour is a real effect, it also raises some interesting questions about its genetic and/or experiential basis. There were also main effects of social contact and food on average daily weight gain (ADG) in Experiment 3, with both food restriction (P<0.001) and social restriction (P=0.032) reducing ADG. While the food effect is expected, one interpretation of the social effect is that social deprivation, through stress, may have reduced ADG. The stress-induced catabolic effects of adrenocorticotrophic hormone (ACTH) and corticosteroids are well known (Elsasser *et al.*, 2000). Thus we suggest that the food effect on ADG is likely to be largely explained in terms of reduced feed intake, however the social effect on ADG provides limited support for the notion that deprivation of a highly preferred resource or environmental feature may result in biological dysfunction.

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Supported in part by Our Rural Landscape Initiative Funding (Department of Primary Industries, Victoria).

Effects of Deprivation of a Preferred Resource (Feed or Social Contact) on the Biological Functioning of Pigs

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There is uncertainty within science on the concept of animal welfare, arising because scientists differ in their concept of animal welfare and thus how animal welfare should be measured or judged. Scientists have predominantly used two methodologies to study animal welfare (Fraser, 2003): the welfare of animals has been assessed on the basis of either biological functioning or animal preferences. The first approach is an integrated one measuring behavioural, physiological, health and fitness responses to assess biological functioning on the basis that difficult or inadequate adaptation will generate welfare problems for animals (Broom, 1986). The second uses animal preference (and behavioural demand) testing on the basis that animal preferences are influenced by the animal's emotions, which have evolved to motivate behaviour in order to avoid harm and facilitate survival, growth and reproduction (Duncan, 2004). An important question in addressing this scientific uncertainty is how animal preferences relate to biological functioning. This experiment sought to test the hypothesis that deprivation of a preferred resource results in biological dysfunction.

In the first part of the experiment, 36 female pigs (Large White × Landrace) aged between 10 and 14 weeks at the start of the experiment were studied in a series of preference tests. A Y-maze was used to provide the animals with the opportunity to choose between social contact with familiar animals or access to feed in a distinctive feeder. Animals were tested in a random order once daily over 12 d and allowed two minutes with the resource once the choice had been made. During the 12 d of testing all pigs were fed 70% of voluntary feed intake (VFI) and deprived of tactile and visual contact with other pigs in their home pens. Two groups of eight pigs each were selected, eight that predominantly chose feed (chose feed on average in 80% of trials) and 8 that predominantly chose social contact (chose social contact on average in 91% of trials). The second part of the experiment involved studying preference and restriction in a factorial design. Over a six week period, half of each group of pigs (the "social preferred" and the "feed preferred" pigs) were deprived of visual and tactile social contact but had VFI, while the other half were placed on 70% VFI feed restriction but allowed visual and tactile social contact. At five weeks of treatment, the behaviour of pigs was video recorded and analysed for time budgets. Pigs then underwent surgery to implant catheters to allow for repeated blood sampling to measure basal cortisol (total and free) and the total cortisol response to an acute adrenocorticotropin (ACTH) challenge, and an acute corticotropin releasing hormone (CRH) challenge. Behavioural, liveweight and physiological data were analysed using a general linear model in SPSS, where required data were log transformed.

There were no significant main effects on the liveweight change over the study period. However, there was a significant (P=0.026) interaction on liveweight change with both socially preferred and feed preferred pigs showing lower liveweight gains when deprived of their preferred resource. A similar tendency for an interaction between main effects was evident on free cortisol (P=0.11), with animals deprived of the preferred resource showing higher average day time (ADT) free cortisol. There was a main effect of feed deprivation on cortisol with increased ADT total cortisol (P=0.044) and increased cortisol response to CRH (P=0.013) in the feed deprived pigs. On the basis of changes in free cortisol and liveweight, this study provides limited evidence that deprivation of a highly preferred resource may result in biological dysfunction.

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Supported in part by Australian Pork Ltd and Our Rural Landscape Initiative Funding (Department of Primary Industries, Victoria).

Investigating the Clonal Relationship of Intestinal *Escherichia coli* From Intestinal Sections in the Aging Neonate

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Bacterial colonisation of the gastrointestinal tract (GIT) in neonatal piglets begins as the piglet travels through the birth canal. As the neonate advances in age, the composition of the GIT microflora is believed to fluctuate until a 'mature' community is achieved. We hypothesise that the *Escherichia coli* (*E. coli*) community will become more stable (reduced diversity) as the animal matures and that *E. coli* from older piglets will be more closely related.

The entire intestinal content was collected from 2, 4, 6 and 12 d old piglets from a single gilt litter. Three sections of the small intestine (duodenum, jejunum and ileum) as well as the caecum and colon were analysed. Approximately 20 *E. coli* were isolated from each section and pure cultures were identified as *E. coli* using real time polymerase chain reaction (PCR) amplification of the *E. coli* specific uspA gene (total n = 307). DNA was extracted, and analysis for *E. coli* clonality was determined using random amplified polymorphic DNA (RAPD) PCR profiles using the 1254 primer. The RAPD profiles were visualised in 1.5% agarose gels stained with ethidium bromide. BioNumerics software package (Applied Maths, Sint-Martens-Latem, Belgium) was used to analyse the RAPD profiles with curve based analysis and Pearson's correlation. Dendrograms were generated to determine the percentage similarity, and therefore the clonal relationship among isolates (Figure 1).

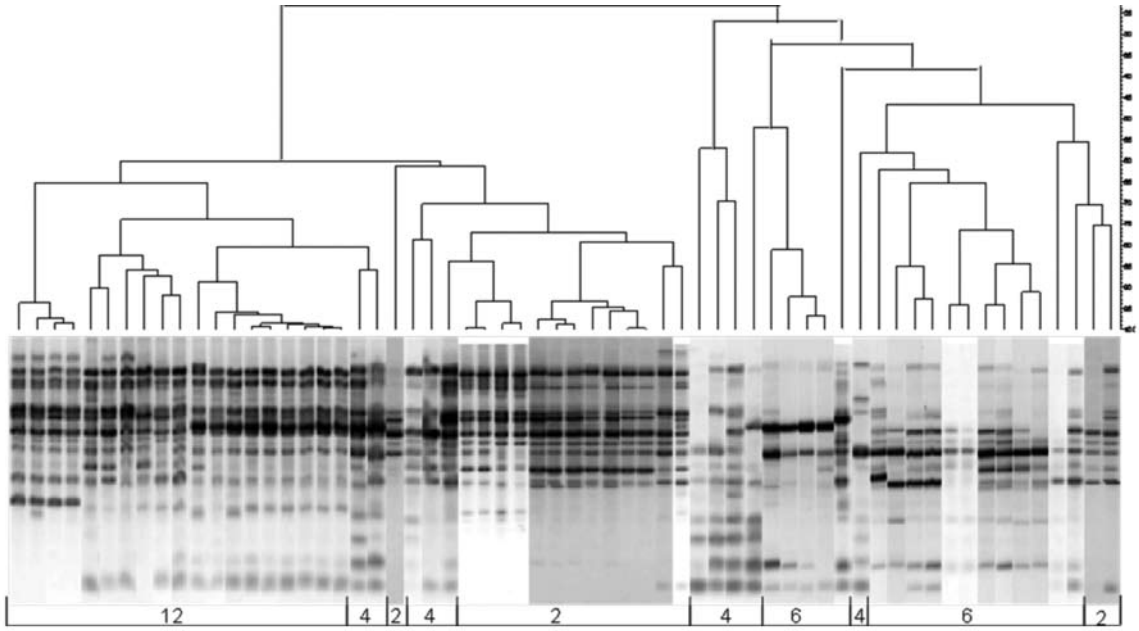

Figure 1: *Dendrogram showing the clonality of Escherichia coli isolated from the colon of neonatal piglets of 2, 4, 6 and 12 d of age.*

The isolates from both the youngest (2 d) and the oldest (12 d) piglets had the tightest clustering with the percentage of similarity beginning at 55%; compared to isolates from the four and six d old animals, that showed a greater divergence (20% similarity). This data indicates that this type of *E. coli* present in the 2 d old piglet were the initial colonisers of the GIT. From four to six days of age, community succession leads to an influx of diversity, as the *E. coli* population adapt to the changing physical environment. Stabilisation occurs around 12 d of age resulting in the seed *E. coli* population for the mature intestine. To further investigate this trend, an additional two gilt litters and three third parity sow litters will be analysed.

Supported in part by the Pork CRC Ltd.

The Effects of Fatty Acid Subtype on Performance and Respiratory Exchange Ratio in Gilt Progeny

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Previous studies have shown that dietary fatty acids influence growth and development, respiratory exchange ratio (RER; Newman *et al*., 2002), behaviour and stress-mediated responses in rats (Takeuchi *et al*., 2003). The aim of this study was to investigate the effects of dietary saturated fatty acids and polyunsaturated fatty acids (PUFA) of the n-3 and n-6 series on growth during the pre- and post-weaning phases. Pre-wean respiratory exchange ratio and the stress response to weaning in piglets were also assessed.

Gilts (n=14; Large White x Landrace) were fed diets containing saturated (tallow), n-3 (Salmate®, Feedworks Pty Ltd, Romsey, VIC.) or n-6 (safflower oil) fatty acids two weeks prior to mating and throughout gestation and lactation. Progeny from gilts were observed for body weight and average daily gain (ADG) during lactation. RER was measured in a subset of male piglets at approximately d 16±1.5 of age by open-system respirometry. Forty-seven female pigs were placed in individual cages at weaning (d 29±0.26) and salivary samples were collected at weaning (basal) and 90 min post weaning for cortisol determination. Pigs were maintained on the same fatty acid treatment as their maternal diet and fed *ad libitum* for 4 weeks. Feed was offered to maintain approximately 1kg in each trough and feed residues and body weights were recorded weekly. Water was provided *ad libitum* via nipple drinkers. A linear mixed model was fitted to the data using a REML procedure in Genstat.

Table 1. *Pre- and post-weaning treatment means for gilt progeny fed different fatty acids.*

Treatment	Birth weight (kg)	RER	Wean weight (kg)	Grower weight (kg)	Wean-Grow ADG	Feed Intake (g/day)	FCR	Weaner diet n-6:n-3
Saturated	1.80	0.75^{a}	8.79	24.63^{a}	577^{a}	691^{aa}	1.13	15.3
n-3 PUFA	1.50	0.77^{ab}	9.72	25.48^{a}	574^{a}	647^{aa}	1.03	8.2
n-6 PUFA	1.43	0.79^{b}	9.19	17.27^{b}	288^{b}	345^{bb}	1.00	23.2
SEM	0.07	0.01	0.34	0.84	14.16	29.1	0.04	
P value	NS	*	NS	*	*	**	NS	

^{abc}Means within columns with different superscripts differ significantly; ADG, average daily gain; FCR, feed conversion ratio; RER, respiratory exchange ratio; SEM, standard error of mean; NS, not significant; *, P<0.05; **, P<0.01.

No significant differences were found for bodyweight at farrowing (Table 1). Respiratory exchange ratio was affected by fatty acid subtype with the n-6 PUFA treatment group resulting in a significantly higher RER than the saturated treatment group, indicative of greater carbohydrate oxidation. There was no significant difference in weaning body weights, however, one week post-weaning pigs from the n-6 PUFA group weighed significantly (P<0.05) less than both the saturated and n-3 PUFA groups, which continued for the duration of the cage experiment. Pigs from the n-6 PUFA treatment group had significantly reduced ADG and feed intake for the weaner period compared to the saturated and n-3 PUFA groups. There were no significant differences in salivary cortisol concentrations between treatment groups at each time point, however, salivary cortisol levels significantly increased within treatment groups at 90 min post-weaning. The negative effects of dietary n-6 PUFA on ADG and liveweight during the weaner phase indicates that the ratio of n-6 PUFA to other fatty acid subtypes should be considered in diet formulations.

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Supported in part by the Pork CRC Pty Ltd.

Spray-Dried Porcine Plasma Improves the Performance of Weaner Pigs Regardless of Weaning Weight

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Two major problems facing the Australian pig industry with respect to weaning of pigs are first, the low feed intake in the first 7-14 days following weaning, and second, the more variable and poorer performance of light-for-age pigs (eg. <5.0 kg at 21 days). Spray-dried porcine plasma (SDPP) is used extensively in diets for weaner pigs in some parts of the world because of its capacity to enhance feed intake after weaning, which is thought to be linked to its IgG concentration (eg. van Dijk *et al*., 2001), however we are unaware of any research examining SDPP under Australian conditions. The main objective of this study was to see whether weaner diets containing SDPP could assist light-for-age pigs to perform better in the post-weaning period.

A total of 96 pigs weaned at 21 d were used in a 2x2 factorial experiment with the respective factors being (1) light- (4.9±0.67 kg liveweight (LW)) or heavy- (6.9±0.73 kg LW) for-age pigs and (2) a diet containing SDPP (50 g/kg and 25 g/kg, for Stage I and II, respectively) or a control diet not containing SDPP. Stage I diets were fed for the first week and Stage II for the following 2 weeks until the experiment ceased at 21 d after weaning. The SDPP was included in diets at the expense of soybean meal and fishmeal. Concentrations of IgG, IgM and IgA in the SDPP were 10.8, 3.3 and 0.7%, respectively. Each treatment had 8 replicates (pens) with 3 pigs per pen. Pigs were weighed weekly and feed refusals daily to calculate performance indices. One pig per pen, randomly selected, was bled on d 7 and 14 to measure circulating levels of Ig and plasma urea nitrogen (PUN). Data were subjected to a two-way analysis of variance (Table 1).

Table 1. *Performance of light- and heavy-for-age pigs fed diets with or without spray-dried porcine plasma (SDPP) in the first week post-weaning (n=8).*

	Light pigs		Heavy pigs			P value	
	Control	SDPP	Control	SDPP	SEM	DIET	LW
Week 1							
ADFI (g/d)	129	183	161	215	11.4	<0.001	0.023
ADG (g/d)	63	134	92	164	1.04	<0.001	0.023
FCR (kg/kg)	2.38	1.51	2.06	1.19	0.21	0.002	0.214
IgG (mg/ml)	5.68	6.32	8.49	6.18	0.713	0.254	0.076
PUN (mmol/l)	5.25	3.83	5.27	3.85	0.219	<0.001	0.941
Overall							
ADFI (g/d)	324	351	394	421	0.12	0.121	<0.001
ADG (g/d)	205	225	253	274	0.09	0.090	<0.001
FCR (kg/kg)	1.59	1.56	1.57	1.54	0.32	0.315	0.652

n, number of replicates; SEM, standard error of mean; ADFI, average daily feed intake; ADG, average daily gain; FCR, feed conversion ratio; IgG, immunoglobulin G; PUN, plasma urea nitrogen.

The inclusion of SDPP in the diet improved performance of both light- and heavy-for-age pigs in the first week after weaning (Table 1). Such effects disappeared in the following 2 weeks and over the 3-week study, pigs supplemented with SDPP gained 20 g more per d than the control pigs (P = 0.090). On d 7, PUN was lower (P<0.001) in pigs fed SDPP than in control pigs, suggesting an increased efficiency of dietary protein utilisation as a result of SDPP supplementation. There was no difference in IgG levels between treatments. The inclusion of 50 g/kg SDPP in pig diets in the first week following weaning improves pig performance.

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Supported in part by the Pork CRC Ltd.

Assessing Pig Performance in Energy Reduced Diets in the Presence of Exogenous Feed Enzymes

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The utilisation of an enzyme complex produced by solid state fermentation (Allzyme® SSF, Alltech, Serdan, Mexico) has been well researched in poultry diets and led to the confident use of matrix values to account for improved digestibility of the diet (Acevedo *et al.*, 2008). However, the information available to verify the matrix values for growing and finishing pigs, especially when using Australian ingredients, is limited. The aim of the current experiment was to investigate the effectiveness of the enzyme complex when reformulated using matrix values in typical Australian pig diets.

The experiment was conducted at a commercial grow-out site in a simple open sided, naturally ventilated shed, which incorporated a series of pens on either side of a central aisle. The animals used were 144 male commercial crossbred pigs (housed in pens of 12 pigs each) of approximately 11 weeks of age and 30 kg liveweight. The pigs were weighed in groups initially and then individually after 5 weeks. Feed was offered *ad libitum* and feed intake was monitored for the 5 week period. The experiment consisted of four replicates of three treatments. The treatment groups included A) a standard grower diet (14MJ digestible energy (DE)/kg, 0.9% Ca and 0.4% available phosphorous (AVP)), B) a reformulated diet with reduced nutrient density (13.5 MJ DE/kg, 0.8% Ca and 0.3% AVP and same amino acid (AA):DE ratio as diet A) and C) diet B plus 200 g/T of the enzyme complex. Data was analysed by using the general linear models (GLM) procedure to determine the effect of treatments on performance parameters.

Table 1. *Performance of growing pigs fed either a standard diet (diet A), a low density diet (energy, calcium and available phosphorus; diet B) diet or low density diet plus enzyme complex (diet C).*

Diet …	A	B	C		
Dietary Energy (MJ DE/kg)...	14 .0	13.5	13.5 + enzyme	SEM	P-value
Average initial weight (kg)	29.5	30.5	29.7	0.32	0.432
Average final weight (kg)	61.9	61.9	61.9	0.23	0.994
ADG (g/d)	926	897	919	11.34	0.592
ADFI (kg/d)	1.88	1.93	1.93	0.01	0.283
FCR	2.03	2.15	2.10	0.03	0.359

ADG, average daily gain; ADFI, average daily feed intake; FCR, feed conversion ration; DE, digestible energy; SEM, Standard error of mean.

No significant differences were found between treatment groups for any of the performance indicators despite the significant drop in nutrient density (-3.6% in diets B and C). This would indicate that current specifications are above the actual requirements for growing pigs and a drop of 3.5% is not sufficient to detect any significant production response. However, the reduction in nutrient density resulted in a no significant (P>0.05) increase in feed intake or feed conversion ratio. Given the coefficients of variation on growth rate are of the order of 10% or higher it may have been ambitious to expect to be able to detect a 2% difference in performance with only 4 replicates.

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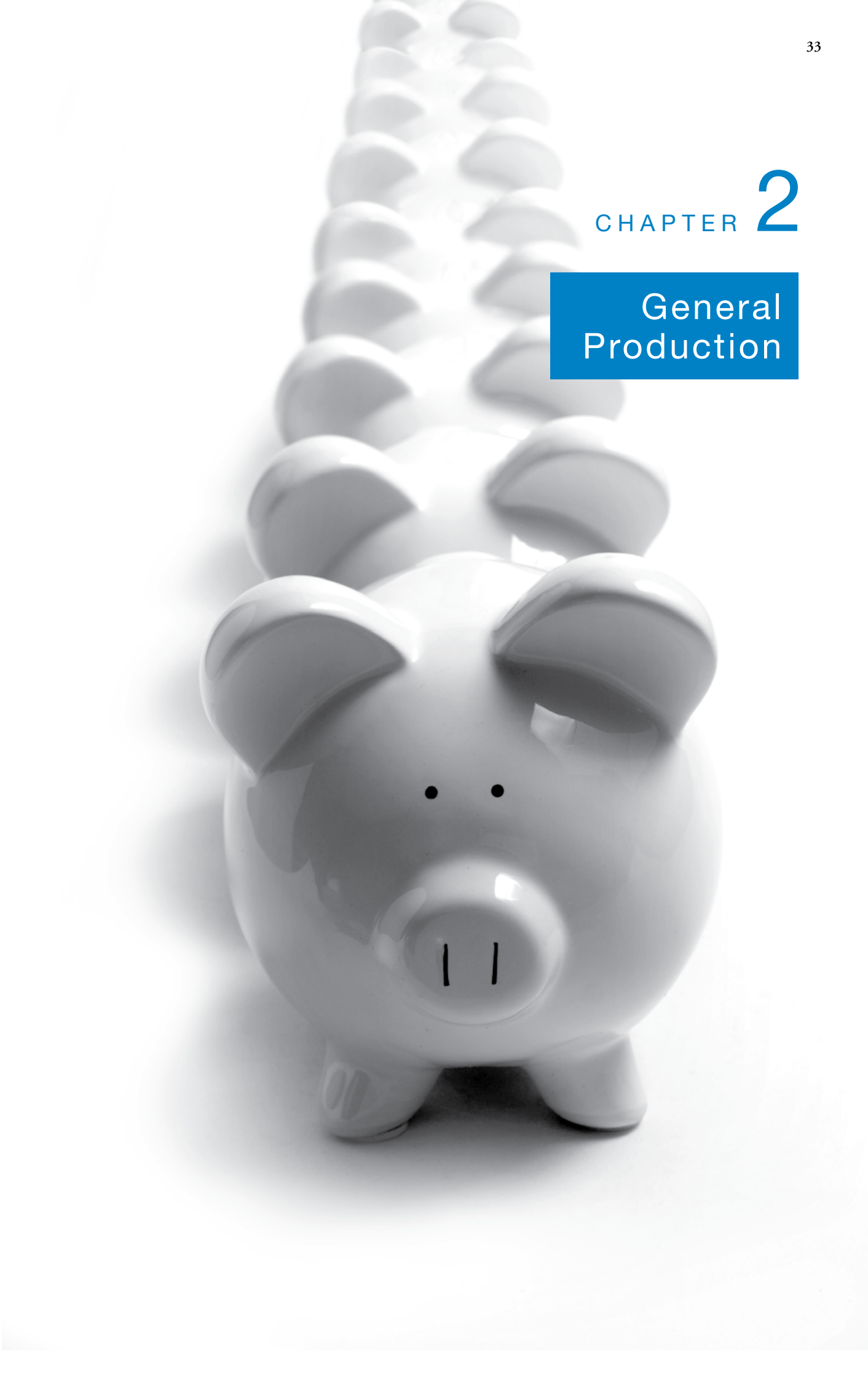
CHAPTER 2

General Production



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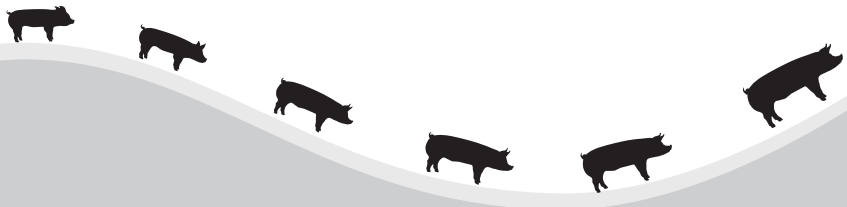

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Frequency of an IGF2 SNP Related to Postnatal Growth and Body Composition in a Commercial Herd in Australia

M.J. De Blasio[1], C.T. Roberts[1], K.L. Bunter[3], M. Tull[2], B. Luxford[2], M.B. Nottle[1] and J.A. Owens[1]

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Utilising selection for genetic markers of economically important traits could increase productivity in the Australian pig industry. Insulin-like growth factor-2 (IGF2) is a peptide produced by many tissues and is present in blood in prenatal and postnatal life, with high blood levels associated with reduced adiposity in several species. Recently, a single nucleotide polymorphism (SNP) has been identified in the IGF2 gene (IGF2-intron3-G3072A) in pigs that accounts for 15-30% of phenotypic variation in muscle mass and 10-20% of backfat thickness in intercrosses of diverse breeds (van Laere *et al*., 2003). The SNP is a Guanine (G) to Alanine (A) substitution. Boars with the AA (high IGF2) genotype have 3 times more skeletal muscle IGF2 mRNA compared with boars with the GG (low IGF2) genotype (van Laere *et al*., 2003). Selection for rapidly growing lean progeny in commercial herds in Australia may have increased the frequency of the A-allele. We therefore hypothesised that the frequency of the high IGF2 (AA) genotype in Australian boars and gilts is high.

Previously collected and stored semen samples from 93 Large White (LW) and 73 Landrace (LR) historical maternal line boars (born 2000-2005) were supplied from Rivalea Australia Pty Ltd, NSW. Additional samples were collected for DNA from maternal line boars (59 LW, 63 LR, hair sample, born 2006,) which were mated to 61 LW and 61 LR gilts (ear punch sample). Tail samples were collected at birth (2007) from the progeny of these boars and gilts, totalling 303 LW and 319 LR male piglets and 260 LW and 287 LR female piglets. DNA was extracted from either semen, hair, ear or tail samples and genotyped for the IGF2 SNP using an EP-Motion Automated DNA extraction robot with Charge-Switch Mass Extend Assay, which combines PCR with MALDI-TOF to achieve high accuracy, high throughput genotyping. Primers were designed using 300bp (due to high GC content) either side of the SNP (performed at Australian Genome Research Facility). The frequency of the A-allele of the IGF2 SNP was determined within breed and gender groups by Chi-Square test.

Table 1. *The frequency of the IGF2 SNP in Australian boars and gilts.*

Group	N	AA genotype (%)	GA genotype (%)	GG genotype (%)	f(A)
Historical maternal line LW boars	93	78	18	4	0.87
Historical maternal line LR boars	73	75	24	1	0.87
Maternal line LW boars	59	76	14	10	0.83
Maternal line LR boars	63	84	16	0	0.92
Purebred LW gilts	61	88	10	2	0.93[a]
Purebred LR gilts	61	74	19	7	0.83[b]
Young LW purebred boars	303	83	15	2	0.90
Young LR purebred boars	319	75	24	1	0.87
Young LW purebred gilts	260	84	13	3	0.91[a]
Young LR purebred gilts	287	77	22	1	0.88[b]

N, number of animals; f(A), frequency of A allele. [ab]Means with different superscripts within group pairs in a column are significantly different (P<0.05).

The frequency of the A-allele was higher in Purebred LW gilts compared with LR gilts (P<0.05), and young LW progeny compared with young LR progeny (P<0.05), but did not differ with gender (Table 1).

The frequencies of the IGF2 SNP in these commercial lines is very high, but further selection of the IGF2 SNP is still possible to increase lean muscle for production, since it appears that the A-allele is not fixed in these populations.

VAN LAERE, A., NGUYEN, M., BRAUNSCHWEIG, M., NEZER, C., COLLETTE, C., MOREAU, L., ARCHIBALD, A.L.,HALEY, C.S., BUYS, N., TALLY, M., RAN ANDERSSON, G., GEORGES, M. and ANDERSSON, L. (2003). *Nature*. **425**:832-836.

Supported in part by the Pork CRC Ltd.

Maternal Dietary Arginine Supplementation During Late Gestation Improves Reproductive Efficiency in Pigs

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Vascular development in reproductive tissues may be limited by the supply of arginine (a non-essential amino acid) and its conversion to nitric oxide (NO), which regulates angiogenesis (formation of new blood vessels). NO is a potent vasodilator, relaxing blood vessels and reducing resistance in the placenta during pregnancy, and may increase the delivery of oxygen and nutrients to support foetal growth and survival. Arginine concentrations peak in uterine fluids in early pregnancy (d 30-40) and again at 110 d in pigs. In parallel, placental angiogenesis increases from 25-44 d gestation, with another increase in late gestation (d 90 to term; Vonnahme *et al*., 2001). It is possible that maternal arginine supplementation (MAS) will enhance gestational changes in vascularity and blood flow in the placenta of the pig. MAS (1%) from d 30 to term has also been shown to increase survival and number of live born pigs (Mateo *et al*., 2007). We therefore hypothesised that MAS during late gestation, when placental angiogenesis increases, would improve reproductive outcomes.

Large White (LW) and Landrace (LR) gilts (parity 0, N=285) and sows (parity 3, N=326), were fed either a control or arginine supplemented (+25g/d arginine, Progenos premix, Trouw Nutrition, Netherlands) diet (2.5kg/d) in late gestation from d75 to term (~114 d). The number of total born, born alive, still born and birth weight and day 10 weight of progeny were measured. Data were analysed using Univariate analysis of variance, with total born included as a covariate except for total born analysis.

Table 1. *The effect of MAS in late gestation on reproductive outcomes.*

	LW gilts		LR gilts		LW sows		LR sows			Statistics		
	Con	Arg	Con	Arg	Con	Arg	Con	Arg	SEM	B	P	BxP
Total born	10.7	10.8	11.8	12.1	11.8	12.1	12.9	12.7	0.60	NS	NS	NS
Number born alive	9.37	9.28	10.6	11.1	10.6	11.0	12.0	11.6	0.60	0.005	0.009	NS
Number still born	1.21	1.02	1.17	0.80	1.12[a]	0.77[b]	1.16	0.80	0.30	0.04	NS	0.046
Litter birth weight	13.4[a]	15.3[b]	12.6	14.0	15.9	17.2	18.4	18.9	1.00	P<0.1	0.005	0.021
Average birth weight	1.21[a]	1.34[b]	1.41[a]	1.58[b]	1.37[a]	1.50[b]	1.47[a]	1.60[b]	0.050	0.04	0.003	0.042
Day 10 weight	2.43	2.55	2.58	2.53	3.27	3.28	3.38	3.53	0.10	NS	NS	NS

[ab]Means in a row within a breed and parity with different superscripts differ significantly (P<0.05). B, breed; P, parity; NS, not significant; CON, control; Arg, arginine; LW, Large White; LR, Landrace; MAS, maternal arginine supplementation.

MAS in late gestation did not alter total born. In LW sows, MAS reduced still borns by 0.35 pigs (P=0.046). In LW gilts, MAS increased average birth weight of live born by 0.13 kg (P=0.041), and litter birth weight by 1.9kg (P=0.033). In LW sows, MAS in late gestation increased average birth weight of piglets by 0.13 kg (P<0.039) and reduced still borns by 0.35 pigs (P<0.026). In LR sows, MAS in late gestation increased average birth weight of piglets by 0.13 kg (P<0.048). MAS did not alter d 10 weight of piglets. (Table 1).

Therefore, late gestation maternal arginine supplementation improves pregnancy outcomes in terms of piglet survival and piglet birth weight, in both LW and LR gilts and sows. Maternal arginine supplementation during critical periods of placental development may enhance placental-fetal blood flow and nutrient transfer, thereby improving fetal growth and survival and reproductive outcomes.

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Supported in part by the Pork CRC Ltd.

Performance of Pigs Treated With an In-Water Probiotic Preparation Compared With an Antibiotics and Vitamin and Mineral Program

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The search for effective medications to improve post-weaning performance is always a priority in any pig operation. A citric acid buffer (Acid-Pak-4way-2x (AP4w2x), Alltech Inc., Phillipines) which also contains enzymes and lactic acid producing bacteria has shown potential in some commercial piggeries. Very little is known as to the effects of AP4w2x in the nursery. Thus, this experiment was completed to determine the influence of AP4w2x on growth performance, the prevalence of scours and post- weaning mortality on newly weaned pigs compared to the performance of an existing water medication program.

Three hundred and forty-four newly weaned and mixed sex pigs (Large White-Landrace x Pietrain-Duroc) weighing 7.40±1.06 kg were randomly allocated to either control (20 pens) or treatment (16 pens) groups.

The number of pigs per pen was determined by maintaining a floor space allowance of 0.5 m^2/pig. Feeder space and waterers in each pen were set to support this space allowance. The control was given in-water antibiotics (Amoxicillin 20% water soluble powder (WSP) at 10 g/l of drinking water) plus water soluble multi-vitamins and minerals (Stress-pak, Marival Trading Inc, Philippines) at 10 g/3.8 l of drinking water. The treatment group was given AP4w2x only at 0.5 g/l of drinking water. The treatments were administered from 28 to 70 d old. No antibiotics were used in the feed. Injectable antibiotics (Dufamox 15% LA, Dutch Farm International, The Netherlands) were administered at 3 cc/pig/day to control spot diarrheal cases (profused and watery) in both groups. Scouring percentage per pen was calculated as the number of scouring pigs divided by the number of pigs in the pen x 100. Pig performance data were analysed using analysis of variance in a completely randomised design using GenStat (v8.1). Mortality % and scouring % were analysed using Chi-Square analysis with MS Excel.

Table 1. *Performance of pigs treated with in-water antibiotics and multi-vitamins and minerals or a probiotic program.*

	Control	AP4W2x	SEM	Significance
Initial weight (kg)	7.57	7.43	0.176	NS (P=0.287)
Final weight (kg)	21.98	23.30	0.514	NS (P=0.202)
Average daily gain (g/d)	358	387	0.009	NS (P=0.147)
Average daily feed intake (g/d)	560	561	0.010	NS (P=0.971)
Feed conversion ratio	1.59	1.47	0.036	NS (P=0.081)
Mortality %	9.76	4.03		NS
Scouring %	36	27		NS
In-water medication cost/pig ($AUD)	1.83	1.42		
Injectable antibiotics/pig ($AUD)	0.04	0.03		
Total cost of medication/pig ($AUD)[1]	1.87	1.46		

[1]Total cost of medication per pig is the cost of in-water medication plus the cost of injectable antibiotics administered; NS, not significant (P>0.05); SEM, standard error of mean; AP4W2X, Acid-Pak-4way-2x.

There was no significant difference in growth performance between the treatments (Table 1) but the total cost of medication was lower for AP4W2x by $AUD 0.41/pig. Results suggest that this probiotic approach may be an option to reduce antibiotic dependence without affecting overall pig performance.

Colonic Antibody Responses in Pigs With Swine Dysentery

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Swine dysentery (SD) is a mucohaemorrhagic colitis of pigs resulting from infection of the large intestine with the anaerobic intestinal spirochaete *Brachyspira hyodysenteriae*. The infection has been reported to result in the development of specific IgG, IgA and IgM antibodies in serum and the production of secretory IgA in the gut mucosa (Rees *et al.*, 1989). The hypothesis tested in this experiment was that colonic antibody levels can be used as a diagnostic tool to assist the diagnosis of SD. The experimental design involved testing samples from non-infected pigs to define appropriate cut-off values for the assays, and then using these in assays of serum and colonic samples from pigs that had been experimentally exposed to *B. hyodysenteriae*.

Colonic samples from 110 pigs from an SD-free farm, confirmed negative for *B. hyodysenteriae* by selective anaerobic culture and polymerase chain reaction (PCR), were obtained at slaughter. These were used to establish cut-off values for colonic antibodies, based on the mean ELISA reading plus three standard deviations. Commercial pigs (n=58) of ~25kg from the same farm then were purchased, bled and experimentally challenged with cultures containing 1010 cells of *B. hyodysenteriae*, over three successive days. The initial serum samples served as negative controls for establishing cut-off values. The pigs were killed when they developed signs of SD, or 30 d post-infection if they remained healthy. Serum and colonic samples were collected as previously described (Rees *et al.*, 1989), and tested in ELISAs using *B. hyodysenteriae* whole cell sonicates (2µg/ml) as the coating antigen, and appropriate conjugates to detect serum IgG and IgM, and colonic IgG and IgA.

Table 1. *Experimentally infected pigs (n=58) with positive antibody levels against Brachyspira hyodysenteriae.*

	Serum ELISA		Colonic ELISA	
	IgG	IgM	IgG	IgA
Pigs with disease (47)	3	4	27	12
Pigs without disease (11)	3	0	2	1

Forty-seven (81%) pigs became culture positive and developed clinical signs of SD. Only six (10%) developed serum IgG ELISA values consistent with infection, while 29 (50%) developed colonic IgG levels exceeding the negative cut-off value at post-mortem. Antibody levels were not correlated to lesion severity in individual pigs. More than half of the diseased pigs had elevated colonic IgG values, but 2 of 11 (18%) challenged pigs that remained healthy and culture negative also had colonic IgG levels exceeding the cut-off. Measuring colonic IgG was more discriminatory for detecting diseased pigs than using colonic IgA. This observation has not been made previously, as colonic IgG was not measured in the study by Rees *et al.* (1989).

These results indicate that elevated colonic IgG levels are a useful indicator of recent infection with *B. hyodysenteriae*, and could be used as an adjunct to the diagnosis of SD at the individual pig or herd level.

REES, A.S., LYSONS, R.J., STOKES, CR. and BOURNE, F.J. (1989). *Research in Veterinary Science*. **47**:263-269.

Supported in part by the Pork CRC Ltd.

Real Time PCR for *Haemophilus parasuis* - A New Diagnostic Option

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Haemophilus parasuis causes Glässer's disease, which is associated with polyserositis and arthritis. There are currently 15 serovars recognised, with these serovars ranging from high, moderate and mild pathogenicity all the way to being non-pathogenic. However, there is a high percentage of isolates that cannot be serotyped – with these isolates being called non-typable (NT) (Turni and Blackall 2005). Knowledge of the serovars of *H. parasuis* present in a herd is very important as the current killed vaccines only offer very limited cross-serovar protection if any.

A major problem with the diagnosis of *H. parasuis* is the fastidious nature of the bacterium. In the absence of serotyping, the ERIC polymerase chain reaction (PCR) technique has been successfully used by groups around the world to distinguish different strains of *H. parasuis*. The PCR test is a rapid test that detects a specific segment of DNA present only in *H. parasuis*. So far only two conventional PCR tests have been published, with conventional PCR tests lacking sensitivity. The alternative is a Real Time PCR, a variation on the PCR theme and a technology that is generally more sensitive. We have developed a Real Time PCR for *H. parasuis* and then evaluated if the new assay could be more specific and more sensitive than the conventional PCR assays available and as sensitive as culture methods.

The Real Time PCR amplifies the infB gene. It was validated with 68 *H. parasuis* strains from diverse sources (all were positive) and 36 strains of closely related species that could be expected to be present in pigs (all were negative). As the real application for this PCR is the diagnosis directly from tissue and fluids, 239 samples of stored DNA from tissue and fluids of artificially challenged animals were tested with the Real Time PCR. The results of the Real Time PCR were compared to results obtained for these tissue by culture and a conventional PCR (both tests applied when the tissue were freshly sampled). The Real Time PCR produced significantly more positive results than the conventional PCR (Generalised linear mixed model analysis, $P < 0.05$) (Table 1). In some instances, the Real Time PCR outperformed the culture method ($P < 0.05$).

Table 1. *Percentage of samples, either swabs of tissue/fluid or tissue/fluid processed directly, from artificially infected pigs that yielded positive results for the three evaluated methods of Real Time PCR, conventional PCR and culture.*

	RT PCR	PCR	Culture
Swabs of tissue/fluid	66[a]	35[b]	58[a]
Tissue/fluid direct	74 [a]	37 [b]	ND

[ab]Means in a row with different superscripts differ significantly ($P<0.05$); PCR, polymerase chain reaction; RT PCR, real time PCR; ND, not determined.

One disadvantage of identification by PCR is that the organism is not available and thus cannot be used for autogenous vaccine production. However, PCR can be performed by any diagnostic laboratory and once a diagnosis is made the case can then be referred to a specialised laboratory that can isolate the organism from nasal swabs and find the pathogenic strains by serotyping. It is still difficult to be certain of finding all serovars on a farm, especially if the prevalence of a serovar is low. It then all comes down to sample size. Sampling might have to be repeated if vaccine failure is observed. The future might be to use Real Time PCR methods to serotype. Multiplex PCRs to determine serovars have been developed for *Actinobacillus pleuropneumoniae* (Gram *et al.*, 2000). Unfortunately, the genes that are associated with export and serovar-specific biosynthesis regions of the capsular polysaccharide are not known for *H. parasuis* and further research is needed in this area.

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Supported in part by the Pork CRC Ltd.

The Frequency and Distance of Movements of Potential Disease Conveyors Between New Zealand Commercial and Non-Commercial Piggeries

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Disease transmission between farms can occur through many previously identified routes including direct contact between animals, aerosolization, and animal contact with contaminated inanimate vectors. Knowledge about the frequency of these kinds of interactions is fundamental to accurately populating disease outbreak models being used by animal health officials in planning responses to national diseases outbreaks (Anonymous, 2004). A study was conducted with the aim of identifying movement patterns of disease conveyors in the New Zealand (NZ) pig industry. The principal objectives of the study were to identify the movement patterns of potentially important disease conveyors amongst pig holdings in NZ, and determine the social network structure within and between the commercial, para-commercial, and non-commercial pig sectors of the New Zealand pig industry. The study was carried out during 2008 in three phases involving a combination of postal and telephone interviews.

Study phase one consisted of a postal questionnaire mail out and was comprised of a demographic update form (to update/capture basic farm profile information) with a supplementary questionnaire designed to capture specific information directly related to the study. The questions quantified the a) type and number of disease conveyors used on the farm (pigs, semen, feed, effluent, people, trucks), b) the frequency and distances for these movement occurrences and c) the direction of movement (to/from the farm). Phase two consisted of in-depth telephone interviews conducted on a randomly selected subset of farms responding to the phase one survey. The purpose of these interviews was to provide context to the quantitative data previously collected and to better understand the networks operating within and between the three sectors of the pig industry. Phase three consisted of a regionally-based survey of businesses supplying services or products to pig farms.

The commercial sector questionnaire was posted to a total of 275 commercial pork producers; out of the 127 surveys that were returned, 114 (90.6%) reported still having pigs on their premise. The non-commercial survey was mailed to 6980 farms known to recently keep pigs and of these, out of the 1814 that responded to the survey; 1363 (75.1%) reported they still owned pigs. Pig-owning premises were categorised into farm types based on pig inventory, their risk of transmitting disease onward to another farm (their "movement off" profile), and the farm's business profile (ie. were they highly motivated to be in the business, or more likely to go in/out as conditions changed?).

The study concluded that farm staff and feed (notably kitchen waste on less commercial farm types) were the most common potential disease conveyors arriving onto NZ pig farms. Introduction of germplasm through semen or live breeding stock was a frequent occurrence on some farm types, and people (staff and visitors, travelling both to homes and saleyards), abattoir-destined pigs, and cattle movements were frequent off-farm movements on pig farms. It was common for stock movements both on and off properties to occur over long distances. Interaction between the three main farm types (commercial, para-commercial and non-commercial) appeared limited. Overall, use of saleyards by pig farms was infrequent. Movements to abattoirs accounted for nearly 80% of off-farm movements and even if the per-movement risk was considered to be low-risk, the total number of moves was substantial suggesting more study is required. Non-pig, cloven-hoofed animals were commonly found on NZ farms that also kept pigs.

The common practise of waste-food feeding to non-commercial pigs, the extensive geographical overlap of commercial and non-commercial farms, and the presence of multiple-species on a farm premise are important factors to consider when planning disease surveillance or response activities in the NZ pig industry.

ANONYMOUS (2004). "Biosecurity Surveillance Strategy 2020 - MAF Biosecurity New Zealand Discussion Paper No: 008/04", (New Zealand Ministry of Agriculture and Forestry: Wellington).

Supported in part by the Ministry of Agriculture and Forestry-New Zealand Biosecurity and New Zealand Pork.

Efficacy of Medicating Grower Pigs With Injectable Oxytetracycline During Outbreaks of Diarrhoea

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There is pressure to minimise antibiotic use in food producing animals due to the risks of selecting resistant strains of bacteria. In Denmark, pressure to reduce macrolide antibiotics has resulted in a one third increase in tetracycline use from 2006-2007 (Emborg *et al*., 2007). Most antibiotics are used to treat intestinal infections of grower (>10 weeks) pigs, and often includes treating groups of pigs rather than individuals. The efficacy of treating non-diarrhoeic pen-mates has not been tested. Our hypothesis was that individual treatment of affected and non-affected in-contact pigs with oxytetracycline would reduce the prevalence of diarrhoea.

Forty grower pigs (20 diarrhoea, 20 no diarrhoea) were randomly selected on six farms in Denmark. Each pig was ear-tagged and assessed for diarrhoea (+/-) and faecal consistency (normal=3, loose=2, fluid=1). Non-diarrhoea clinical parameters (backbone/ribs visible +/-, hollow belly +/-, hairy +/-, pale +/-, enlarged inguinal lymph nodes +/-), were also measured. Half of the pigs in each group were randomly selected on Day 1 and injected for three consecutive days with oxytetracycline (Engemycin, Intervet, Boxmeer, The Netherlands). Pigs were re-assessed on Day 4. Three diarrhoeic pigs from each farm were euthanised and samples submitted for laboratory diagnosis (culture, histology, *in situ* hybridisation for *Brachyspira spp*.). The effect of oxytetracycline on diarrhoea on Day 4 was determined using Generalized Linear Mixed Models (GLMM, Genstat 11th edition), with diarrhoea on Day 1 and treatment as explanatory variables, and farm and pen as random variables. Ordinal logistic regression was conducted in SAS 9.1 (SAS Institute Inc., NC, USA) to assess the effect of treatment and faecal consistency on Day 1 on faecal consistency and the other combined clinical parameters on Day 4.

Brachyspira pilosicoli was confirmed in euthanased pigs on five of the six farms, with *Lawsonia intracellularis* on three farms. Two farms had dual infections. In pigs with diarrhoea on Day 1, subsequent diarrhoea at Day 4 was recorded in 65% of non-treated pigs and 37% of treated pigs. In pigs without diarrhoea on Day 1, subsequent diarrhoea at Day 4 was recorded in 21% of the non-treated and 15% in the treated pigs. The interaction term between diarrhoea on Day 1 and treatment was not significant and was removed from the model. Treated pigs were almost half (adjusted odds ratio 0.41) as likely to have diarrhoea on Day 4 than non-treated pigs, after adjusting for their diarrhoea status on Day 1 and accounting for clustering in a farm and pen.

Table 1. *Effects of oxytetracycline and diarrhoea on Day 1 on likelihood of diarrhoea in pigs on Day 4.*

Factor	B	SE (b)	Adjusted odds ratio	*P* value
Constant	-1.19	0.33	-	
Treatment – yes	-0.87	0.31	0.41	0.005
Treatment – no	0	-	1	
Day 1 diarrhoea – yes	1.66	0.32	5.25	<0.001
Day 1 diarrhoea - no	0	-	1	

B, coefficient of variation; SE(b), standard error of the coefficient of variation.

As expected, pigs with diarrhoea on Day 1 were 5.25 (95% CI: 2.81, 9.82) times more likely to have diarrhoea on Day 4 than those without diarrhoea (Table 1). Compared to treated pigs, untreated pigs were 2.24 (95% CI: 1.25, 3.99) times more likely to have fluid or loose consistency than normal consistency (P=0.006), although treatment did not affect the development of the non-diarrhoea clinical parameters measured (P=0.5).

Our results suggest that individual treatment of diarrhoeic pigs has more impact in reducing the short-term incidence of diarrhoea than treatment of in-contact pen-mates. Treatment did not improve the non-diarrhoea clinical parameters measured.

EMBORG, H.D., VIBEKE, F.J., LARSEN, L.S., STRUVE, T., JENSEN, L.B., SEYFARTH, A.M., AGERSØ, Y., SKJØT-RASMUSSEN, L., JENSEN, U.S., OLSEN, S.S., HAMMERUM, A.M. and SKOV, R.L. (2007). In "Use Of Antimicrobial Agents And Occurrence Of Antimicrobial Resistance In Bacteria From Food Animals, Foods And Humans In Denmark". DANMAP. ISSN 1600-2032.

Supported in part by Australian Pork Ltd.

Immune Suppression Does Not Lead to a Carrier State in Pigs Previously Infected With *Lawsonia intracellularis*

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Attempts to eradicate ileitis with antibiotic medication and partial Swiss depopulation of herds have consistently failed. Ileitis re-emerges as diarrhoea in grower pigs or as the haemorrhagic form of ileitis in finisher pigs. The potential for *Lawsonia intracellularis* (LI) to persist in pigs after recovery from disease has been suggested as one reason for the failure of ileitis eradication programs (Jensen *et al*., 2000). This study aimed to determine if previously infected pigs could re-commence faecal shedding of LI when stressed, and transmit infection to naïve, in-contact pigs.

Two groups of 4 naïve weaner pigs (commercial Large White x Landrace) were orally inoculated with 4.4 x 109 LI and monitored for clinical signs of disease and evidence of LI infection (faecal polymerase chain reaction (PCR) and LI specific antibodies; Collins and Love, 2007). After faecal shedding of LI ceased, the pigs were cleaned to remove organic matter, and then housed in two well separated, cleaned and disinfected pens. One group of 4 pigs (Group 1A) were injected intramuscularly (IM) with 2ml of Dexafort (DMX, Intervet Schering-Plough, Bendigo, VIC) to suppress their immune system, and housed in contact with 9 naïve grower pigs (Group 2A). The remaining group of 4 pigs (Group 1B) were housed in contact with a second group of 9 naïve growers (Group 2B), and were not treated with DMX. All pigs were monitored for LI infection for 4 weeks. The in-contact Groups 2A and 2B pigs continued to be monitored for LI infection for an additional 3 weeks. After this time, they were orally challenged with 8.8 x 109 LI and monitored for clinical disease and LI infection for 3 weeks post inoculation (PI). Student's *t* tests were used to determine the significance of differences in disease severity between treatments.

L.intracellularis infection was demonstrated in all Group 1 pigs following oral challenge; however, clinical signs of ileitis were mild. Faecal shedding of LI was detected between 10 and 42 d PI in all pigs. Antibodies to LI were detected between 21 and 77 d PI, with no significant difference ($P>0.05$) in titre between Group 1A and 1B pigs at 77 d PI. Faecal shedding of LI was not detected in any Group 1 pigs after 42 d PI. Treatment of Group 1A pigs with DMX at 77 days PI did not lead to re-shedding of LI and did not lead to significant differences in antibody titres between treatments at 2 and 4 weeks post DMX treatment.

No evidence of LI infection was observed in the Group 2A and 2B pigs over 7 weeks post exposure to the recovered pigs (4 weeks in contact, and another 3 weeks). Following experimental challenge with LI, all of the Group 2A and 2B pigs shed LI in their faeces between 10 and 21 d PI and developed antibodies to LI. Severe diarrhoea was observed in some Group 2A and 2B pigs, but no significant differences were observed in the faecal consistency score, duration of faecal shedding or antibody titre between Group 2A and 2B pigs.

This study demonstrated that pigs do not continue to intermittently shed detectable numbers of LI in their faeces and do not transmit infectious doses of LI to naïve, in-contact pigs after recovering from ileitis. Experimental infection of the Group 2A and 2B pigs demonstrates their susceptibility after contact with recovered pigs. Previous studies have demonstrated that pigs previously exposed to high or low doses of LI are immune to re-infection (Collins and Love, 2007). Treatment of recovered pigs with DMX did not induce re-shedding of LI or changes to the LI specific humoral immune response. Although unlikely, we are unable to state that under different conditions, such as greater immune suppression, or higher infection pressure in a less hygienic environment, recovered pigs could not transmit LI infection to naïve, in-contact pigs. In this study, pigs had 11 weeks to recover before treatment with DMX and contact with naïve pigs. Such a long recovery period is unlikely to occur commonly in piggeries. However, the demonstrated absence of carrier pigs infected with LI in this study will aid in the design of effective ileitis eradication programs.

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JENSEN, T.K., MOLLER, K., LINDECRONA, R. and JORSAL, S.E. (2000). *Research in Veterinary Sciences*. **68**:23-26.

Supported in part by the Pork CRC Ltd..

Intestinal Thickening Caused by Subclinical Proliferative Enteropathy Can be Quantified by Computed Tomography

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Proliferative enteropathy (PE) is a common production limiting disease, causing weight loss and diarrhoea in pigs of all ages. Although clinical disease can be controlled with antibiotics or vaccination, subclinical disease is difficult to diagnose, and production losses may go unnoticed. *Lawsonia intracellularis* (LI), the aetiologic agent of PE, causes abnormal proliferation of crypt cells in the ileum, leading to a grossly thickened mucosa (Lawson and Gebhart, 2000). The aim of this experiment was to use cross-sectional x-ray computed tomography (CT) to quantify the density of tissue between the lumen and muscle layer of the intestine in pigs and to determine if pigs infected with LI have a higher density compared to a cohort of uninfected pigs.

Thirty-six male, hybrid weaner pigs (mainly Large White x Landrace) were randomly allocated at 13.8±1.0 kg (mean±SD) liveweight to two treatments: pigs infected with LI and a cohort of uninfected controls. The pigs were housed in individual pens in four separate rooms with two rooms per air space, and maintained at 22ºC. Each treatment was replicated in two rooms in different air spaces. Strict quarantine was used to prevent faecal contamination between treatments. Pigs were tested for faecal shedding of LI and serological antibodies to LI from 5 to 9 weeks of age to verify they remained naïve to LI. At 9 weeks of age, one group of 18 pigs was orally inoculated with 5.9 x 10^9 LI extracted from PE-affected mucosa and the control group were inoculated with phosphate buffered saline. Pigs were monitored daily for clinical signs and evidence of LI infection (faecal shedding and serology) over 6 weeks post-inoculation (PI). Each pig was anaesthetised and scanned with a Picker spiral CT scanner (PQ2000, Philips Medical Systems, Highland Heights, Ohio, USA) at 14 d pre-inoculation and 21 and 42 d PI. The CT density of the intestinal mucosa was measured at 10 randomly selected locations over two intestinal positions (1st and 2nd lumbar vertebrae) for each pig. A single before and after (d 21 and 42 PI combined) inoculation comparison was used for scan time (Table 1). The final mixed model fitted the square root of the CT density, with treatment x scan times as fixed effects, and room, animal and scan time as nested random effects.

Table 1. *Mean (±SE) infection parameters for 36 pigs either infected with LI or uninfected (controls).*

Infection parameter	Control pigs	LI infected pigs
Antibody titre pre-infection[1]	0±0	0±0
Antibody titre post-infection[1]	0±0[a]	5.5±0.9[b]
Duration of faecal shedding (d)	0±0[a]	14±4[b]
Mucosal CT density pre-infection (√)	5.12±0.11[a]	4.84±0.11[a]
Mucosal CT density post-infection (√)	5.24±0.10[a]	5.82±0.10[b]

[ab]Means in the same row with different superscripts differ significantly (P<0.05); significance was determined by Student's *t* test. LI, *Lawsonia intracellularis*; CT, computed tomography; SE, standard error. 1Expressed as log 2 of reciprocated end point dilution.

The majority of pigs infected with LI were subclinically affected with PE. Faecal shedding of LI and antibodies to LI were detected in all pigs inoculated with LI. No evidence of LI infection was detected in any control animals. After inoculation, the mucosal CT density for LI infected pigs was significantly higher than control pigs (Table 1). Post infection, mucosal CT density was moderately correlated (r=0.63) with duration of faecal shedding and antibody titre. This experiment demonstrated that CT imaging can be used to demonstrate the characteristic intestinal thickening of PE and can be used to evaluate PE control measures in live pigs.

LAWSON, G.H.K and GEBHART, C.J. (2000). *Journal of Comparative Pathology*. **122**:77-100.

Supported in part by the Australian Research Council.

Dietary n-6 and n-3 Polyunsaturated Fatty Acids (PUFA) Have a Differential Effect on Gilt Litter Characteristics

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Dietary polyunsaturated fatty acids (PUFA) particularly from the n-3 and n-6 series regulate reproductive function via actions on biosynthetic pathways involved in prostaglandin synthesis and steroidogenesis (Mattos *et al.*, 2000). Diet formulation is becoming an increasingly important management tool for improving production performance. This strategy is particularly important with gilts in efforts to optimize reproductive capacity and longevity (Azain, 2001). The objective of this study was to determine if dietary n-3 and n-6 PUFA can improve reproductive performance in gilts fed these fatty acids prior to and throughout the period of gestation.

Seventy Large White x Landrace gilts were fed fat enriched diets containing 30 g/kg safflower oil (n = 23), tuna oil (n = 30) or tallow (n = 17) (sources of n-6, n-3 PUFA and saturated fatty acids, respectively) *ad libitum* two weeks prior to mating, Gilts were offered these diets throughout the first and second trimesters at 2.6 kg/d. During the third trimester, the dietary fat concentration was increased to 50 g/kg for all treatment groups. Gilts were housed in individual gestation pens (4 m2) from the day of mating until day 110 of gestation and then transferred to individual farrowing crates for the remainder of gestation. A linear mixed model was fitted to the data using a REML procedure in Genstat.

Table 1. *Litter characteristics from gilts fed tuna oil (n-3 PUFA), safflower oil (n-6 PUFA) or tallow (saturated fatty acids) and total levels of n-3 and n-6 PUFA for 3% and 5% fat enriched diets.*

					Dietary n-3 PUFA (g/kg)		Dietary n-6 PUFA (g/kg)	
Treatment	Born alive/ litter	Still born/ litter	Mummified Foetus/litter	Total born/ litter	30	50	30	50
n-3 PUFA	11.2[a]	0.70	0.12[a]	11.88	59	89	299	281
n-6 PUFA	9.19[b]	1.53	1.05[b]	10.77	29	21	528	593
Saturated	10.9[ab]	1.14	0.21[a]	12.16	25	24	337	279
SEM	0.48	0.20	0.14	0.57				
P value	0.054	0.203	0.002	0.331				

[ab]Means within columns with different superscripts differ significantly (P<0.05); PUFA, polyunsaturated fatty acid; SEM, standard error of the mean.

Gestational length and birth weight was unaffected by fatty acid source. However, there was a differential effect of fatty acid source on litter characteristics (Table 1). Feeding n-3 PUFA during gestation significantly increased (P < 0.05) the number of piglets born alive compared to gilts fed n-6 PUFA with saturated fatty acids being intermediate. In addition, the number of mummified foetuses were significantly lower (P <0.01) in litters of n-3 PUFA and saturated fat fed gilts compared to those gilts fed n-6 PUFA. The safflower oil diet contained a greater proportion of n-6 PUFA compared to the tuna oil or tallow diets whereas the tuna oil diet contained a greater proportion of n-3PUFA compared to safflower oil or tallow diets (Table 1).

Dietary n-6 PUFA had a deleterious effect on the number of piglets born alive while substantially increasing the percentage of both still born and mummified foetuses when compared to feeding diets containing either n-3 PUFA or saturated fatty acids. This study demonstrates that n-6 PUFA has a negative impact on litter performance and this should be considered in the formulation of gilt and sow gestation diets.

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MATTOS, R., STAPLES, C. R. and THATCHER, W. W. (2000). *Reviews of Reproduction*. **5**:38-45.

Supported in part by the Pork CRC Ltd.

Rearing Dam Parity Affects Piglet Pre-Weaning Growth Rate

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The parity of the dam has a significant influence on the birth and subsequent weaning weights of piglets (Miller *et al*., 2006). During lactation, gilts must support their own growth, as well as provide colostrum and milk for their offspring. To achieve this, gilts may limit nutrient incorporation into colostrum and milk. Our hypothesis was that differences in pre-weaning growth performance between gilt and sow progeny were associated with parity differences in nutrient composition of colostrum.

Sixteen gilts (parity 0) and 16 sows (parity 2-5) were randomly selected at the point of farrowing at a commercial farm in southern NSW. Sows and gilts were induced to farrow with 2 ml Lutalyse (Pfizer Australia, West Ryde, NSW) injected intramuscularly. Piglets were separated from their dams prior to suckling then weighed and fostered onto another randomly-selected sow or gilt. Re-formed litters consisted of 10 piglets (5 sow-born and 5 gilt-born). Piglets were allowed to suckle without further interventions until weaning, when a second weight was recorded. Colostrum samples (10 ml/dam) were collected from the hind teats by manual palpation. Colostrum samples collected from gilts and sows were analysed for protein, fat and lactose concentrations. Weight data were analysed using linear regression (REML). Colostrum composition data were analysed by one-way analysis of variation in Genstat (Release 10).

Table 1. *Comparison of colostrum composition between gilts and sows (n=10). Data are presented as Mean + SEM.*

Parity	Protein (%)	Lactose (%)	Fat (%)
Sow	18.3 +/- 0.8[a]	4.0 +/- 0.5	5.7 +/- 0.1
Gilt	16.1 +/- 0.9[b]	4.3 +/- 0.3	5.8 +/- 0.3

[ab]Means in a column with different superscripts differ significantly (P<0.05). SEM, standard error of mean.

Table 2. *Model-based mean liveweights (kg) per piglet treatment group.*

	Gilt Reared		Sow Reared	
	Gilt-born	Sow-born	Gilt-born	Sow-born
Birth	1.4[a]	1.6[b]	1.4[a]	1.6[b]
4 weeks	6.6[a]	7.0[b]	7.5[c]	7.7[d]

[abcd]Means in a column with different superscripts differ significantly (P<0.05).

There were no significant differences in lactose or fat content of colostrum between sows and gilts although significant differences were observed for colostral protein content (Table 1). Piglets reared on sows, irrespective of their dam of origin, grew significantly faster than those reared on gilts (P<0.05; Table 2). There was a significant association between faster pre-weaning growth and colostral protein concentration (P<0.001). There was no significant effect of parity on colostrum composition other than protein percentage. Sows have been found to yield more colostrum containing a higher total antibody concentration (and therefore protein %) than gilts (Devillers *et al*., 2007). In this experiment the parity of the dam rearing the piglets appeared to be more important than the parity of the birth-dam in determining pre-weaning growth performance.

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Supported in part by the Pork CRC Ltd.

Supplementary Ractopamine During Lactation Reduces Sow Weight Loss and Improves Reproductive Performance

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Reproductive failure is accepted to be the largest reason for culling of primiparous sows, with excess mobilisation of body protein reserves during lactation impairing ovarian function at weaning, and thought to be a primary cause of the delay, or failure, of sows to return to reproductive function post-weaning. Adding the beta-agonist ractopamine (Paylean®; Elanco Animal Health Pty Ltd, Macquarie Park, NSW) to the diets of growing pigs increases net protein accretion, and causes redistribution, but not a reduction, in fat deposition (Dunshea, 1993). The current study tested the hypothesis that ractopamine supplementation of lactating sow diets reduces maternal weight loss and improves subsequent reproductive performance.

Sixty Large White first parity sows were allocated to one of two treatment groups (n=30 sows/treatment). One group (CONT) received a standard lactation diet (0.71g available lysine/MJ digestible energy (DE)) throughout lactation, whilst the other group (RAC) received the standard lactation diet supplemented with ractopamine at 10 ppm from d 1–13 of lactation and 20 ppm from d 14 of lactation until mating. The amount of feed offered each day was stepped up gradually, reaching 5 kg/day by d 4 of lactation, and maintained at this level for the rest of lactation. Sows were weighed and P2 backfat measured on d 1, 14 and 20 of lactation, with litter size standardised to 9 piglets within 24 hours of lactation. Sows were weaned on d 21 of lactation, with boar exposure commencing 4 d after weaning and sows artificially inseminated twice at their first oestrus post-weaning. Subsequent reproductive performance of all sows was recorded: weaning-to-oestrus interval (WOI) and second litter size. Sows failing to express oestrus within 10 d of weaning were deemed to be anoestrus and allocated a nominal weaning-to-oestrus interval of 15 d. A general analysis of variance model was used to study the effects of RAC supplementation on sow weight loss during lactation and subsequent reproductive performance.

Table 1. *Effect of dietary ractopamine during lactation on sow feed intake, liveweight and P2 backfat loss, and the number of piglets born at the subsequent (second) litter*

	Daily feed intake	Lactation weight loss (kg)		P2 backfat	Piglets born at second litter	
Diet	(kg/day)	Days 1-14	Days 15-20	loss (mm)	Total born	Born alive
CONT	5.0 ± 0.14	7.2 ± 1.33	4.3 ± 0.90[b]	3.7 ± 0.55	8.5 ± 0.80	8.1 ± 0.74
RAC	4.9 ± 0.14	4.6 ± 1.41	1.3 ± 0.96[a]	2.3 ± 0.57	9.7 ± 0.54	9.5 ± 0.52

[ab]Means in a column with different superscripts differ significantly (P<0.05); CONT, control; RAC, ractopamine.

On d 1 of lactation, sow liveweight and P2 backfat were 177.7±2.8 kg and 21.2 ±1.2 mm, respectively. RAC supplementation significantly decreased (P<0.05) liveweight loss between d 15 and 20 of lactation, tended (P<0.1) to reduce P2 backfat loss over the whole lactation, and increased piglets born alive at the second litter (Table 1). A numerical decrease in WOI (6.4±0.63 vs 7.5±0.80) and the proportion of sows exhibiting oestrus within 10 d of weaning (0.95±0.08 vs 0.75±0.08) was observed for RAC compared to CONT sows.

The current data indicate that dietary ractopamine stimulates the conservation of maternal body reserves, particularly during the third week of lactation. Although second litter sizes were low overall, these data provide preliminary evidence of a beneficial effect on subsequent reproductive performance. Pain *et al*. (2007) reported reduced milk protein concentrations in response to ractopamine supplementation during lactation. It is, therefore, suggested that adding ractopamine to lactation diets inhibits degradation of protein reserves, likely improving ovarian function at weaning and thus subsequent reproductive performance.

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Supported in part by the Pork CRC Ltd.

Sow Follicular Progesterone Levels Decrease During The Period of Seasonal Infertility

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Embryo survival *in vivo* and oocyte developmental competence *in vitro* has been positively correlated with systemic and follicular progesterone (P4) levels in pre-pubertal gilts and mature sows (Archibong *et al.*, 1992; Grupen *et al.*, 2003). Reductions in farrowing rate resulting from early disruption of pregnancy are greater among females mated in summer/autumn than those mated in spring/winter (Tast *et al.*, 2002). It was hypothesised that follicular progesterone levels decrease during the period of seasonal infertility, which may contribute to pregnancy loss by reducing oocyte quality. The aim of this experiment was to characterise the steroid content of follicular fluid obtained from small and large follicles between seasons.

Ovaries were collected from slaughtered Large White x Landrace sows at 4 d post-wean during winter (June – July: n = 96; 6 replicates) and summer (February – March: n = 56; 10 replicates). All sows were culled for non-reproductive reasons such as lameness. Ovaries were trimmed of excess tissue and total ovarian weight and the number of corpora lutea (CL) were recorded. The contents of small (3 to 4 mm) and large (5 to 8 mm) follicles of each pair of ovaries were aspirated into separate collection tubes. Follicles less than 3mm and greater than 8mm in diameter or were observed to have viscous follicular fluid were excluded from the study. The concentrations of follicular P_4, androstenedione (A_4) and oestradiol (E_2) were determined using commercial radioimmunoassay kits (Diagnostic Systems Laboratories, Webster, TX, USA). Data were analysed using analysis of variance and a generalised linear mixed model using GenStat Release 10.2 (Numerical Algorithms Group®, Ltd. Oxford, UK).

Table 1. *The effect (mean ±SE) of season on follicular steroid concentration at four days post-weaning.*

	Steroid concentration (mol/L)					
	P4		A4		E2	
Season	Small[1]	Large[2]	Small	Large	Small	Large
Winter	1.23±0.16[a]	2.47±0.16[a]	0.95±0.11[a]	2.19±0.19[a]	0.11±0.02[a]	0.32±0.04[a]
Summer	0.70±0.12[b]	1.47±0.16[b]	0.90±0.11[a]	1.69±0.16[a]	0.10±0.01[a]	0.30±0.03[a]

[ab]Means in a column with different superscripts differ significantly (P<0.001). P4, Progesterone; A4 Androstenedione; E2 Oestradiol; [1]Small follicles (3-4mm), [2]Large follicles (5-8mm).

Follicular P4 concentrations were higher in ovaries collected in winter than those collected in summer, independent of follicle size (P<0.001; Table 1). Concentrations of A4 and E2 were affected by follicle size but not season, with large follicles containing more of both steroids than small follicles (P<0.05). Ovaries collected in winter were heavier (20.07 ±1.01g vs 7.63 ±0.39g; P<0.001) and had more CL (20 ±1.42 vs 9 ±1.70; P<0.001) than those collected in summer.

The present study describes and compares the steroid composition of antral follicle size cohorts on the surface of ovaries recovered from sows four days after weaning during winter and summer. The findings may reflect differences in the ability of follicles to respond to gonadotrophins and synthesise steroids between seasons, suggesting that hypothalamo-pituitary-gonadal axis activity is impaired during seasonal infertility. The findings support the proposal that pregnancy loss in sows during the period of seasonal infertility may in part be due to a reduction in oocyte quality brought about by decreased follicular P4 levels.

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Supported in part by the Pork CRC Ltd.

Influence of Maternal Nutrition in First Lactation and Weaning Weight on Growth Performance of Progeny

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The performance of the pig in the grow-finisher phase has long been associated with its birth weight and subsequent weaning weight. It is generally established that those pigs which are heavier at weaning perform better post-weaning. However, Lawlor *et al.* (2002) found that birth weight was also significant, with pigs that were light at birth but reared to heavier weaning weights losing this weight advantage by 14 d post-weaning. Dam parity also has a significant influence on both birth and weaning weights (Miller *et al.*, 2006) with gilt progeny being lighter at birth and weaning and maintaining poorer production throughout their life. It is hypothesised that diet and lactational demand influences progeny performance post-weaning..

Gilts were offered either a standard diet (14.3 MJ digestible energy (DE)/kg, 0.56 g available lysine (AvL) /MJ DE) or a high-lysine diet (14.5 MJ DE/kg, 0.90 g AvL/MJ DE) during first lactation and assigned one of two litter sizes, seven or twelve pigs per litter, which was maintained throughout the lactation, in a 2x2 factorial design. Over a two-week period, male piglets from litters of each of the four treatment groups were individually identified. Piglets were weaned at approximately 21 d of age and maintained within their contemporary groups within a large-group (n=1000) straw-based shelter. At 13 weeks of age pigs were transferred to a large-group (n=167) conventional finishing unit feeding a grain-based liquid diet. Pigs were slaughtered at approximately 20 weeks of age and carcase weight was recorded. The individual data of slaughtered pigs was pooled and averaged on a litter basis, with the litter being the treatment unit. Litter data were subjected to an analysis of variance with diet and litter size as treatments and piglet weight at 24 h as a covariate.

Table 1. *Mean growth performance of litters from gilts offered either a standard (S) or a high-lysine (H) diet and maintained with a litter size of seven (7) or twelve (12) pigs.*

	Treatment					P-value		
	S12	S7	H12	H7	SED	Diet	Litter	Diet x Litter
Number	17	16	14	17				
24 h weight[1] (kg)	1.60ab	1.73b	1.51a	1.66ab	0.08	0.267	0.028	0.894
Wean weight (kg)	5.24a	6.43b	5.35a	6.16b	0.28	0.778	<0.001	0.237
Wean ADG (kg/d)	0.162a	0.209b	0.168a	0.201b	0.011	0.875	<0.001	0.324
Age at sale (d)	139.9	140.4	139.8	139.8	1.2	0.554	0.516	0.766
HSCW[2] (kg)	66.6a	69.8b	70.6b	70.4b	1.6	0.010	0.612	0.094

[ab]Means in a row with different superscripts differ significantly (P<0.05); [1]24 h weight, Individual piglet weight 24 hours post-partum after litter size treatment was applied; [2]HSCW, hot standard carcase weight (Trim 1);SED, standard error of difference; ADG, average daily gain.

Piglets were randomly fostered to establish litter sizes, however, significant differences between treatments in 24 h weight were observed (Table 1). There was a strong effect (P<0.001) of litter size on piglet growth rate prior to weaning, with those piglets from litters of seven growing at 40 g/d faster during this period resulting in a one kg advantage at weaning, a reflection of greater milk availability.

A significant difference in HSCW occurred between dietary treatments (P=0.010). Feeding a high-lysine diet in lactation resulted in improvements in growth rate. Although piglets from the high-lysine, large litter size treatment (H12) were lighter at 24 h than those from the standard diet, large litter size treatment (S12), they were significantly heavier at sale. This response is unlikely to be due to changes in milk volume or composition but may imply some immunity factor expressed by the gilt during lactation impacting on progeny performance. Whilst the effects of maternal nutrition in gestation are understood, this data suggests that maternal nutrition during lactation influences the post-weaning performance of her progeny, irrespective of weaning weight.

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MILLER, Y.J., COLLINS, A.M., SMITS. R.J. and HOLYOAKE, P.K. (2006). Proceedings 19th International Pig Veterinary Science Congress, Copenhagen, Denmark.

Supported in part by the Pork CRC Ltd.

Plasma Lithium Cannot be Used to Predict Feed Intake of Individual Pigs Housed in Groups

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The measurement of feed intake of individual pigs housed in groups would allow better management of the variation that exists in pig performance. However, it can be a difficult or costly task. Electronic feeders work well but are capital intensive, whilst markers such as tritiated water (Dove, 1984) and lithium chloride (Kahn, 1994) have been used successfully to measure supplement intake in sheep. Whilst feed aversion can be associated with lithium intake, Hewitt *et al*. (2007) established inclusion rates that allowed for the measurement of plasma lithium concentrations without affecting feed intake. The objective of this experiment was to validate the feed intake of individual pigs housed in groups as calculated by plasma lithium concentration against measured feed intake via an electronic feeder.

One hundred and twenty male pigs (Large White x Landrace, PrimeGro™ Genetics, Corowa, NSW) were selected at 63.2±7.1 kg and housed in group pens of 30 pigs. Each pen contained three electronic feeders, with pigs offered *ad libitum* access to a pelleted diet (13.8 MJ digestible energy (DE)/kg, 0.70g available lysine/MJ DE) for eight days to become accustomed to the feeders. On the ninth day, pigs were offered the same diet with lithium chloride included (0.8g LiCl/kg feed). Lithium chloride was added to the vitamin and mineral premix prior to diet manufacture to ensure even distribution (ten samples analysed had a coefficient of variation of 6.8%). Thirty-six hours after first offered, feed access was removed and blood samples were collected by jugular venapuncture and plasma lithium concentration was measured. Feed intake from plasma lithium concentration was estimated using the method described by Kahn (1994).

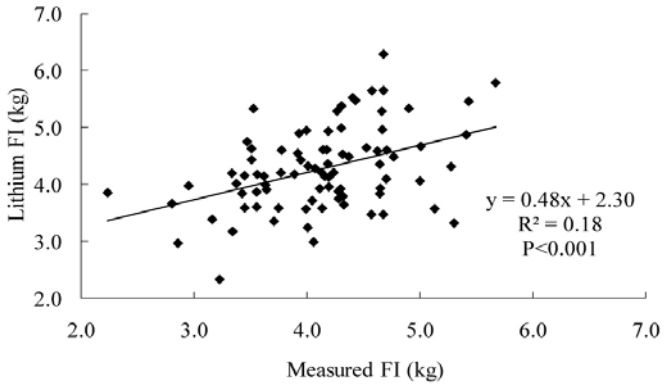

Figure 1. *Comparison of feed intake as estimated by plasma lithium concentration (Lithium FI) and actual feed intake as measured by an electronic feeder (Measured FI), with linear regression.*

Whilst there was a statistically significant association (P<0.001) between feed intake as estimated from plasma lithium concentration and measured feed intake, the strength of the relationship was poor (R^2=0.18). This variation between intakes appears to be a result of differences in the timing of feed intake for each individual pig within the group, most likely due to group dynamics and feeding hierarchy. The time from feed being offered to first feeding event ranged from 8 minutes to almost 6 hours, resulting in deviation from the critical 36 hour period. Other markers may be less time critical, however, investigation of bromide in earlier research showed similar variability whilst the use of antipyrine is limited by testing costs. Previous studies in sheep (Kahn, 1994) have shown the value of lithium chloride as a marker of supplement intake, but these results indicate it is too variable to be of value in measuring the feed intake of individual pigs housed in groups.

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Supported in part by the Pork CRC Ltd.

The Synergistic Effects of Ractopamine and Porcine Somatotropin on Finisher Gilt Performance.

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Ractopamine hydrochloride (Paylean®, RAC, Elanco Animal Health Pty Ltd, Macquarie Park, NSW) is an approved ingredient for pigs used to increase lean tissue growth and improve production efficiency (Dunshea *et al*., 2005). Porcine somatotropin (Reporcin®, pST, OzBioPharm Pty Ltd, Knoxfield, VIC) is a protein naturally produced by the pig that induces the redirection of nutrients towards increased muscle growth and decreased fat growth (Dunshea *et al*., 2005). Recent research (Rikard-Bell *et al*., 2009) has shown that combining RAC and pST in the last two weeks of production improves feed efficiency. The aim of this experiment was to evaluate changes in production efficiency obtained by combining RAC and pST in the last four weeks of growth.

Twenty pens of gilts, approximately 45 gilts/pen, were allocated via a randomised block (blocked on weight) to one of five treatments, fed for 28 d prior to sale. Treatments consisted of a control diet (13.4 MJ digestible energy (DE)/kg, 0.55 g available lysine (AvL)/MJ DE), a high specification diet (14.0 MJ DE/kg, 0.70 g Avl Lys/MJ DE) without RAC, a high specification diet with RAC (5 ppm), a high specification diet with RAC plus daily pST (5 mg/d) and a high specification diet with RAC plus pST in oil injected twice per week (15 mg Tuesday, 20 mg Friday). Porcine somatotropin was administered during the final two weeks. Data were subjected to an analysis of variance and means separated by least significant differences (P<0.05).

Table 1. *Effect of diet density, ractopamine (RAC) and somatotropin (pST) on average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR) in gilts (75.4±3.3 kg) for the four week finisher phase and average daily feed intake (ADFI pST) in the final two-week pST treatment phase (n=4).*

	Treatment[1]						
	A	**B**	**C**	**D**	**E**	**SED**	**P value**
Final weight (kg)	96.3	97.4	99.7	100.8	100.8	3.10	0.504
ADG (kg/d)	0.735[a]	0.783[a]	0.865[b]	0.915[b]	0.906[b]	0.04	<0.001
ADFI (kg/d)	2.57	2.59	2.58	2.39	2.42	0.08	0.069
FCR	3.50[c]	3.31[c]	2.99[b]	2.61[a]	2.68[a]	0.13	<0.001
ADFI pST (kg/d)	2.68[b]	2.63[b]	2.67[b]	2.29[a]	2.37[a]	0.09	<0.001

[abc]Means in a row with different superscripts differ significantly (P<0.05). [1]A - Control, B – High Specification (Hi-spec), C – Hi-spec with RAC, D - Hi-spec, RAC, daily pST, E – Hi-spec, RAC, twice weekly pST; SED, standard error of difference; n, number.

Average daily gain was significantly increased by the incorporation of RAC into the diet (P<0.001), although non-significant additive effects were seen for both diet density and the use of pST. Average daily feed intake was not altered by the inclusion of RAC, but was significantly reduced through the use of pST (P<0.001), whether through daily or twice weekly injections, during the final two weeks. Whilst the inclusion of RAC alone significantly improved feed conversion, combining its use with pST led to even greater improvement (P<0.001). RAC and pST have additive effects on growth rate in finishing gilts, whilst pST can significantly reduce feed intake and subsequent FCR. The non-significant difference in response between daily or twice-weekly administration of pST allows for a more practical application of pST and confirms the efficacy of these products used alone or in combination under commercial conditions.

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Supported in part by the Pork CRC Ltd.

Arginine Supplementation Did Not Improve Post-Weaning Growth Performance or Survivability of 27 Day Old Pigs

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Young mammals including pigs have a high dietary requirement for arginine, predominantly due to its role as a nitrogen carrier in tissue proteins, and role in gastrointestinal growth and development. There has been limited research conducted on the requirements for arginine in the post-weaning period. Hernandez *et al.*, (2008) showed that the addition of 6g/kg arginine to the diets of newly weaned pigs for 10 d post-weaning, improved daily feed intake and daily gain in the dietary transition period between d 11 and 14 post-weaning. It is hypothesised that supplemental arginine will improve growth performance of newly weaned pigs. The aim of this experiment was to investigate the effect of arginine supplemented at different rates ranging from 0 to 9 g/kg for 12 d post–weaning, on the growth performance and survivability of newly weaned pigs.

Nine hundred and sixty pigs (Large White x Landrace, PrimeGro™ Genetics, Corowa, NSW; 480 males and 480 females) were selected at weaning (27 d of age) and allocated to single-sex pens of 10 pigs. The average weaning weight was 7.64 (± 0.07) kg. The experimental design was a four treatment, dose-response with 0, 3, 6 or 9 g/kg of arginine supplemented to the commercial weaner starter diet for 12 d post-weaning. The diets were formulated to contain 15.2 MJ digestible energy (DE)/kg and an available lysine: DE ratio of 0.93. Common commercial weaner diets were fed to all pigs from d 12 post- weaning to d 40. The pigs were weighed at weaning, 12, 20 and 40 d post-weaning. The feed intake for the pigs was also recorded at these times. The data were analysed by general linear model, analysis of variance and linear or quadratic relationships were analysed.

Table 1. *Influence of 0, 3, 6 and 9 g/kg arginine supplementation on growth performance of weaner pigs.*

Arginine (g/kg)...	0	3	6	9	SEM	P value
Average daily gain (kg/day)						
0 to 12 d post-weaning	0.230	0.223	0.201	0.201	0.006	NS
Wean to 40 d post-weaning	0.494	0.495	0.483	0.479	0.004	NS
Average daily intake (kg/day)						
0 to 12 d post-weaning	0.232	0.229	0.209	0.218	0.005	NS
Wean to 40 d post-weaning	0.646	0.656	0.643	0.653	0.006	NS
Feed conversion rate						
0 to 12 d post-weaning	1.03	1.05	1.11	1.14	0.02	NS
Wean to 40 d post-weaning	1.31	1.33	1.33	1.37	0.01	NS

SEM, standard error of mean; NS, not significant.

There were no significant improvements (P>0.05) in rate of gain, daily feed intake and feed conversion ratio of pigs fed arginine between 0 to 12, 12 to 20 and 20 to 40 d post-weaning (Table 1). There were no significant (P>0.05) interactions between sex and treatment. There were no significant differences (P>0.05; χ^2=2.74) in survivability between treatments. There were no significant (P>0.05) linear or quadratic relationships observed.

There was no advantage of supplementing diets with arginine at 3, 6 or 9 g/kg for the first 12 d post-weaning. The NRC (1998) requirement for total dietary arginine for pigs weighing 5 to 10 kg is 2.7 g/d. It is concluded that the pigs in the control treatment were receiving sufficient arginine (2.9g/d), from naturally occurring arginine in the diet, resulting in no significant differences between treatments. Further research is required to investigate supplemental arginine in light-weight weaner pigs, whose lower feed intakes results in reduced arginine intake.

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Supported in part by the Pork CRC Ltd.

Maternal Outcomes Following Treatment With Porcine Somatotropin During Pregnancy: Reproduction and Longevity

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Piglet neonatal survival and postnatal growth and feed conversion efficiency are positively related to birth weight. Maternal porcine somatotropin (pST) injections increase the birth weight of gilt litters when treatment is continued throughout most of pregnancy (d 25 to 100), but not if stopped in mid-pregnancy at d 50 (Gatford *et al*., 2004). Fetal growth at d 50 of gestation is increased similarly by maternal pST treatment in gilts and sows (Gatford *et al*., 2009), implying that maternal constraint prevents the increased size being maintained until term. We hypothesised that a shorter period of pST injections would increase birth weight in sow litters, with less competition for nutrients from maternal growth than in gilts. In addition to responses in the pregnancy of treatment and subsequent lactation, we were interested in longer-term effects of maternal pST on retention of sows within the breeding herd and reproduction in the subsequent pregnancy.

Landrace x Large White (PrimeGro™ Genetics, Corowa, NSW) gilts and sows were uninjected (controls), or injected daily with pST (Reporcin®; gilts 2.5 $mg.d^{-1}$; sows 4.0 $mg.d^{-1}$, ~15 $\mu g.kg^{-1}.d^{-1}$ in each) from d 25 to 50 of pregnancy, or from d 25 to 100 of pregnancy (n=120 per parity and treatment, 2x3 factorial design). Litter size and weights were recorded at birth, d 14 of lactation and at weaning (d 27). All dams were followed through their subsequent mating and pregnancy and any removal reasons and subsequent litter size were recorded.

Maternal injections with pST from d 25 to 100 of pregnancy, but not from d 25 to 50, increased average piglet birthweight in both gilts and sows (9.2%, P<0.01 for each). However, litter size was lower by 0.6 live born in litters from either maternal pST treatment, regardless of parity (d 25 to 50, P=0.018; d 25 to 100, P=0.024). Total litter weight was nevertheless altered by treatment in sows (P=0.018), although not in gilts (P=0.417). Total litter weight at birth tended to be higher in sows treated with pST from d 25 to 100 of pregnancy (P=0.057) and was not altered in sows treated with pST from d 25 to 50 of pregnancy (P=0.368) compared to controls. Piglet weight at weaning was increased similarly in both parities (4.3%, P=0.018) in litters whose mothers were treated with pST from d 25 to 100 of pregnancy. In gilts, daily feed intake in lactation was increased by maternal pST treatment from d 25 to 100 of pregnancy (P=0.001), with a similar trend in gilts treated with pST from d 25 to 50 of pregnancy (P=0.073). In sows only, more dams treated with pST from d 25 to 100 of pregnancy were culled after weaning, prior to the subsequent mating (P=0.037), mostly for poor body condition or feet and leg problems at weaning. In pigs re-mated after the treatment pregnancy, weaning-remating interval, conception rates and subsequent litter sizes for the first estrus after the treatment pregnancy were similar between treatments and parities.

Consistent with earlier studies in gilts, maternal treatment with pST from d 25 to 100 of pregnancy increased progeny birth weight, with similar responses in sows and gilts. Shorter periods of elevated maternal pST in early-mid pregnancy induced by treatment from d 25 to 50 did not increase birth weight in either parity. Maternal pST treatment does not impair subsequent reproduction of mated pigs, although sustained maternal pST treatment decreases retention rates in sows prior to remating, partly reflecting their increased body weight gain in pregnancy and loss in lactation. We are currently evaluating the efficacy of a shorter period of maternal pST treatment in late gestation (d 75 to 100 of pregnancy) for increasing birth weight and progeny performance in gilts and sows.

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Supported in part by the Pork CRC Ltd.

Evaluation of an Innovative Feed Sensor Under Simulated Field Conditions

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[1]South Australian Research and Development Institute, Roseworthy, SA 5371. [2]FlowForce Technologies, Bowden, SA 5007.

Measurement of feed intake by growing pigs is important for development of feeding programs and also as a way to monitor performance. Recently an innovative sensor was developed by Banhazi *et al*. (2009) to measure the amount of feed delivered to individual feeders in livestock buildings. The primary aim of this study was to assess the accuracy of the feed sensor under simulated field conditions by comparing the actual feed delivered with sensor measurements.

Grower feed was carried from a mini-silo by a commercial 75 mm Auger system (IFS Corporation Pty Ltd, Dry Creek, SA) to individual feeder outlets. The sensor (Figure 1) was inserted between a 75 mm diameter downpipe and a large container representing the feeder. The feeder system dispensed a set amount of pelleted feed (range 3.3-18.4 kg, n=59) to create a simulated feed delivery episode. The actual amount of feed deposited in the container at each "feeding episode" was weighed using an electronic weight scale. The sensor-calculated feed weight (kg) and the actual feed weight (kg) were then compared. Sensor-calculated feed weight was subtracted from the actual scale measurements and the difference (error) was calculated in kg and as a percentage for use is statistical analysis.

Figure 1. *Feed sensor used to calculate feed weight*

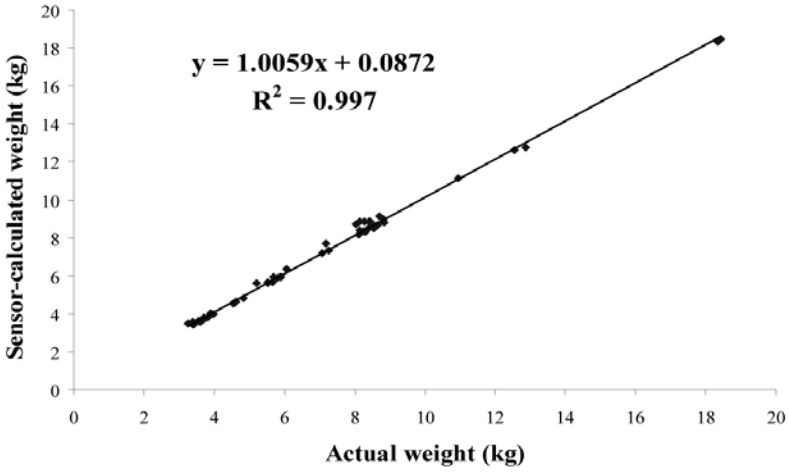

Figure 2. *Sensor-calculated weights versus weights of feed batches.*

A strong and consistent correlation between the sensor-calculated and the actual feed batch measurements was demonstrated (R^2=99.7; P<0.01). During this study, the sensor-calculated feed amount was found to be in agreement with the actual feed delivered (Figure 2) within 0.1 kg (±0.1-0.4 kg, mean and range of error). The test results demonstrated that the system can perform with an accuracy of 1.7 % (±1-4 % mean and range of error) that is more than adequate for commercial purposes. However, further tests are planned to evaluate the robustness and reliability of the system under commercial farm conditions, taking into account such factors as feed type, consistency and communication issues. Use of the sensor will enable producers to better understand feed usage and to measure feed efficiency within their production units.

BANHAZI, T.M., RUTLEY, D.L., PARKIN, B.J. and LEWIS, B. (2009). *Australian Journal of Multi-Disciplinary Engineering*. **7**(1):27-38.

Supported in part by the Pork CRC Ltd.

Feed Intake Of Pigs Can Be Measured Across Experiments Using Radio Frequency Identification

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The use of Radio Frequency Identification (RFID) tagging is widespread in the Australian cattle industry and is increasing in the sheep industry. Apart from monitoring stock movements, animals carrying RFID tags can be subjected to individual segregation, controlled feeding and medication. We wished to demonstrate that a reliable feed consumption duration monitoring system can be implemented for individual pigs housed in group pens, utilising RFID technology.

Two studies, each involving 10 Landrace x Large White gilts were conducted, the first with pigs starting at 10 weeks of age and continuing to 22 weeks, and the second from 13 to 20 weeks of age. Half-duplex, low frequency, lightweight sheep RIFD tags (Allflex Pty Ltd, Brisbane, QLD) were placed in one ear of each pig. A two-place feeder was modified by the addition of antennas on each side of the feeder, and a single RFID transponder (Unique Micro Designs Pty Ltd, Clayton, VIC). Presence of a tag in the reader field was measured every two seconds. Custom software developed within the project was used to filter tag detections to remove isolated readings and gaps due to missed readings. Video recordings were taken at weekly intervals over four to six h, and duration of occupancy in the feeder was measured for each pig. Data was analysed by regression analysis (Genstat, 11th Edition).

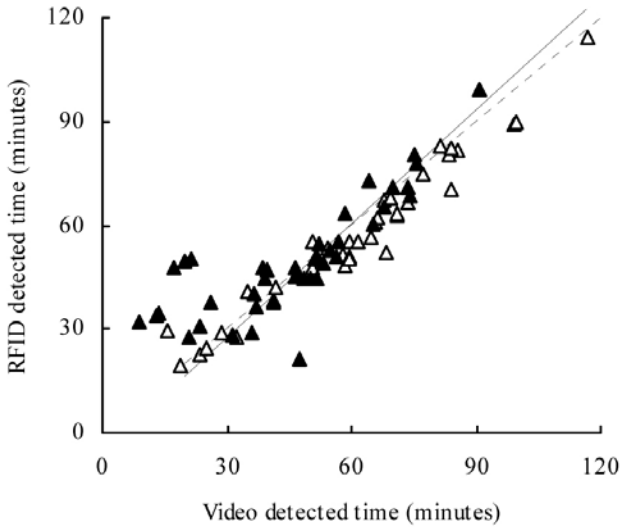

Figure 1. *Comparison of feeding duration measured by RFID and video observation. Line of identity (—); Line of best fit (.....); Experiment 1 (△); Experiment 2 (▲).*

There was a highly significant relationship between the duration of feeding measured directly by video observation and detection of the presence of tags (RFID measure = -5.63 (standard error (SE) 3.13) + 1.10 (SE 0.0546) x Video measure, R^2=0.839, P<0.0001; N=79) using the pooled data from both experiments. Reassuringly, the slope was close to unity and the intercept was not significantly (P=0.076) different from zero. If the intercept was constrained to zero the slope of the relationship was 1.01. While a slightly better fit was obtained if the model also included experiment (R^2=0.856) and individual pig (R^2=0.882), this would likely be impractical and statistically unnecessary if implemented commercially. Outliers may be due to failure to detect some tag events, and "loitering" of pigs near the feeder when not feeding, particularly where an individual pig is regularly implicated. In conclusion, monitoring of RFID tagged pigs can provide accurate measures of feeding duration.

Supported in part by the Pork CRC Ltd.

Dietary Iron Improves Iron Status in Finisher Pigs Fed Wheat-Based Diets

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Inulin-type fructans (IFT) have been shown to increase the absorption of copper, zinc and iron. Bacterial fermentation of IFT in the large intestine has been implicated in the increased intestinal absorption of iron naturally present in plant-based diets (Yashuda *et al*., 2006). Hence, inulin may promote the absorption of iron from the pig's diet and increase muscle iron content in pork. Attempts to increase muscle iron levels using iron supplements alone have largely been unsuccessful. Therefore, this study investigated effects of supplemental inulin (In) and organic iron (Fe) on growth, iron status and pork quality of boars and gilts.

Thirty-two individually-housed Large White x Landrace pigs (16 boars and 16 gilts) (51.1± 0.41 kg) were allocated to a 2x2x2 factorial with the respective factors being supplemental organic iron (0 and 500 mg/kg Bioplex™, Alltech Inc., Kentucky, USA), inulin (0 and 50 g/kg Fibruline®, Warcoing, SA Belgium) and sex. The wheat-based diets were offered at 95 % of estimated *ad libitum* intake to ensure consistent inulin and Fe intakes within a treatment. After 5 weeks blood was obtained by venipuncture and analysed for blood cells and haematocrit and serum analysed for iron and haemoglobin. Color (L* value) and drip loss of the *Longissimus dorsi* muscle was measured at 24 h post-slaughter. Data were analyzed using analysis of variance. For brevity P-values below 0.005 are presented as 0.00 and some established sex effects are not discussed.

Table 1: *Effects of dietary treatments on carcase traits, serum iron and haemoglobin content in finisher pigs fed wheat-based diets.*

Sex (S)…	Boar				Gilt							
Iron (Fe), g/kg …	0		500		0		500		Significance			
Inulin (In), g/kg…	0	50	0	50	0	50	0	50	SED	S	Fe	In
Daily gain (g/d)	816	866	843	932	774	806	748	872	58.8	0.04	0.26	0.02
Carcase weight (kg)	64.6	65.9	62.7	68.7	63.5	61.5	60.8	64.7	1.86	0.01	0.65	0.02
Serum iron (µmol/l)	26.6	30.5	32.0	29.4	27.0	29.3	32.5	29.5	2.57	0.96	0.05	0.93
Haemoglobin (g/l)	115	118	114	117	129	123	124	124	4.30	0.00	0.96	0.81
Haematocrit (%)	36.5	37.6	35.9	36.8	41.7	38.7	39.3	39.3	1.40	0.00	0.68	0.51
Erythrocytes[1,2]	7.1	6.4	6.4	6.5	7.5	7.0	6.9	7.1	0.29	0.00	0.08	0.21
Drip loss (%)	6.9	6.9	6.8	7.1	6.6	6.6	6.5	6.8	0.21	0.01	0.83	0.16
Colour-L* value[3]	55.7	52.5	57.9	56.3	52.6	54.1	52.5	53.0	1.62	0.00	0.16	0.41

[1]significant Fe x In interaction (P<0.05), [2]x 106/ml, [3]significant S x Fe and S x In interactions (P<0.05); SED, standard error of difference.

Dietary In increased daily gain (795 vs 869 g/d, P=0.02) and this translated to an increase in carcase weight (62.9 vs 65.2 kg, P=0.02; Table 1). However, there was an interaction (P=0.01) between Fe and In such that the response was most marked in pigs receiving supplemental Fe. Serum iron was increased by supplemental Fe although there was an interaction (P=0.03) such that it was increased when pigs were fed diets without In (26.8 v. 32.3 µmol/l) but not with In (29.9 vs 29.4 µmol/l). Boars had lower (P=0.00) haemoglobin (116 vs 125), haematocrit (36.7 vs 39.7%) and erythrocytes (6.6 v. 7.1 x 10^6/ml) than gilts. Inulin tended to decrease erythrocytes (P=0.08) especially when no supplemental Fe was fed as indicated by the Fe x In interaction (P=0.01). Pork from boars had higher (P<0.01) drip loss (6.9 vs 6.6%) and was lighter (55.6 vs 53.1) than gilts. In conclusion, these data suggest that serum iron can be increased by feeding organic iron. Also, boars have lower erythrocytes, haemoglobin and haematocrit values than gilts suggesting some differences in iron status.

YASUDA, K., RONEKER, K.R., MILLER, D.D., WELCH, R.M. and LEI, X.G. (2006). *Journal of Nutrition*. **136**:3033-3038.

Supported in part by the Pork CRC Ltd.

Fermentation End-Products From the Small and Large Intestines of Pigs Fed Grain-Based Diets

B.A. Williams[1], S.K.J. Peucker[2], A.M. Finn[2], S.G. Nielsen[3], A.T. Tredrea[4], D.N. Singh[2], R. J. van Barneveld[5] and M.J.Gidley[1]

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Controlled carbohydrate fermentation can improve gastro-intestinal (GI) health, by stimulation of so-called "colonisation resistance" in the pig. This concept includes mechanisms such as the presence of short-chain fatty acids (SCFA) which provide an acidic environment, and limit the growth of some potential pathogens, and other health benefits (Williams *et al*., 2001). Protein fermentation (as indicated by increased digesta ammonia (NH3), on the other hand, provides a GI environment which is conducive to growth of potential protein-fermenting pathogens (Konstantinov *et al*., 2004). The aim of this experiment was to evaluate the fermentation which takes place by the terminal ileum, compared with the large intestine as indicated in the faeces, within pigs fed a range of different grains.

Ileal digesta and faecal samples were collected from male pigs (commercial genotype; ~35kg n=40) fitted with a simple T-piece cannula 15 cm anterior to the ileo-caecal valve. The design was based on a non-resolvable incomplete block design with four runs over 16 weeks. Each pig was used four times within a run and the 32 diet treatments were replicated five times. The diets comprised mainly the test grain (~94%) combined with vitamins, minerals and an acid-insoluble ash marker. Seven barley, ten sorghum, five triticale and nine wheat grains were tested. One sorghum diet was repeated with the additive Zingibain (a protease extracted from ginger; Natbio Pty Ltd., Annerley, QLD). Samples were collected 1 h after feeding on d 7 after introduction of the diet and analysed for characteristics of fermentation such as SCFA, NH_3 and dry matter. A linear mixed model was used to analyse the data in ASReml-R, which had fixed effects for sample site, grain type, variety and Zingibain and their interactions, and random effects for pig, run and cage.

Table 1. *Differences in fermentation characteristics between ileal digesta and faeces in growing pigs fed grain-based diets.*

Parameter[1]	Ileal	Faecal	P value
Dry Matter (DM, g/kg)	123[b]	385[a]	<0.001
Ammonia(µg/g DM)	430[b]	1648[a]	<0.001
Acetic acid (mg/g, DM)	7.6[b]	9.5[a]	<0.001
Propionic acid (mg/g, DM)	0.31[b]	4.5[a]	<0.001
n-Butyric (mg/g, DM)	0.98[b]	2.46[a]	<0.001
Total SCFA[2] (mg/g, DM)	9.0[b]	19.5[a]	<0.001

[1]These predictions are main effect predictions, done in the presence of a significant interaction. Means in the same row with different superscripts differ significantly (P<0.05); [2]SCFA, short chain fatty acids.

Significant fermentation occurred (Table 1) in the SI, where total SCFA was at least half of that measured across the whole tract, except for acetic acid. NH3 was also significantly different, suggesting that hind gut protein fermentation was greater than in the small intestine (SI). The significant fermentation occurring in the SI, as evident from total SCFA values, has positive implications for small intestinal health, which might benefit young pigs in particular.

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WILLIAMS, B.A., VERSTEGEN, M.W.A. and TAMMINGA, S. (2001). *Nutrition Research Reviews.***14**:207-227.

Supported in part by the Pork CRC Ltd.

Variation in Fermentation End-Products From Faeces of Grower Pigs Fed Different Grains

B.A. Williams[1], S.K.J. Peucker[2], A.M. Finn[2], S.G. Nielsen[3], A.T. Tredrea[4], D.N. Singh[2], R. J. van Barneveld[5] and M.J.Gidley[1]

[1]University of Queensland, St. Lucia, QLD 4072. [2]Queensland Department of Primary Industries and Fisheries, Wacol, QLD 4076. [3]NSW Department of Industry and Investment, Orange, NSW 2800. [4]University of Sydney, Narrabri, NSW 2390. [5]Barneveld Nutrition Pty Ltd, Springwood, QLD 4127.

The presence of dietary fermentable carbohydrates is important for gut health of monogastrics (Williams *et al.*, 2001), but may reduce intake by stimulation of the ileal/colonic brake (Black *et al.*, 2009). Various grains are fed to pigs according to cost and availability, but little information is available concerning the contribution grains could make to colonic fermentation. The aim of this experiment was to evaluate whether feeding different grains led to significantly different fermentation characteristics of pig faeces.

Faecal samples were collected from male pigs (commercial genotype; ~ 35kg; n=40) fitted with a simple T-piece cannula 15 cm anterior to the ileo-caecal valve. The design was based on a non-resolvable incomplete block design with four runs over 16 weeks. Each pig was used four times within a run and the 32 diet treatments were replicated five times. The diets comprised mainly the test grain (~94%), combined with vitamins, minerals and an acid-insoluble ash marker. Seven barley, ten sorghum, five triticale and nine wheat grains were tested. One sorghum diet was repeated with the additive Zingibain (a protease extracted from ginger, Natbio Pty Ltd., Annerley, QLD). The pigs were fed at 2.5 times maintenance. Samples were collected 1 h after feeding on d 7 after introduction of the diet and analysed for characteristics of fermentation such as short-chain fatty acids (SCFA), ammonia (NH_3), dry matter and ash. A linear mixed model was used to analyse the data in ASReml-R (Butler *et al.*, 2007), which had fixed effects for sample site, grain type, variety and Zingibain, and their interactions and random effects for pig, run and cage. Results for fermentation characteristics, according to grain type, are presented in Table 1.

Table 1: *Comparison of faecal fermentability characteristics between four grain types.*

Characteristics	Barley	Sorghum	Triticale	Wheat	P value
Dry Matter (DM, g/kg)	369	384	381	397	NS
Ash (% of DM)	25.8[a]	38.5[d]	30.1[b]	32.8[c]	<0.001
Ammonia (µg)	1659	1683	1756	1572	NS
Acetic acid (mg/kg, DM)	10.0[b]	10.4[b]	8.9[ab]	8.2[a]	0.051
Propionic acid (mg/kg, DM)	5.0[b]	5.0[b]	4.0[ab]	3.8[a]	0.007
n-Butyric acid (mg/kg, DM)	3.0	2.6	1.9	2.2	0.082
Total SCFA(mg/kg, DM)	21.6[b]	20.9[b]	17.9[ab]	17.0[a]	0.030

[abcd]Means in the same row with different superscripts differ significantly (P<0.05). SCFA, short chain fatty acids; NS, not significant.

There were significant differences between grain types for some of the characteristics (Table 1), though differences were small. Barley had the highest total SCFA, and wheat the lowest. This was essentially due to higher acetic and propionic acid concentrations for barley. Values for sorghum and triticale fell between the other two grains. Wheat may be the least fermentable in the large intestine as it is likely to be the most digestible in the small intestine. All grains tested could make a contribution to large intestinal health, based on the SCFA results.

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Supported in part by the Pork CRC Ltd.

Effect of Particle Size on *In vitro* Starch Digestion of Barley and Sorghum by Porcine α-Amylase

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Grain particle size influences starch digestibility (Blasel *et al*., 2006). For example, in corn, for each 100 µm increase in average particle size, the degree of starch access by α-amylase was found to decrease by 26.8 g/kg starch (Blasel *et al*., 2006). Particle size is conventionally described by the average particle size and geometric standard deviation determined by sieve analysis (ASAE, 2003). Our hypothesis was that within single milled grain samples, individual particles show significant difference in their enzyme digestion rates *in vitro* depending on their size.

Barley and sorghum were hammer milled using a 4 mm sieve, after which the ground material (control) was fractionated using eight sieve sizes (4.7, 2.8, 1.7, 1.0, 0.50, 0.25, 0.125 and 0.045 mm). The enzyme digestion rate for each fraction was then determined using a split plot design (Figure 1), where samples (combinations of grain type and sieve size) formed the whole plots and incubation time formed the subplots. The data was analysed using linear mixed model methodology.

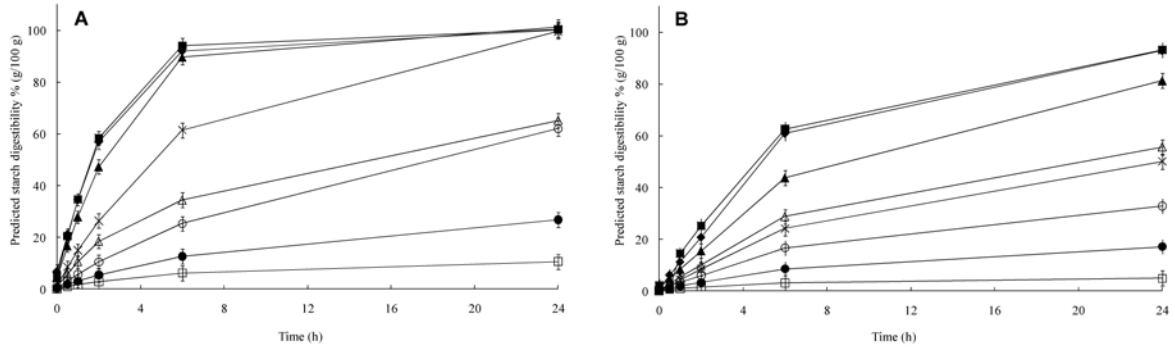

Figure 1. *Time dependence of fraction digestion (proportion of total starch) of predicted in vitro starch digestion for different particle sizes (mm): 2.8 (□), 1.7 (●), 1.0 (○), 0.50 (×), 0.25 (▲), 0.125 (◆), 0.045 (■) and control (△) of barley (A) and sorghum (B). Non-overlapping confidence intervals (as indicated by error bars) indicates a significant difference (P<0.05).*

This experiment showed that particle size after fractionation has a significant effect on starch digestibility (P<0.001). For both barley and sorghum, starch digestibility increased as the sieve size decreased (Figure 1). In barley, incomplete starch digestion occurred for particles greater than 1 mm sieve size after 24 hrs *in vitro*. In sorghum, there was incomplete starch digestion even for the smallest fraction size after 24 hrs. The slower starch digestion in sorghum could be attributed to the presence of a protein matrix that surrounds starch granules (Ezeogua *et al*., 2005). Conventional milling of grains leads inevitably to highly heterogeneous digestion behaviour as individual particles vary greatly in size. Thus, the digestion profile of a standard milled grain (ie. Controls in Figure 1) is an average across a wide range of individual particle digestion rates. For pig production, the target is to ensure complete digestion and maximize energy delivery in the small intestine. This study proposes that slow or incomplete starch digestion is due mainly to the presence of large particles within the wide distribution of sizes caused by the milling process.

BLASEL, H.M., HOFFMAN, P.C. and SHAVER, R.D. (2006). *Animal Science and Feed technology.* **128**: 96-107.

EZEOGUE, L.I., DUODUA, K.G. and TAYLOR, J.R.N. (2005). *Journal of Cereal Science.* **42**:33-44.

ASAE (2003). Standard no. S319.3. American Society of Agricultural and Biological Engineers. pp. 202-205.

Supported in part by the Pork CRC Ltd.

Effect of Particle Size on Viscosity and Pasting Properties of Milled Sorghum

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During the gelatinisation process, viscosity increases due to swelling of starch granules and the formation of a gel from amylose leached from granules. The Rapid Visco Analyser (RVA) measures swelling, gelatinisation and retrogradation properties of starch-based materials such as grains. This technique has been also reported to be a sensitive method for estimating the concentration of starch in grain-based diets (Gates *et al*., 2005).

To evaluate the effect of particle size on viscosity and integrity of starch granules within grain fragments, sorghum was hammer-milled through a 4 mm sieve, then the ground material was fractionated using eight sieves (4.7, 2.8, 1.7, 1.0, 0.50, 0.25, 0.125 and 0.045 mm). Confidence interval ($P<0.05$) for each particle size was used to compare viscosity profiles between particle size. The viscosity of fractions 0.045 to 1.0 mm in addition to a control was determined using RVA (RVA model 4, Newport Scientific, NSW).

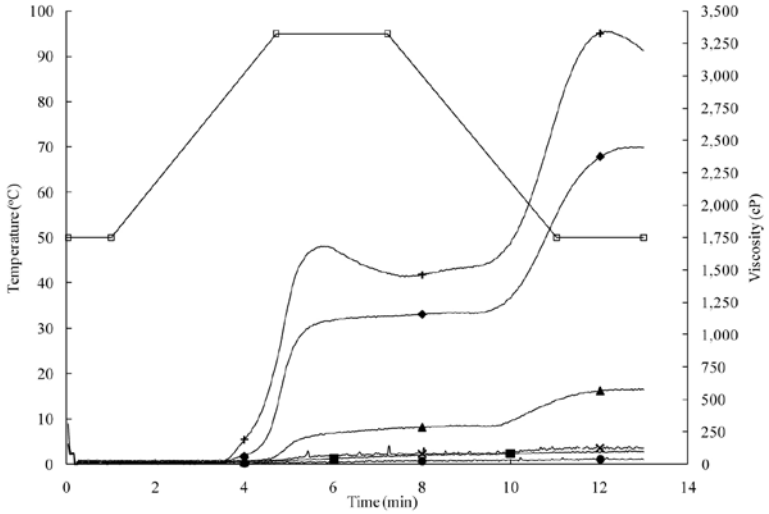

Figure 1. *Rapid Visco Analyser (RVA) pasting profiles of sorghum (10% of dry matter) at different sieve fraction sizes (starch content % ± standard error; fraction yield %): + 0.045 mm (64.98±0.37; 1.9); ◆ 0.125 mm (63.89 ±0.29; 5.2); ▲ 0.25mm (57.78±0.67; 16.2); ■ 0.50 mm (57.03±0.63; 38.6); ● 1.00 mm (65.31±1.60; 29.1); ✕ Non-fractionated control (61.22±0.07) and temperature profile (□).*

This experiment demonstrated that there was a progressive reduction in viscosity (pasting curve) with increasing size fractions even though the starch content was similar (Figure 1). The lower viscosity profile for big particles may be attributed to lower water penetration into starch granules (less granule swelling) and less amylose leaching (gel formation) during heating to 95°C. This is likely to be due to the restraining influence of cell walls and/or protein bodies within the grain fragments. The results of this experiment suggest that finer grinding or fractionation of sorghum can modify the physio-chemical properties (extent and amount of starch gelatinisation) that increase binding between particles (Svihus *et al*., 2005), which may improve pellet quality, reduce fines and feed wastage.

GATE, K.K., ANTTILA, H., SONTAG-STROHM, T. and SALOVAARA, H. (2005). *Annual Transactions of the Nordic Rheology Society*. **13**:255-257.

SVIHUS, B., UHLEN, A.K. and HARSTAD, O.M. (2005). *Animal Feed Science and Technology*. **122**:303-320.

Supported in part by the Pork CRC Ltd.

Effect of Particle Size of Barley and Sorghum on the Kinetics of *In vitro* Starch Digestion by Porcine α-Amylase

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Numerous studies have shown that the digestion rate of starches within milled grains increases as grind size decreases. However, the fact that milled grains contain a broad distribution of particle sizes has not previously been taken into account in understanding measured (average) starch digestion rate. Starch digestion in grains typically follows first order kinetics (Weurding *et al*., 2001). We hypothesise that milled grain fragments, after being segregated by size provide a wide range of individual particle digestion rates from a single milled sample. The aim of this experiment was to characterise the kinetics of starch digestion for ground sorghum and barley grain fragments after segregation by size.

Barley and sorghum grains were hammer milled using a 4 mm screen size and then fractionated using eight sieve sizes (4.7, 2.8, 1.7, 1.0, 0.50, 0.25, 0.125 and 0.045 mm). First-order kinetics was found to be sufficient to describe the kinetics of starch digestion under simulated small intestine conditions by α-amylase for each particle size fraction from the milled cereal samples. For the purpose of data fitting, the value of k_i was obtained by linear-least-squares fit of the solution to the first order rate equation: $C_i = 1 - e^{-kit}$, where :C_i is the starch fraction digested at time t in the i^{th} sieve screen size, k_i is the fractional digestion rate coefficient (h^{-1}), and t is the incubation or digestion time (h).

Table 1. *Fraction yield (%) and fractional-digestion rate coefficient (k) (±standard deviation) for the in vitro digestion by α-amylase and amyloglucosidase of starch (based on the starch content of each fraction) in barley and sorghum particles fractionated from single hammer milled grain samples.*

Sieve opening (mm)	Average sieve size (mm)	k_b (Barley)	Barley yield (%)	k_s (Sorghum)	Sorghum yield (%)
4.76		NM	0	NM	0
2.8	3.78	$(4.3\pm0.5)\times10^{-3}$	2.4	$(71.9\pm0.2)\times10^{-3}$	1.3
1.7	2.25	$(1.2\pm0.7)\times10^{-2}$	25.5	$(7.5\pm0.6)\times10^{-3}$	6.6
1.0	1.35	$(4.0\pm0.1)\times10^{-2}$	39.8	$(1.6\pm0.1)\times10^{-2}$	29.1
0.5	0.75	$(2.3\pm0.1)\times10^{-1}$	19.7	$(2.9\pm0.2)\times10^{-2}$	38.6
0.25	0.375	$(3.9\pm0.2)\times10^{-1}$	7.2	$(7.0\pm0.3)\times10^{-2}$	16.2
0.125	0.188	$(4.3\pm0.3)\times10^{-1}$	2.8	$(1.1\pm0.06)\times10^{-1}$	5.2
0.045	0.045	$(4.7\pm0.2)\times10^{-1}$	2.3	$(1.1\pm0.1)\times10^{-1}$	1.9
Control		$(4.2\pm 0.2)\times10^{-2}$		$(3.4\pm0.2)\times10^{-2}$	

NM, no sieved material was present at this sieve size; k_b, fractional-digestion rate coefficient for barley; k_s, fractional-digestion rate coefficient for sorghum.

A good fit to first-order kinetics was found for all samples, with r^2 values from 0.90 to 0.99 and from 0.87 to 0.99 for barley and sorghum, respectively. Rate coefficients decreased with sieve size (Table 1), and were approximately 100 times greater for particles at 0.045 mm compared to particles at 2.8 mm size for both barley and sorghum. This suggests that in single milled grain samples, individual particles are digested at widely varying rates. Formulating diets using different grain size fractions could be used to control the supply of glucose (produced from starch digestion) such that this was in balance with amino acid uptake, thus maximising protein deposition, especially in growing pigs. This strategy could thus minimise nutrient asynchrony, defined as separation of amino acid and glucose uptake with time (van den Borne *et al*., 2007).

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WEURDING, R.E., VELDMAN, A., VEEN, W.A.G. and VAN DER AAR, P.J. (2001). *Journal of Nutrition*. **131**:2336-2342.

Supported in part by the Pork CRC Ltd.

Sorghum Inclusion in Pig Diets - Effects on Pellet Durability, Mill Throughput and *In vitro* Starch Digestion

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[1]Better Blend Stockfeeds Pty Ltd, Oakey, QLD 4402. [2]Rivalea Australia Pty Ltd, Corowa, NSW 2646. [3]University of Queensland, St Lucia, QLD 4072. [4]NSW Department of Industry and Investment, Orange, NSW 2800. [5]University of Sydney, Narrabri, NSW 2390. [6]John L Black Consulting, Warrimoo, NSW 2774.

Pellet quality can be affected by both grain type and inclusion level and the conditioning and press conditions of individual mills. Anecdotal reports suggest that under commercial conditions, pellet durability is adversely affected when sorghum represents 40% or more of the diet. Pellet quality is believed to improve with increased conditioning time, but the implications for throughput and the nutritional value of feeds are unknown. This experiment tested the hypothesis that increasing the sorghum content of grower pig diets reduces pellet durability and *in vitro* starch digestion.

The effect of varying the sorghum content of grower feeds was examined at two stock feed mills with different conditioning and pelleting systems. Mill 1 pelleted feed after a mixer conditioning process of approximately 100 sec. Mill 2 steam pelleted feed following conditioning for around 20 sec. Test diets were formulated to contain similar, but not the same, raw material inclusions and to provide 13.8 MJ digestible energy (DE)/kg and 0.68g available lysine/MJ DE. A separate randomisation was used at each mill; both were incomplete block designs with two replicates. Data from each mill were analysed separately because of differences in grain source and treatments. Statistical comparisons were made within mills only using a linear mixed model. Diet throughput was obtained from the respective mill batching systems. Pellet samples were assessed for durability using a Holmen pellet tester (TekPro Limited, Willow Park North Walsham Norfolk, UK). Starch digestion at 240 min in pellets was determined *in vitro* by the method of Sopade and Gidley (2009).

Table 1. *Change in press throughput, pellet durability and in vitro starch digestion (mean (SEM)), resulting from increased sorghum inclusion in pig grower diets.*

	Mill 1			Mill 2		
Sorghum (%)	Press throughput (T/h)	Pellet durability (%)	Starch digestion (% starch)	Press throughput (T/h)	Pellet durability (%)	Starch digestion (% starch)
0	7.64(0.22)	95.7(0.8)	78.7(2.0)[a]	9.20(0.65)	94.5(2.2)[a]	47.2(1.6)[a]
40	7.53(0.17	96.3(0.8)	88.6(1.8)[c]	9.47(0.55)	87.2(1.8)[b]	67.8(1.4)[b]
60	7.46(0.21)	98.0(0.8)	82.5(2.0)[b]	9.30(0.65)	75.5(2.2)[c]	75.1(1.6)[c]
P Value	NS	NS	***	NS	**	***

[abc]Means in a column with different superscripts differ significantly (P<0.05); NS, not significant; **, P<0.01; ***, P<0.001; SEM, standard error of mean.

Sorghum inclusion level showed no significant effect on throughput in either mill (P>0.05; Table 1). Within each mill there were significant differences in starch digestibility (P<0.001) and in Mill 2 pellet durability was also significantly reduced as the level of sorghum inclusion increased (P<0.01). In contrast, sorghum inclusion level had no effect on pellet durability at Mill 1. There was clear evidence of differential responses to processing conditions at the two mills. Further research is required determine what effect conditioning time and temperature have on the chemical composition of the final product and their implications for animal intake and subsequent performance.

SOPADE, P.A. and GIDLEY, M.J. (2009). *Starch/Stärke*. **61**:245-255.

Supported in part by the Pork CRC Ltd.

Production Responses to Dehulling and Level of Inclusion of Australian Sweet Lupins (*Lupinus angustifolius*) in Weaner Pig Diets

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[1]Department of Agriculture and Food WA, South Perth, WA 6151. [2]Murdoch University, Murdoch, WA 6150.

It is generally perceived that high quality energy and protein sources in diets for newly-weaned pigs, such as milk powders, lactose and cooked cereals, promote better performance after weaning. However, their higher cost and stability of supply sometimes requires nutritionists to explore potential for other ingredients for use in the formulation of weaner diets. Recent research in grower pigs demonstrated that lupins could be included at up to 350g/kg in place of soybean meal, without compromising growth, carcase composition or meat quality (Kim *et al.*, 2007). However, the use of lupins in a weaner diet to reduce or replace more expensive protein sources, such as milk products, has not been examined to date. The hypothesis tested was that increasing the concentration of whole or dehulled Australian sweet lupins in place of milk by-products such as skim milk powder and dried whey in a diet would reduce performance of weaner pigs.

A total of 180 entire male pigs weighing 6.4±0.1 kg at weaning were housed in pairs in a completely randomised block design having 9 dietary treatments (n=10 pens), with pigs blocked based on initial body weight. Two replicate studies were conducted with 90 piglets each to increase the number of observations. The diets were (i) a wheat-based control diet containing 240 g/kg of whey and skim milk powder, and (ii) 8 diets containing whole or dehulled lupins (*cv* Coramup) that substituted the milk products at 60, 120, 180 and 240 g/kg of diet. Digestible energy (DE) and ileal digestible amino acid contents were equalised using soy protein concentrate, canola oil, full fat soybean meal and meat meal. The diets were isoenergetic (15 MJ DE/kg), and were formulated to contain the same ileal standardised digestible lysine content (0.85 g/MJ DE) and ideal patterns of other essential amino acids. As lupins contain fewer sulphur amino acids, the dietary crude protein (CP) contents for diets containing 240 g/kg whole lupins and 180 g/kg and 240 g/kg dehulled lupins were 240, 234 and 245 g CP/kg, respectively. By comparison, the other diets contained 230 gCP/kg. Piglets had *ad libitum* access to feed and water for 3 weeks after weaning. Feed intake and body weight gain were measured weekly. Data were analysed using the analysis of variance (SPSS v. 16, SPSS Inc., Chicago, Illinois). As a significant block effect and replication effect were observed for feed intake and daily gain ($P<0.001$), initial body weights and replicates were used as covariates for subsequent statistical analysis.

Table 1. *Effects of dehulling and concentration of lupins on performance of weaner pigs.*

		Whole lupin (g/kg)				Dehulled lupin (g/kg)				
Item	Control	60	120	180	240	60	120	180	240	SEM
Gain (g/d)	330[a]	351[a]	342[a]	354[a]	344[a]	352[a]	359[a]	326[a]	305[b]	6.5
Intake (g/d)	495[a]	523[a]	524[a]	519[a]	498[a]	516[a]	502[a]	507[a]	424[b]	10.7
FCR (g/g)	1.45	1.46	1.55	1.43	1.43	1.44	1.36	1.52	1.49	0.03

[ab]Means in a row with different superscripts differ significantly ($P<0.05$). SEM, standard error of mean.

Piglets fed diets containing whole lupins up to 240 g/kg ate comparable amounts of feed, and had similar FCR and daily gains compared to piglets fed the milk-powder-based diet (Table 1). However, piglets receiving 240 g/kg of dehulled lupins ate less feed ($P<0.05$) and grew slower ($P<0.05$) than piglets fed the other diets. These data suggest that dehulled lupins in a weaner diet should be limited to less than 180 g/kg while whole lupins can be included up to 240 g/kg without deleterious effects on production. This result reinforces the previous finding that high levels of fermentable fibre, but not insoluble fibre, could have anti-nutritional effects for weaner pigs.

KIM, J.C., MULLAN, B.P., RICHOLLS, R.R., D'SOUZA, D.N. and PLUSKE, J.R. (2007). In "Manipulating Pig Production XI", P. 204, eds J.B. Patterson and J.B Barker (Australiasian Pig Science Assoc.: Werribee).

Supported in part by the WA Agricultural Produce Commision:Pig Producers' Committee.

Assessing *In vitro* Starch Digestibility of Sorghum Using its Rapid Visco-Analysis (RVA) Pasting Parameters

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The rapid visco-analyser (RVA) is a simple, rapid and versatile tool for investigating pasting properties. Various RVA parameters (eg. peak viscosity (PV) and trough viscosity (TV)) have been related to feed properties (Stevenson *et al*., 2007; Zhao *et al*., 2008). Prediction of feed digestibility using robust factory-applicable technology such as the RVA would be useful to assess the effectiveness of processing techniques and conditions for optimal animal performance. This study investigated how selected RVA parameters predicted *in vitro* starch digestion in processed sorghum.

Sorghum (*Buster var.*) was extruded in a replicated randomised full factorial experimental design (3 moisture levels x 3 screw speeds). The pasting properties were analysed (10% solids; 25g total weight) with the RVA Model 4 (Newport Scientific Pty Ltd, Warriewood, NSW) standard profile 1 to obtain the peak (95°C) and trough (95°C; 150 s) viscosities. Starch digestion was analysed by a rapid *in vitro* procedure (37°C; 85 rpm; 0–4 hr; Accu-Chek Performa® glucometer). Minitab® 15 was used for the statistical analysis, and very rapidly digested starch, D_o, and rate of digestion, K, were computed from a modified first-order kinetic model.

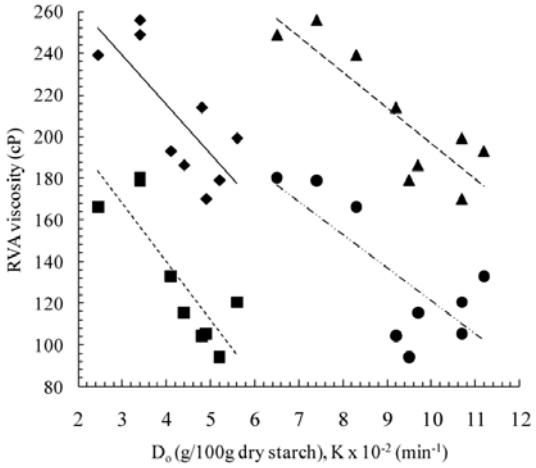

Figure 1: *Relationship between pasting and digestibility properties (◆-PV-K, ■-TV-K, ▲-PV-D_o, ●-TV-D_o); RVA, rapid visco-analyser; D_o, digested starch; K, rate of digestion; PV, peak viscosity; TV, trough viscosity.*

Extruded sorghum exhibited a defined RVA peak, and reduced in viscosity during holding to suggest the disruption of starch-protein interactions in the sorghum grain. This enhanced starch swelling and digestion. Expanders work on the same principles as extruders, and with a careful choice of process conditions, starch-protein interactions in sorghum-based expandates could be disrupted for ease of swelling of the starch to enhance end-use functionalities. The RVA parameters were dependent on the extrusion conditions, and were significantly ($p<0.05$) inversely related (Figure 1; PV = 310 - 2400 K, PV = 370 - 17.1 D_o, TV = 250 – 2820 K, TV = 280 - 15.9 D_o, $r^2>0.56$) to either D_o or K. The weakening of starch-protein interactions and the disruption of starch structures are expected to aid accessibility of starch molecules to amylolysis. These demonstrated relationships show the RVA would be valuable to pig feed manufacturers to predict feed digestibility, and potential energy delivery from feeds, however, future pig studies are required to confirm this.

STEVENSON, M.C, WILLIAM, B., SOPADE, P., BRYDEN, W.L. and HOSKING, B.J. (2007). In "Manipulating Pig Production XI". p. 99, eds J.E. Patterson and J.A. Barker. (Australasian Pig Sciences Association: Werribee).

ZHAO, R., BEAN, S., WU, X. and WANG, D. (2008). *Cereal Chemistry*. **85**:830–836.

Supported in part by the Pork CRC Ltd.

Functional and Digestibility Properties of Pig Feeds: Gelatinisation Properties From Differential Scanning Calorimetry(DSC)

P.A. Sopade[1], S.G. Nielsen[2], H.D. Rodrigues[3], D.N. Singh[3], A.T. Tredrea[4], J.L. Black[5] and M.J. Gidley[1]

[1]University of Queensland, St Lucia, QLD 4072. [2]NSW Department of Industry and Innovation, Orange, NSW 2800. [3]Queensland Department of Primary Industries and Fisheries, Wacol, QLD 4076. [4]University of Sydney, Narrabri, NSW 2390. [5]John L Black Consulting Pty Ltd, Warrimoo, NSW 2774.

Starch is the main component of cereals, which are base materials for pig feeds. During processing, starch is gelatinised to degrees that are dependent on process conditions. Starch gelatinisation influences physicochemical characteristics of feeds, and may control functional and digestibility properties, the knowledge of which is important in understanding energy delivery to and biological response of the animal (White *et al.*, 2008). This study reports on the gelatinisation properties of feeds subsequently used to provide near infrared spectrophotometry (NIRS) calibrations for ileal and whole tract pig digestibility. The null hypothesis was that these properties are independent of the cereal species, varieties and enzyme treatments.

Barley (7 varieties), sorghum (10 plus one zingibain-treated (ZT, Natbio Pty Ltd, Annerley, QLD)), triticale (5), and wheat (9) were formulated to contain about 940 g/kg of the cereal, and cold-pelleted in a pilot mill. The pellets and grains were hammer-milled (1 mm sieve), and the gelatinisation properties were analysed (Mahasukhonthachat *et al.* 2010) using a duplicated randomised incomplete block design over seven runs. The data were analysed using Universal Analysis™ software and ASReml-R linear mixed models containing fixed effects for grain type, variety, ZT, and sample state (grain or pellet) and their interactions, with replicate and run as random effects.

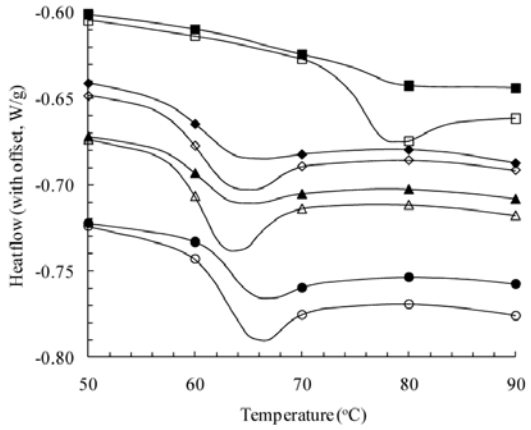

Figure 1: *Typical thermograms of the feeds: ZT sorghum, pellets (■), grains (□); wheat, pellets (◆), grains (◇); triticale, pellets (▲), grains (△); barley, pellets (●), grains (○).*

Pelletisation partially gelatinised starch as depicted in the thermograms (Figure 1) of the pellets and grains. The degree of starch gelatinisation caused by cold-pelletisation was determined from the ratio of peak area (enthalpy) for pellet and grain. This varied with grain species (barley, 17-33%; sorghum, 34-68%; triticale 14-25%; wheat 15-33%), possibly because of different heat-moisture trajectories of feeds in the pelletiser. The gelatinisation parameters (onset, peak and end temperatures, and enthalpy) were significantly affected by the sample state, and cereal species and variety. ZT did not materially affect the parameters. Cold-pelletisation can lead to starch gelatinisation, and hot-pelletisation, as occurs in commercial feed processing, would be expected to gelatinise the starch more. Sorghum gelatinised at a higher temperature showing the need for it to be processed at a higher temperature than other grains for equivalent levels of gelatinisation.

MAHASUKHONTHACHAT, K., SOPADE, P.A. and GIDLEY, M.J. (2010). *Journal of Food Engineering.* **96**:18-28.

WHITE, G.A., DOUCET, F.J., HILL, S.E. and WISEMAN, J. (2008). *Animal*. **2**:867–878.

Supported in part by the Pork CRC Ltd.

Functional and *In vitro* Starch Digestibility Properties of Pig Feeds: Any Correlations With *In vivo* Starch Digestibility?

P.A. Sopade[1], S.G. Nielsen[2], A.T. Tredrea[3], J.L. Black[4] and M.J. Gidley[1]

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Functional and *in vitro* starch digestibility properties are valuable in the choice of feed materials (White *et al.*, 2008), and optimisation of process controls during manufacture. There are limited studies relating feed properties and animal performance. Using a material science approach, we investigated how *in vivo* starch digestion (terminal ileum), *in vitro* starch digestion, and pasting and gelatinisation properties are related.

Reinette (BR), Haruna Nijo (BHN) and Namoi (BN) varieties of barley, and waxy (WS) and normal sorghum (NS) varieties, formulated to contain about 94% of the cereal, were cold-pelleted and hammer-milled prior to analysis in a duplicated randomised incomplete block design in single or multiple runs. The pellets were analysed separately or with other pellets and/or grains. Pasting was studied with a Rapid Visco-Analyser (RVA), gelatinisation with Differential Scanning Calorimetry, and starch digestion with a rapid *in vitro* method based on glucometry. Data were analysed with a linear mixed model using fixed and random terms that depended on the properties being studied. *In vivo* starch digestion data were obtained from Black (2008).

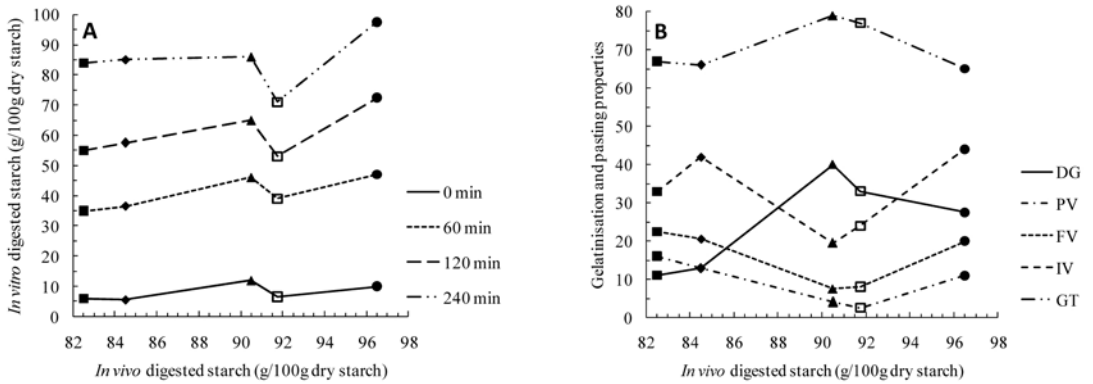

Figure 1: *Relationship between functional and digestibility properties of sorghum; waxy (▲), normal (□) and barley; Reinette (●), Haruna Nijo (◆), Namoi (■) pellets. Figure A shows digestion rates over time, 0 min, 60 min, 120 min, 240 min. Figure B shows gelatinisation and pasting properties; degree of gelatinisation (DG), gelatinisation temperature (GT), initial viscosity (IV), peak viscosity (PV), final viscosity (FV).*

High *in vitro* digestion could indicate high *in vivo* starch digestion (Figure 1A). BR had the highest degree of gelatinisation (DG), was the most digested and exhibited the least peak (PV) and final (FV) viscosities (Figure 1B). Low PV and FV, and a high initial viscosity (IV), indicative of high DG, were associated with high *in vivo* starch digestion. Despite higher gelatinisation temperatures, the sorghums were more gelatinised than the barleys, possibly due to a higher frictional heat-moisture input during the pelletisation. The higher DG of the sorghums reflected in starch digestibility, but the starch-protein interactions in the sorghum mitigated against complete swelling/pasting (Figure 1B), and high starch digestibility (Figure 1A). Based on *in vitro* digestion, WS would be predicted to be more digested than NS, but this was not reflected in *in vivo* digestion (Figure 1A). Functional and *in vitro* digestion properties, which are relatively easy to obtain, can assist with the assessment of *in vivo* digestion and animal performance. However, more data are required with a wide range of differences in these properties, and preferably from one cereal or a cereal variety for the same molecular structure.

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Supported in part by the Pork CRC Ltd.

Performance of Grower Pigs Offered 37 Different Grain Diets

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Significant variation (up to 2 MJ/kg in digestible energy (DE)) has been shown in the nutritional quality of cereal grains used in pig production in Australia (van Barneveld, 1999). Finn *et al* (2007) reported significant variation in weaner pig performance which was influenced by variation within and between grain types. There is limited information on variation in voluntary feed intake and growth of pigs fed different grain species and cultivars. The aim of this experiment was to evaluate variation in pig growth performance using 37 different diets from 4 different grain types (11 wheat, 9 barley, 14 sorghum and 3 triticale).

Grower diets were formulated to contain on average 13.5 MJ DE/kg and an available lysine content of 0.65 g/MJ DE. The design was based on a non-resolvable incomplete block with 7 runs of 53 cages. However, due to presence of mould in the feed only 5 runs of 53 cages in each run was possible. This resulted in each of the 37 grains being replicated at least 7 times within the 5 runs. The experiment was terminated on d 21 of the 5th run. The diets were comprised of approximately 820 g/kg of the test grains with the remainder a combination of blood meal, soybean meal, meat and bone meal, essential amino acids and vitamin and mineral premixes. The diets were prepared in two batches but the supplement was pre-mixed in a single batch to try and ensure uniformity of the other ingredients. Large White male pigs weighing 20.85 ± 3.32 kg were placed in individual pens and fed *ad libitum*. Body weight and feed intake were measured on d 0, 14, 21 and 28 d. A linear mixed model was used to analyse the data in ASReml-R. The model contained fixed main effects for batch, grain type, grain cultivars and mould. A covariate for the starting weight of the pig was also fitted. All the appropriate interactions of the main effects and the covariate were tested for significance. The random effects included run and cage. Only significant main effects and interactions are discussed.

Table 1. *Predicted values of the effects on intake and performance of pigs growing from 20 – 40kg with mould effect removed.*

Grain Type	Average daily intake (kg/d)	Rate of growth (kg/d)	FCR(kg feed/kg gain)
Barley	1.515[ab]	0.849[b]	1.784[a]
Sorghum	1.572[b]	0.804[a]	1.968[b]
Triticale	1.444[a]	0.813[ab]	1.799[a]
Wheat	1.497[a]	0.846[b]	1.777[a]
P value (between grains)	0.021	0.029	<0.001
P value (within grains)	0.043	0.115	0.018

[abc]Means in the same column with different superscripts differ significantly (P<0.05).

Both the between and within grain type effects for daily feed intake and feed conversion ratio (FCR) were significant (Table 1) and only between grain type effect was significant for growth rate. FCR for pigs on sorghum diets ranged from 1.76-2.19, barley from 1.75-1.97, wheat from 1.73-1.88 and triticale from 1.81-1.91. There was a significant mould by grain type interaction (P=0.02) for feed intake. Although presence of mould had a significant effect on the feed intake of pigs on sorghum based diets only (1.74 and 1.55 kg/d respectively for mouldy and non-mouldy sorghum), the FCR was not significantly different. The results provide evidence to that variation in pig performance is influenced by both within and between grain types.

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Supported in part by the Pork CRC Ltd..

Use of Groundnut Cake in Grower and Finisher Diets in Vietnam

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Groundnut (*Arachis hypogaea*) cake (GNC) or peanut meal is a rich source of crude protein (~456 g/kg). In 2006, Vietnam had 246,700 hectares of groundnut crop with an annual yield of approximately 462,500 tonnes; 40% of this yield was pressed into GNC. Despite the nutritional potential, availability and relative cost as a local feed ingredient in Vietnam, most large feed mills are reluctant to increase GNC use, mainly due to concerns over aflatoxin contamination and potential toxicity issues in livestock. Previous work in Vietnam (Le Anh *et al*., 2001) in ducks showed that use of mycotoxin binders in diets improved performance, and this could potentially overcome toxicity concerns with the use of GNC in pig diets. This experiment measured the performance of pigs fed diets containing GNC and the effectiveness of an added mycotoxin binder.

A total of 300 hybrid (Duroc x Pietrain x Yorkshire x Landrace) pigs with an average initial weight of 25.2± 0.03 kg were allocated randomly to 5 treatments, with 5 pen replicates and 12 pigs per pen, with the pen as the experimental unit. Pigs were fed one of five pelleted diets based on corn, rice bran and soybean meal, consisting of a control with 0 g/kg GNC and four similar balanced diets with soybean meal and rice bran partly replaced by GNC at 100 g/kg or 150 g/kg inclusion, with or without 1 g/kg aflatoxin binder (Mtox™- Montmorillonite E558: 42%, Kieselgur E51C: 30%, yeast cell walls and seaweed extract; Olmix Pty Ltd, Ho Chi Minh City, Vietnam). These diets were formulated to nutrient specifications for Vietnamese pigs (ie grower (20-60 kg) diets of 13.85 MJ digestible energy (DE)/kg; 6.9 g lysine/MJ DE and with finisher (60-100 kg) diets of 13.85 MJ DE/kg, 5.9 g lysine/MJ DE). Assay of the GNC showed that it contained 495 µg aflatoxins/kg, so that diets contained either 50 or 75 µg aflatoxin/kg. One-way analyses of variance of performance results was conducted using Genstat.

Table 1. *Performance of pigs fed diets with groundnut cake (GNC) with or without mycotoxin binder.*

	ADG (kg)		ADFI (kg)		FCR (kg/kg)	
Treatment	Grower	Finisher	Grower	Finisher	Grower	Finisher
0 g/kg GNC	0.59^{a}	0.77^{a}	1.50	2.40	2.54^{a}	3.11^{d}
100 g/kg GNC	0.56^{c}	0.74^{c}	1.49	2.39	2.67^{b}	3.21^{bc}
150 g/kg GNC	0.54^{cd}	0.72^{d}	1.51	2.40	2.78^{a}	3.32^{a}
100 g/kg GNC + binder	0.58^{ab}	0.76^{b}	1.48	2.41	2.57^{cd}	3.16^{cd}
150 g/kg GNC + binder	0.57^{bc}	0.75^{c}	1.50	2.41	2.65^{bc}	3.23^{b}
SEM	0.005	0.003	0.012	0.016	0.027	0.019

^{abcd}Means in a column with different superscripts differ significantly (P< 0.05); SEM, standard error of mean; ADG, average daily gain; ADFI, average daily feed intake; FCR, feed conversion ratio.

Inclusion of GNC had no effect on feed intake but adversely affected feed conversion and growth rate (Table 1). An aflatoxin tolerance in pigs of 100 µg/kg for growers and finishers has been suggested from other studies (Kopinski and Blaney, 2008), while aflatoxin usually also reduces feed intake. Our results suggest that another anti-nutritive factor may be present in the GNC. The addition of 1 g/kg binder, when GNC was included at 100 g/kg, significantly improved average daily gain and feed conversion. Despite reduced pig performance, local GNC is still an attractive protein source at half the cost of soybean meal in Vietnam and its inclusion in diets with a binder may reduce the cost of feed per kg weight gain.

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Supported in part by the Australian Centre for International Agricultural Research.

Inoculating a Fermented Liquid Feed For Grower Pigs Does Not Increase the Lactic Acid Content

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Fermented liquid feed (FLF) has the potential to reduce the requirement for in-feed antibiotics, however, naturally fermenting liquid feed, using only the natural population of lactic acid bacteria on the cereal grains, has proven to be an unreliable process. Natural ferments are unable to produce a consistent amount of lactic acid above 100mmol/l in the feed, which is considered to be bactericidal to enteropathogens (Brooks *et al.*, 2003). The use of an inoculant to promote high levels of lactic acid bacteria may help to overcome this. The aim of this experiment was to investigate how an inoculant of *Lactobacillus plantarum* influences the organic acid and volatile fatty acid (VFA) profile of the cereal component in a fermented liquid feed compared to a naturally fermented liquid diet.

Liquid feeds were produced by batch fermentation, whereby only the cereal component of the feed was fermented. A commercial source of *L. plantarum* was added to water and dry hammer milled sorghum (500-1,000 microns) at a ratio of 1:3.7 (grain:water). Four to five days before the first feeding of the test diets, the inoculant was placed into a fermentation tank that contained 30,000 l of sorghum plus water so that the final concentration of *L. plantarum* in the inoculated cereal component of the feed was approximately 5.4x104 colony-forming units (CFU)/ml liquid feed. The tank was left for 4-5 d to ferment so as to reach a steady state before fresh feed was introduced into the tank. At least 50% residue was left in the tank daily to inoculate incoming fresh feed. Naturally fermented cereal was utilised from sorghum formerly fermenting on-site in a fermentation tank with a 197,000 l capacity. Samples of the fermented cereal component of the diet were taken from the tank prior to adding concentrates and immediately placed in a -20°C freezer and frozen prior to analysis for VFA content via gas chromatography. Analysis of variance was conducted to determine the effect of the inoculant on the chemical composition of the cereal component of the diet (Table 1).

Table 1. *Organic acid and volatile fatty acid analyses (mmol/l) of naturally fermented and inoculated fermented cereal component (n=6) of the diet.*

Fermentation product	Diet NAFLF	Diet IFLF	SEM	P-value
Lactic acid (mmol/l)	52.32	76.29	18.16	0.37
Acetic acid (mmol/l)	56.57	70.92	11.85	0.41
Butyric acid (mmol/l)	11.27	10.41	3.65	0.87
Propionic acid (mmol/l)	18.70	14.91	4.63	0.58
Succinic acid (mmol/l)	28.25	68.08	13.11	0.05

NAFLF, naturally fermented liquid feed; IFLF, inoculated fermented liquid feed with L. plantarum; SEM, standard error of mean; All lactates and VFA analyses recorded on "as received" basis.

On average, the lactic acid concentration of both NAFLF and IFLF failed to obtain a concentration greater than 100 mmol/l, which is considered to be bactericidal to enteropathogens (Brooks *et al.*, 2003). *L. plantarum* was added to IFLF in an attempt to control the fermentation more rigorously than a natural ferment. However, other end products produced from the IFLF, such as succinic and acetic acids are at concentrations too high for the inoculant to be a viable alternative to naturally fermented liquid feed as both of these end products are bitter and likely to be unpalatable to pigs (Brooks *et al.* 2003).

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Supported in part by Australian Pork Limited.

Increasing Ractopamine Levels in Finisher Pig Diets Improves Growth Performance in Light, Medium and Heavy Boars

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Ractopamine hydrochloride (RAC; Paylean®, Elanco Animal Health, Macquarie Park, NSW) is an approved β-agonist used to improve the production efficiency of pigs. A recent dose-response study in gilts indicated that average daily gain (ADG), feed conversion ratio (FCR) and hot standard carcase weight (HSCW) increased in a linear manner to dietary RAC up to at least 20 ppm, and that responses were similar regardless of starting weight between 65 and 95 kg (Rikard-Bell *et al*., 2007). There has been little research on the responses of intact males (boars) to dietary RAC or how the responses might be affected by starting weight. The objective of this study was to determine the dose response to RAC in light, medium and heavy-weight boars.

Ninety-six individually penned boars were assigned to a 3x4 factorial design with the respective factors being starting weight [light (L; 65kg), medium (M; 80 kg) and heavy (H; 95 kg)] and dietary RAC (0, 5, 10 or 20ppm for 28 d). All diets were formulated to contain 13.9 MJ digestible energy (DE)/kg and 0.62 g available lysine/MJ DE. Pigs were slaughtered at the end of the study and carcase weight was recorded. Data were analysed by analysis of variance.

Table 1. *Effect of starting weight and ractopamine dose on voluntary feed intake (VFI), average daily gain (ADG), feed conversion ratio (FCR), carcase weight (HSCW) and dressing % in finisher boars.*

Weight (W)…	Light				Medium				Heavy					Significance		
Dose (D, ppm)…	0	5	10	20	0	5	10	20	0	5	10	20	SED[1]	W	D	W x D
ADG (kg)	1.09^{a}	1.30^{c}	1.23^{b}	1.24^{bc}	1.22	1.25	1.17	1.28	1.17a	1.20^{a}	1.36^{b}	1.33^{b}	0.063	0.286	0.007	0.022
VFI (kg/d)	2.75	3.06	2.92	3.09	3.10	3.19	3.14	3.18	3.36	3.28	3.56	3.34	0.117	<0.001	0.148	0.075
FCR (kg/kg)	2.54	2.36	2.39	2.50	2.57	2.57	2.68	2.51	2.88	2.77	2.64	2.55	0.127	<0.001	0.289	0.202
HSCW (kg)	71.2^{a}	74.8^{b}	72.4^{a}	75.5^{b}	83.8	85.4	84.3	86.1	96.5^{a}	96.3^{a}	98.5^{a}	99.4^{b}	2.09	<0.001	0.082	0.790
Dressing %	74.4^{a}	73.6^{ab}	72.7^{b}	75.8^{c}	73.5^{a}	74.7^{b}	75.4^{b}	75.1^{b}	76.2^{a}	75.7^{ab}	74.9^{b}	76.1^{a}	0.84	<0.001	0.050	0.034

[1]Standard error of the difference for Weight x Diet, ^{abc}Means within a row and starting weight category with different superscripts differ significantly (P<0.05).

RAC-treated pigs within each weight category grew faster than their respective control counterparts (p=0.007). Within the L starting weight group, pigs on the 5 ppm RAC treatment grew faster than those on the higher RAC doses (P<0.05; Table 1). There was a linear relationship for ADG (P=0.031), dressing % (P=0.045) and HSCW (P=0.018) such that incremental increases of RAC resulted in increases in these traits for all start weight categories. FCR was not altered by dietary RAC (P=0.289), however a recent study (Rikard-Bell *et al*., 2009) indicated that dietary RAC reduced FCR in both sexes with starting weights at 65 kg and RAC treatment for 28 d. These data indicate that for boars of all start weight categories, ADG, HSCW and dressing % increase linearly with increasing dosage of dietary RAC up to at least 20 ppm. However, in light boars ADG was maximised when dietary RAC was included at 5 ppm.

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Supported in part by the Pork CRC Ltd.

Combining a Ractopamine Feeding Regime and Porcine Somatotropin Has Additive Effects on Finisher Pig Performance

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Treatment of finisher pigs with dietary ractopamine (RAC; Paylean®, Elanco Animal Health, NSW) improves daily gain and feed efficiency commensurate with increased protein deposition in finishing pigs (Dunshea *et al.*, 1993). However, effects of RAC on P2 fat deposition are equivocal. Dunshea *et al.* (1993) found no change in gilts and barrows, whilst a trend towards reduced P2 depth was observed in boars fed dietary RAC. Exogenous porcine somatotropin (pST; Reporcin®, OzBioPharm Pty Ltd, Victoria) improves daily gain and feed efficiency and increases the ratio of lean to fat in carcases of boars, gilts and barrows (Campbell *et al.*, 1989). As both technologies are applied at the end of the finishing phase, it is of interest to determine whether a combination of RAC and pST has additive effects on pig performance.

This study involved 48 individually penned pigs in a 2x3 factorial design with 2 sexes (gilts, boars) and 3 RAC dose regimes (0 ppm, 5 ppm, and 5 ppm) for 28 d, respectively, plus daily pST (5mg/ml) injections for the last 14 d (RAC+). All diets were formulated to contain 13.9 MJ digestible energy (DE)/kg and 0.62 g available lysine/MJ DE. Pigs were weighed at -7, 0, 7, 14, 21 and 28 d and voluntary feed intake (VFI) determined at d 7, 14, 21 and 28. Backfat at the P2 site was determined using ultrasonics at d 0, 14 and 28. Body composition was determined using dual energy X-ray absorptiometry (DXA) at d -1, 15 and 29 of treatment. Data were analysed by analysis of variance.

Table 1. *Effect of sex and dietary ractopamine (RAC) for 28 d without porcine somatotropin (pST) and with daily pST (RAC+) over the last 14 d of treatment on growth performance and tissue deposition.*

Sex (S)...		Gilt			Boar				P-Value		
Treatment (T)...		Control	RAC	RAC+	Control	RAC	RAC+	SED	T	S	T x S
ADG	d0 – 14 (kg/d)	1.30	1.36	-	1.49	1.50	-	0.078	0.550	0.005	0.650
ADG	d15 – 28 (kg/d)	0.91	1.08	1.15	1.30	1.20	1.25	0.081	0.260	<0.001	0.025
FCR	d0 – 14 (kg/d)	2.34	2.29	-	2.15	2.13	-	0.101	0.640	0.017	0.800
FCR	d15 – 28 (kg/d)	3.10	2.88	2.17	2.87	2.66	2.43	0.299	0.008	0.710	0.420
Lean	d0 – 14 (kg/d)	0.84	0.94	-	1.15	1.14	-	0.065	0.330	<0.001	0.230
Lean	d15 – 29 (kg/d)	0.64	0.81	0.93	0.93	0.90	1.13	0.070	<0.001	<0.001	0.170
Fat	d0 – 14 (kg/d)	0.33	0.36	-	0.35	0.33	-	0.026	0.710	0.360	0.200
Fat	d15 – 29 (kg/d)	0.28	0.32	0.20	0.33	0.32	0.21	0.033	<0.001	0.280	0.740
ΔP2[1]	d0 -14 (mm)	1.75	1.44	-	2.0	1.9	-	0.46	0.227	0.504	0.770
ΔP2[1]	d14 -28 (mm)	1.75	1.69	0.69	2.3	1.6	0.8	0.42	<0.001	0.548	0.558

[1]ΔP2 calculated by difference between d0 and 14 or d14 and 28; ADG, average daily gain; FCR, feed conversion ratio; SED, standard error of difference.

In the final two weeks RAC and RAC+ increased average daily gain (ADG; P<0.05) and lean tissue deposition (P<0.001) by 0.17 and 0.29 kg/d respectively in gilts and RAC+ treatment increased lean tissue deposition in boars by 0.9 kg/d (Table 1). In the final two weeks RAC reduced change in P2 (ΔP2) in boars (P<0.05) but not fat mass, whereas the RAC+ treatment reduced ΔP2 (P<0.001) and fat tissue deposition (P<0.001) for both sexes. Only the RAC+ treatment reduced feed conversion ratio (FCR). This study demonstrates that RAC treatment alone alters lean tissue deposition in gilts and confirms that RAC treatment reduces ΔP2 in boars, whereas RAC+ further improves lean and fat tissue deposition, ΔP2, and enhances FCR in both sexes.

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Supported in part by the Pork CRC Ltd.

Responses of Finisher Boars and Gilts to Dietary Lysine and Ractopamine

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The minimum total lysine requirement for pigs between 80 and 120 kg has been reported as 0.65 g/kg (National Research Council, 1998) whilst the current recommended lysine requirements for pigs fed a diet supplemented with ractopamine (RAC) is 0.70 g/kg of total lysine (approximately 0.56 g available lysine/MJ digestible energy (DE)). More recently (Rikard-Bell *et al.*, 2009) reported that the improvements in growth performance elicited by RAC were similar for pigs offered diets with 0.56 or 0.65 g available lysine/MJ DE. The aim of this experiment was to investigate the performance responses of finisher pigs offered a wider range of dietary lysine levels and three levels of dietary RAC.

The experiment involved 360 individually penned pigs in a 2x5x3 factorial design comprising two sexes (gilts, boars), five levels of dietary lysine (0.40, 0.48, 0.56, 0.64, and 0.72 g available lysine/MJ DE respectively) and three RAC doses (0, 5 and 10ppm Paylean®, Elanco Animal Health, Macquarie Park, NSW) for 28 d. Pigs were weighed at -7, 0, 7, 14, 21 and 28 d. Voluntary feed intake (VFI) was measured at d 7, 14, 21 and 28. Backfat at the P2 site was determined using ultrasonics at d 0, 14 and 28. Data were analysed by analysis of variance.

Table 1. *Effect of ractopamine (RAC) dose and dietary lysine level on average daily gain (ADG), feed conversion ratio (FCR), voluntary feed intake (VFI), carcase weight (HSCW) and P2 in finisher pigs.*

	Sex (S)		RAC (ppm)			Available lysine (L; g/MJ DE)						Significance		
	Gilt	Boar	0	5	10	0.40	0.48	0.56	0.64	0.72	SED	S	RAC	L
Start Wt (Kg)	64.3	65.4	64.8	64.8	64.9	64.7	65.0	64.6	64.9	64.9	1.69	0.009	0.964	0.981
ADG (kg/d)	1.07	1.18	1.08	1.14	1.16	0.98	1.09	1.18	1.18	1.20	0.070	<.001	0.002	<.001
FCR	2.54	2.27	2.49	2.38	2.35	2.80	2.44	2.25	2.27	2.27	0.135	<.001	0.005	<.001
VFI (kg/d)	2.67	2.65	2.62	2.68	2.68	2.69	2.63	2.62	2.66	2.70	0.140	0.502	0.333	0.529
HSCW (kg)	77.9	79.4	77.9	78.9	79.2	76.4	78.4	79.2	79.8	79.4	2.41	0.015	0.175	0.007
P2 (mm)	10.5	10.3	10.6	10.3	10.4	10.8	10.2	10.5	10.3	10.2	1.27	0.451	0.755	0.776

SED. Standard error of difference; DE digestible energy;

The results indicate that 0.56 g available lysine/MJ DE is sufficient to maximize ADG, FCR and carcase weight in boars and gilts (Table 1). Increasing levels of dietary lysine increased ADG in a linear (P<0.001) manner. Similarly a linear (P<0.001) response occurred for FCR with increasing dietary lysine. Likewise increasing dietary RAC further improved ADG (P<0.001) and FCR (P=0.002) linearly. A notable interaction (P=0.016) between dietary lysine and RAC for FCR occurred. The response to 5 ppm dietary RAC diminished on diets containing 0.64g and 0.72g available lysine/MJ DE, however, these diets supported a response when supplemented with 10 ppm RAC. Responses to dietary RAC were noted when dietary lysine was at or below the current recommendations for RAC diets. HSCW increased with increasing dietary lysine whilst dietary RAC tended to increase HSCW linearly (P=0.075). A Sex x RAC interaction (P=0.027) occurred for carcase P2. The higher RAC dose reduced carcase P2 in boars but not in gilts. These data suggest that 0.56 g available lysine/MJ DE is optimal for maximising ADG, FCR and carcase traits in boars and gilts between 65 and approximately 90kg liveweight whilst RAC improves all traits across a wide range of dietary lysine levels.

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Supported in part by the Pork CRC Ltd.

Effects of Fatty Acid Source on Performance and Carcase Composition of Finisher Pigs

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Previous work in chickens has shown that body composition, energy balance and metabolism may be affected by manipulating the n-3:n-6 polyunsaturated fatty acid (PUFA) ratio provided in the diet. More specifically, the inclusion of the long chain n-3 PUFA influences glucose and lipid metabolism and decreases body fat mass (Newman *et al*., 2002). The objective of this study was to investigate the effects of fatty acid source on the growth and carcase composition of grower/finisher pigs.

Forty-seven female hybrid (mainly Large White x Landrace) pigs were randomly allocated to individual grower pens at 22.5±1.09 kg liveweight. The pigs were maintained at 23 ± 1°C and a 12 hour light period (0600 – 1800h) in two air spaces with two rooms per air space and each treatment group represented in each room. Pigs were fed diets containing 30g/kg of either n-3 PUFA (Salmate®, Feedworks Pty Ltd, Romsey, VIC), n-6 PUFA (safflower oil) or saturated (tallow) fatty acids. Diets were formulated to be isoenergetic with 13.8 MJ digestible energy and 8.3g available lysine/kg. Pigs were fed *ad libitum* and feed was offered to maintain approximately 2kg in each trough. Feed residues and body weights were recorded weekly for 5 weeks (approx 97 – 132 d of age). Water was provided *ad libitum* via nipple drinkers. Pigs were subjected to computed tomography (CT) scanning at approximately 120 d of age for determination of body composition. On d 135, a subsample of pigs from each treatment group had cannulae inserted into the external jugular vein via the ear vein. Serial blood samples were collected at hourly intervals for 12 hours on d 137. Plasma insulin and leptin concentrations were determined by radioimmunoassay and glucose and non-esterified fatty acids determined enzymatically. A linear mixed model was fitted to the data using a restricted maximum likelihood (REML) procedure in Genstat.

Table 1. *Treatment means for computed tomography (CT) determined carcase composition at day 120 and production values for the finisher period.*

	CT determined values				Finisher Period			
Treatment	Muscle (%)	Fat (%)	Bone (%)	P2 (mm)	Feed:gain (kg:kg)	ADG (g/d)	Final weight (kg)	Dietary n-6:n-3
Saturated	59.1	18.1	10.0	8.8	2.52	1037[a]	105.14[a]	11.6
n-3 PUFA	58.7	19.1	9.7	8.5	2.53	1041[a]	105.81[a]	6.2
n-6 PUFA	59.1	18.6	9.2	8.1	2.57	966[b]	92.36[b]	18.2
SEM	0.76	0.79	0.17	0.04	0.03	25.1	1.59	
P value	NS	NS	NS	NS	NS	*	**	

[ab]Means within columns with different superscripts differ significantly (P<0.05); NS, not significant; *, P<0.05; **, P<0.01; SEM, standard error of mean; ADG, average daily gain; PUFA, polyunsaturated fatty acids.

Pigs from the n-6 PUFA treatment group had significantly lower average daily gain (ADG; P<0.05) and final body weight (P<0.01) in the finisher period compared to pigs from the saturated and n-3 PUFA groups (Table 1). However, no significant differences were found for feed:gain, body composition and P2 as determined by CT at d 120. In addition, no significant differences were found for circulating plasma glucose, insulin, NEFA and leptin concentrations between treatment groups (data not shown). No evidence was found in this study to support the hypothesis that carcase composition could be manipulated by dietary fatty acids. However ADG and subsequent final liveweight were affected by fatty acid source.

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Supported in part by the Pork CRC Ltd.

Economic Benefits of Feeding High Cost Weaner Diets are Maximised When Offered to Pigs Less Than 6.5 kg at Weaning

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Growth performance is typically reduced in the period immediately post weaning while the piglet adapts to the new environment and feed source. This reduction in growth performance can negatively affect lifetime performance (Tokach *et al*., 1992). The use of high cost weaner diets during the first three weeks post-weaning is extensively practised to reduce the growth check and enhance performance to slaughter. It is hypothesized that the weight of the piglet at weaning will influence the growth performance and economic benefits from such a feeding program. Therefore, the aim of this study was to evaluate the benefits of feeding high cost weaner diets during the period immediately post weaning for pigs of different weaning weights.

Seven hundred and twenty weaners (360 males and 360 females, Large White x Landrace, PrimeGro™ Genetics, Corowa, NSW) were selected at weaning (27 d of age) and allocated to pens of 10 pigs of the same sex. Pens were allocated to a 3x2 factorial experiment with the respective factors being weaning weight (light: pigs < 6.5 kg; medium: 6.5 to 8.0 kg; heavy: > 8.5 kg) and weaner feeding program (high or low cost). Diets fed to both the high and low cost treatment groups over the initial two weeks post weaning contained 15.1 MJ digestible energy (DE)/kg and 0.90 g available lysine/MJ DE. The high cost diets utilised cooked cereals, skim milk powder, Soycomil® (ADM Australia, Bondi Junction, NSW) and 280g/kg whey powder. The low cost diets contained wheat, lupin kernels, canola meal and 80g/kg whey powder. All diets also contained meatmeal, fishmeal, bloodmeal and soybean meal. Common diets were fed to both treatment groups from week three post weaning to slaughter. Pigs were commercially slaughtered at 123 d of age and carcase characteristics recorded on 240 pigs. Differences due to the effects of weaning weight and feeding program were analyzed using residual maximum likelihood mixed model analyses, and included the fixed effects of weaning weight and feeding program and the random effect of replicate. The experimental unit was the pen. All analyses were performed using Genstat 10th Edition.

Table 1. *Influence of weaning weight and feeding program on weight at slaughter and economic returns.*

Weaning weight…	Light		Medium		Heavy			P value	
Feeding program…	High	Low	High	Low	High	Low	SED	FP	W
Weaning weight (kg)	5.51	5.47	7.27	7.25	9.54	9.59	0.115	0.61	<0.001
Weight 123 d (kg)	91.2	88.0	98.5	95.6	101.1	101.4	1.10	0.06	<0.001
Carcase weight (kg)[1]	66.0	64.5	71.8	71.1	75.8	77.4	1.71	0.40	<0.001
Total feed costs ($/pig)[2]	76.5	75.0	83.6	78.8	86.4	85.0			
Feed cost/kg gain ($/kg)[2]	0.89	0.91	0.92	0.89	0.94	0.93			
Return on carcase weight ($)[1]	211.2	206.4	229.7	227.5	242.5	247.7			

[1]Carcase data on a subset of animals. Return on carcase weight calculated at $3.20/kg; [2]Wean to finish; FP, feeding program; W, weight.

Growth performance during the initial 6 d post weaning was influenced by diet complexity, with the pigs offered the high costs diets gaining faster (74.0 and 52.3 g/d respectively; P=0.031) during this time. There were no other main effects of diet complexity on growth performance through to slaughter. Weaning weight had a profound influence on carcase weight, with the pigs classified as 'heavy' at weaning increasing their weight advantage at slaughter (Table 1). The results of this investigation clearly indicate that weaning weight does influence the response to high cost weaner diets. Feeding the high cost diets to heavy weaners was not economical, suggesting that this program should be focused on the light weight weaners to maximise returns.

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Supported in part by the Pork CRC Ltd.

Creep Feed Composition Does Not Influence Lifetime Growth Performance of Pigs Weaned at 22 or 29 Days of Age

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Weaning of the piglet from the sow commonly results in a growth check immediately post weaning, while the piglet adapts to the new conditions and feed source. Offering solid creep feed during lactation aims to reduce this post weaning growth check. Several studies have outlined the benefits of creep feeding, however these benefits are not always observed and may not influence lifetime performance. Piglets weaned at an older age are likely to consume more creep feed than those weaned younger, therefore it is hypothesised that offering creep feed during lactation may have fewer benefits for early weaned animals. In addition, there is evidence to suggest an interaction between weaning age and the ingredient composition of the creep diet (Callesen *et al.*, 2007). The aim of this experiment was to determine the impact of offering different creep diets during lactation on lifetime growth performance and carcase composition of pigs weaned at 22 or 29 d of age.

Ninety-six litters were selected at farrowing over a six week period (4 gilt litters and 12 sow litters/week). Litter size was standardised to 10 for gilts and 12 for sows. Litters were randomly allocated within parity to a 2 x 2 factorial design with the respective factors being weaning age (WA, 22 or 29 d) and creep feed (CF, simple (S) or complex (C)). Creep diets contained 15.0 MJ digestible energy (DE)/ kg and 0.85 g available lysine/MJ DE. The complex creep diet utilized fishmeal, milk proteins, meatmeal, bloodmeal and Soycomil® (ADM Australia, Bondi Junction, NSW) as protein sources, while the simple creep diet utilised peas, soybean meal, meatmeal and bloodmeal, creating a less expensive diet. All other additives remained constant. Creep feed was offered from 9 d of age until weaning. Post weaning, pigs were housed in groups with pigs of the same sex and CF x WA treatment. Growth performance was measured from birth to 152 d of age. Carcase weight and P2 was obtained on 720 pigs. Differences due to the effects of CF and WA were analysed using residual maximum likelihood mixed model analyses, and included the fixed effects of CF and WA and the random effect of replicate. The experimental unit for the lifetime performance analyses was the individual animal, while the finisher pen is the unit for all carcase data. Analyses were performed using Genstat 10th Edition.

Table 1. *Influence of weaning age and creep feed composition on average daily gain (g/d).*

Weaning age…	22 days of age		29 days of age		SEM	Significance		
Creep Feed…	S	C	S	C	CF x WA	CF	WA	CF x WA
Creep intake (g)[1]	487	265	1023	633	57.0	0.004	<0.001	0.33
Birth to 152 d (g/d)	619	613	618	601	6.0	0.24	0.079	0.56
Carcase weight (kg)	76.5	75.5	74.3	73.9	0.92	0.48	0.077	0.74
Carcase P2 (mm)[2]	8.8	9.0	8.6	8.4	0.18	0.95	0.023	0.20

[1]Average total creep intake per litter from d 9 to weaning based on feed disappearance. [2]Carcase weight used as a covariate; S, simple; C, complex; WA, weaning age; CF, creep feed; SEM, standard error of mean.

Estimated creep feed intake was generally small and variable regardless of creep feed composition. Estimated total creep feed intake from 9 d of age to weaning was greater in the litters offered the simple creep diet compared to the complex diet (776.3 and 461.4 g in total, respectively, P=0.004). Creep feed composition had no influence on pre-weaning growth performance (average daily gain from 9 d of age to weaning: 234.6 and 231.3 g/d respectively for the simple and complex diet, P=0.641). Creep feed composition did not influence lifetime growth performance, carcase weight or P2 (Table 1). These results suggest that at low creep feed intakes, the use of complex creep diets pre-weaning does not improve lifetime performance of pigs weaned at either 22 or 29 d of age compared to pigs offered a simple creep diet.

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Supported in part by the Pork CRC Ltd.

Dietary Evaluation of a Yeast Extract for Weaner Pigs

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Diets for weaner pigs are formulated to contain a minimum amount of lactose often derived from whey powder (60% lactose) to enhance feed intake and provide a transition from a milk diet to a starch-based diet over the first three weeks post weaning. A yeast-based product derived from the processing the cell contents (yeast extract) from a specific strain of the *Saccharomyces cerevisiae* yeast with proteolytic enzymes (Nupro™, Alltech Biotechnology, Dandenong South, VIC) has been suggested as a raw material that can enhance gut development of the weaner pig. The hypothesis of this experiment was that yeast extract included in diets for 39 d post weaning will improve performance of weaner pigs against a standard weaner dietary program (containing whey powder in the first 19 d only).

A total of 800 entire male pigs (Large White x Landrace (PrimeGro™ Genetics, Corowa, NSW)) were selected at 4 weeks of age (weaning) over a four week period (200/week) with an average weight of 7.7±0.21kg (mean ± standard error (SE)) and housed in a commercial weaner facility in pens of 10 pigs per pen (0.5m^2/pig). Within time blocks, pens were randomly allocated to four dietary program treatments. The diet program of treatment A involved diets of 14.9 MJ digestible energy (DE)/kg and 13.4 g/kg available lysine containing 100 g/kg whey powder offered between weaning and d 19 (period 1) and diets of 14.5 MJ DE/kg and 12 g/kg of available lysine offered from d 19 to 39 post weaning (period 2). Treatment B was a similar program except whey powder was not formulated into the period 1 diet. Treatment C diets had included 100 g/kg whey powder in period 1 and 40 g/kg yeast extract formulated into both periods. Treatment D diets contained no whey powder in period 1 and 40 g/kg yeast extract formulated into both periods. All pigs were offered treatment diets *ad libitum* in a pelleted form. Data were subjected to a one-way analysis of variance with the pen as the experimental unit.

Table 1. *The growth performance for 0-19 d post-weaning (period 1) given four dietary regimes (n=20).*

Treatment[1]	Yeast Extract (g/kg)	Whey powder (g/kg)	Average daily gain (kg/d)	Average daily intake (kg/d)	Feed conversion ratio (kg/kg)
A	0	100	0.293[a]	0.330[a]	1.13[a]
B	0	0	0.202b	0.285[b]	1.43[b]
C	40	100	0.281[a]	0.321[a]	1.15[a]
D	40	0	0.269[a]	0.323[a]	1.20[a]
P value			<0.001	0.022	<0.001

[a,b]Means in a column with different superscripts differ significantly (P<0.05); n, number of replicates; [1]Treatments formulated to 14.9 MJ digestible energy/kg and 13.4 g/kg available lysine; A, 100 g/kg whey, 0 g/kg yeast; B, 0 g/kg whey, 0 g/kg yeast; C, 100 g/kg whey, 40 g/kg yeast; D, 0 g/kg whey, 40 g/kg yeast.

The results of the experiment show that whey powder in diets of pigs significantly improved the growth and feed efficiency of weaner pigs in the absence of yeast extract. The inclusion of yeast extract in a diet without whey powder improved the performance of the pigs significantly during period 1 (Table 1). Over the entire experiment contrast analysis showed piglets fed the diets containing yeast extract were heavier than pigs that did not receive yeast extract in their diets (23.3±0.6kg, 26.0±0.6kg (mean±SE), P<0.001) with a better feed efficiency (1.43±0.03, 1.32±0.03 (mean±SE), P<0.001) and feed intake (0.57±0.02kg, 0.62±0.02kg (mean±SE), P<0.001).

Inclusion of whey powder or yeast extract in the diet for the first 19 d post weaning improved growth rate and feed intake. Continued use of yeast extract during period 2 also resulted in improved performance, possibly as a result of enhanced gut integrity and subsequent nutrient absorption.

Entire Male and Female Pigs Have Different Available Lysine: Energy Requirements From 20 to 50 kgs Liveweight

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Through genetic selection pigs now deposit relatively more protein and less fat than they did twenty years ago, primarily because of the pressure from consumers to reduce the amount of subcutaneous fat on pork products. As a consequence, the requirement for amino acids relative to energy has slowly increased over this time. It has been several years since experiments to determine the requirement for amino acids relative to energy have been conducted on Australian pig genotypes. The hypothesis of this experiment was that grower pigs will respond to increasing levels of available lysine (Av Lys) per MJ digestible energy (DE) by having an increased growth rate and improved feed conversion ratio, until a plateau is reached at their genetic potential.

Four hundred and twenty pigs (Large White x Landrace x Duroc) were used in a 2x5 factorial experiment. The main treatments were: i) sex (entire males and females) and ii) available lysine (0.6, 0.7, 0.8, 0.9 and 1.0 g Av Lys/MJ DE). The experimental diets were formulated to contain 14.6 MJ DE/kg and were based on the ideal pattern of amino acids. Diets were fed from 22 to 53 kgs liveweight (LW) and the pigs were housed in groups of 7. The pigs were weighed and voluntary feed intake was recorded weekly. To estimate lysine requirements, a spline model was fitted to the data (Auldist *et al*. 1997). Lysine requirements were estimated at either 95% (for ascending curves) or 105% (for descending curves) of the high-lysine plateau (King *et al*. 2000). The main effects of sex were analysed by analysis of variance.

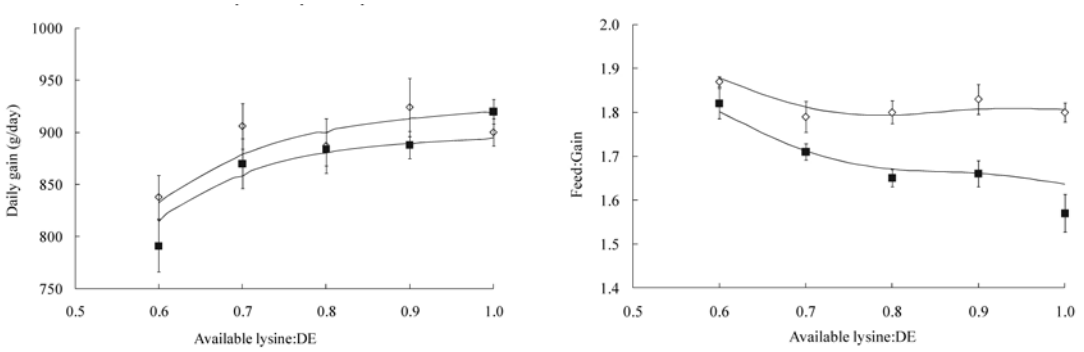

Figure 1. *Difference in daily gain and feed:gain for entire male (■) and female (◇) pigs fed varying levels of available lysine:dietary energy from 22.3 to 53.1 kgs liveweight (n=5; mean ± standard error of the mean).*

The lysine requirement to ensure 95% of plateau daily gain was 0.76 g Av Lys/MJ DE for entire males and 0.74 g Av Lys/MJ DE for females while the lysine requirement to ensure 105% of plateau feed to gain was 0.84 g Av Lys/MJ DE for entire males and 0.78 g Av Lys/MJ DE for females. The entire males had a lower feed:gain and hence were more efficient than the females from 22 to 53 kg ($P<0.001$).

These findings indicate that the minimum lysine requirements for entire males and females are 0.78 and 0.70 g Av Lys/MJ DE, respectively. The lysine requirements are higher than used previously for this genotype and suggest that there may potentially be some feed savings in separating entire males and females in this weight range. The feed:gain values obtained in this experiment demonstrate that Australian genetics are capable of achieving results that compare favourably with other genotypes world wide (R. Campbell, *pers comm.*).

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Supported in part by the Pork CRC Ltd.

CHAPTER 3

Consumer Preferences

Extrinsic Factors Affecting Consumer Purchasing Decisions for Pork

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There is increasing interest among both consumers and policy makers towards food safety, food quality, food related health issues and food production methods and their associated effects on the environment. Key drivers for this increasing interest are consumers' income growth, urbanisation, intensification of food production methods and on-going highly publicised food scares, including those from bovine spongiform encephalopathy (BSE), dioxin and melamine. These drivers are also responsible for the growth in extrinsic cues aimed at the consumer decision making process for meat which include branding, label information, origin, quality marks and other information about the products value to the consumer. This paper assesses the various extrinsic cues and their increasing role in the quality perception of pork in comparison to the more traditional intrinsic quality cues.

Food Quality

The drive to optimally align quality of food with consumer demands, expectations, and desires arises from the consumer's subjective evaluation of quality (Bryhni *et al.*, 2002). Food quality may be defined in terms of either a holistic or an excellence approach (Grunert, 2005). The holistic approach includes within the concept of food quality "all the desirable characteristics a product is perceived to have". By contrast, the excellence approach views food quality as referring only to characteristics that pertain to a higher, more restrictive or "superior" specification of the product. The holistic approach leaves wider scope for interpretation in which quality can mean conforming to standards (including standards pertaining to the environment, local specialties, organic production, ethics, and even taste and smell) and it can refer to subjectively perceived quality attributes (Dries *et al.*, 2006). Quality in the holistic approach involves the entire production process, from raw materials, processing and packaging up to consumption of the product and these are referred to as extrinsic properties. Within the excellence approach, food quality can be defined as an intrinsic property of food which meets a pre-standard requirement determined by nutritional, hygienic, organoleptic and functional properties of the food (Abalaka, 1999).

There have been various attempts to define pork quality. A suitable definition for pork quality must encompass all the different factors involved from the producer to the final consumer. Pork quality can thus be defined as "the totality of all properties and characteristics of pork that are important to its nutritional value, acceptability, human health and the processing of pork" (European Organisation for Quality Control, 1976). Hofmann (1987) classified pork quality characteristics into four main quality groups - technological, nutritional, hygienic and organoleptic. Technological characteristics include those factors that determine the suitability of pork for preparation and packaging for distribution, as well as for cooking and processing into various products and for storage. Hygienic characteristics are concerned with the presence or absence of microorganisms, drugs and pesticides. Nutritional characteristics deal with the chemical composition and nutritional properties of the pork. Organoleptic characteristics include the appearance (colour, marbling, external fat and exudate) and the sensory quality (aroma, tenderness, juiciness, and flavour). Whilst technological, nutritional and hygienic characteristics of pork are very important, the organoleptic characteristics such as the sensory quality of the product are the main factors that influence the consumer to repurchase that pork product.

Food quality can range from "conforming to technical specification" and being objective and measurable (Zeithaml, 1988) to "the perception from the viewpoint of the consumer" that transcends measurement and makes quality a subjective assessment dependent on perceptions, needs and goals of individuals (Northern, 2000). These can be further categorised as "must haves" (have to be present in order for the product or service to be assessed as acceptable), and "wants" (depends on the wishes or expectations that influence choices). In the past, quality was mainly a question of "must haves" where as it now also includes a large proportion of "wants".

Food Quality Attributes

Depending t which point the consumer can determine the quality attribute, dimensions of quality are commonly categorized into search, experience and credence characteristics (Darby and Karni, 1973). A "search" quality such as appearance can be evaluated before the meat is purchased, an "experience" quality such as taste is usually first evaluated after the purchase and a "credence" quality such as animal welfare, is often not evaluated but is based upon trust in the

information provided (Table 1). Food products usually rely on a limited number of search characteristics because in most cases, experience is not possible before purchase. Exceptions would be the tasting of a cheese or processed meat prior to purchase. In order to make a choice therefore, consumers will develop expectations about quality that can only be realized after consumption, although this is often limited in the case of credence characteristics.

Table 1. *Attributes used by consumers to assess product quality (after DEIAgra, 2005).*

Attributes	When Applied	Description
Search	When purchasing the product	Characteristics that can be identified from the outside such as look, colour, shape, smell, hardness, brand, packaging, price, product certificates, etc.
Experience	After consumption	Attributes that can be experienced such as tasty, savoury, tender, sweet, easy to prepare, etc.
Credence	Neither before or after consumption	Attributes related to trust including health, nutritional value, environmentally friendly production, production respecting animal welfare, ethical aspects of production process, presence/use of genetically modified organisms (GMOs), social responsibility, etc.

Quality Cues

Before purchase, quality expectations are mainly based upon search attributes known as quality cues (Steenkamp, 1989). Bredahl *et al.*, (1998) showed that, in the case of fresh meat, end consumers demand attributes such as tenderness, taste and juiciness (ie. criteria which can be experienced during consumption). However, the same consumers use quality cues such as colour, fat levels, cut, trim and meat juice to predict these attributes. Consumers therefore use quality cues to predict the attributes they desire in a product and quality attributes to predict what they want. Caswell *et al.*, (1998) grouped these attributes according to whether they are process attributes or product attributes. Northern (2000) has adapted this further to indicate the types of attribute sub-sets which exist and examples of attributes within each sub-set (Table 2). This list is by no means exhaustive but helps to identify those attributes which are affected by quality policies and assurance initiatives. A product attribute that should also be considered within the list is water holding capacity which in turn affects drip loss which is a sensory attribute. The water holding capacity will also impact tenderness, juiciness and flavor as well as functional properties such as the products ability to hold water during curing.

Table 2. *Process and product attributes (after Northern, 2000).*

	Product Attributes				
Process Attributes	Food Safety	Nutrition	Sensory	Functional	Image
Animal Welfare	Pathogens	Fat content	Taste	Convenience	Snob value
Biotechnology	Residues	Calories	Texture	Storage	
Organic production	Hormones	Fibre	Tenderness		
Traceability	Food additives	Sodium	Juiciness		
Growth enhancers	Toxins	Vitamins	Freshness		
Feed	Genetic modification				
	Fat/cholesterol				
	Physical contaminants				

Product attributes may be split into sub-sets, including food safety, nutrition, sensory, functional and image attributes. Process attributes form part of the production process, for example, animal welfare and systems of production. In some instances process attributes affect the physical product, but in other cases they do not. For example, it is unlikely that animal welfare will alter the physical product to the extent it can be detected by the consumer but they may purchase the product to "consume" these process attributes and create a feeling of wellbeing. Likewise, consumers cannot detect the presence of growth hormone residues in meat but reduce purchase after having the information about their presence in meat or milk disclosed. (Grobe and Houthitt, 1995).

Intrinsic and Extrinsic Cues

There is a significant distinction between intrinsic and extrinsic quality cues (Steenkamp, 1989; Ophuis and van Trijp, 1995). Intrinsic cues are part of the physical product. They cannot be changed without also changing the physical product itself, in contrast with extrinsic cues which are predominantly marketing related. In the case of food, intrinsic cues include visual cues such as colour, fat trim and marbling, in addition to non-visual cues such as smell. Extrinsic cues include price, brands, labels, shop, country-of-origin, and information. Northern (2000) stated that extrinsic cues have the capacity to communicate both experience and credence attributes. In contrast, intrinsic cues are not able to communicate credence attributes; hence, the only way of successfully predicting credence attributes will be through the use of extrinsic cues. However, intrinsic cues will be more successful in predicting experience attributes (Marreiros and Ness, 2009). Table 3 presents the two quality cue categories and gives examples of cues likely to be found in each category, for fresh meat.

Table 3. *Various categories of quality cues for fresh meat (after Northern, 2000).*

Intrinsic cues	Extrinsic cues		Examples of information/labels
Colour	Package materials (aids intrinsic cue)	→ {	"Best before" date
Smell	Information/labels		Price
Leanness	Information/labels		Cut
Marbling	Place of purchase		Tenderness
Cut			Origin
Juiciness			Welfare
			Size/weight
			Brand name

Northern (2000) demonstrated the suggested relationships between attributes and the two types of cues (Figure 1). Extrinsic attributes can thus be modified with marketing efforts, without changing the product itself, and influence how the intrinsic attributes are perceived. The credence attributes category therefore includes all the characteristics related to places and methods of production, use of certain substances and, in a broad sense, the level of safety associated with the product.

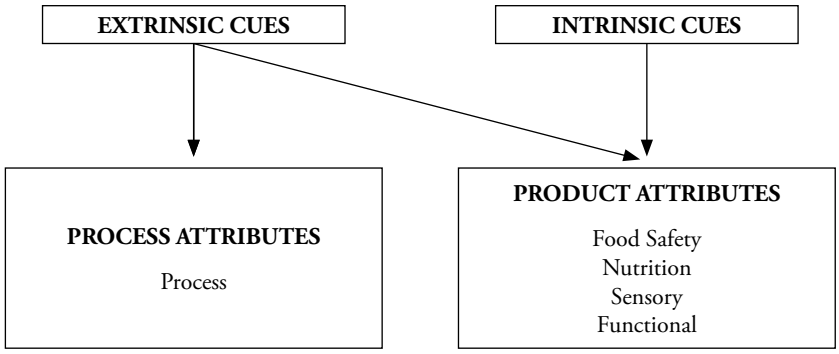

Figure 1. *Relationships between attributes and the two types of cues (after Northern, 2000).*

Credence Attributes: Production, Environment and Marketing

Production characteristics refer to the way a food product is manufactured. In meat production this can encompass a wide range of different welfare systems (intensive, free range, organic etc) as well as feed related issues such as the use of antibiotics, genetically modified organisms and animal by-products.

Environmental aspects reflect the increasing concerns associated with environmental pollution and climate change. Pollution controls are evident in many countries, restricting the level of excretion of minerals and nitrogen. Climate change concerns have impacted not only waste management (packaging and water recycling etc) but also the distance products travel and the carbon and nitrogen footprints for the various systems of animal production.

Marketing is a complex process communicated through branding, labeling and price. These are the drivers for consumer perception and the expectation associated with the extrinsic quality attributes. Of all the cues consumers are exposed to, only those, which are perceived, will have an influence on expected quality. The cues consumers are exposed to and those they perceive are affected by the shopping situation, including the amount of information in the shop, whether purchases are planned or spontaneous and the pressure of time while shopping. According to Becker (1996) there are three decision frames for the consumer when assessing the quality attributes of a product, including:

1. The decision under certainty, at the point of purchase;
2. The decision under risk, when the consumer assumes quality attributes will be realised later at the point of consumption; and
3. The decision under uncertainty, where the consumer may not be able to establish the quality attribute independently.

An example of the first frame, decision under certainty, is the size of a piece of meat. The consumer can be sure of the quality attribute through inspection at the time of purchase. These attributes are referred to as inspection quality attributes (IQA). An example of the second frame, decision under risk, is tenderness. The consumer cannot assess this attribute until the product has been consumed after purchase. These attributes are referred to as experience quality attributes (EQA) to denote those quality attributes only experienced through eating. An example of the third frame, decision under uncertainty, is "welfare friendly" systems, in which the consumer has no means to establish whether the product has these quality attributes but has to rely on third party information. As in the case of EQA, the consumer has to rely on cues but, in the case of credence quality attributes (CQA) trust has to substitute for personal experience (Becker, 2002).

The evaluation of meat quality plays a major role for consumers in determining meat purchases. Several studies show that in many countries aside from intrinsic characteristics referring to those of the physical product, extrinsic meat characteristics, such as the origin or environmental aspects, are becoming increasingly important to consumers. Whether cues or attributes, the information content can be categorized according to the three decision frames. In a study by Glitsch (2000), it was demonstrated that the place of purchase is regarded by consumers as a primary indicator of both food safety and eating quality. Consumers from six different European Union countries were asked to rate the "quality in the shop" characteristics (Figure 2) in respect to their helpfulness in assessing meat quality while shopping for beef, pork and chicken (Table 4).

There were some notable differences between the countries, however for both beef and pork, the place of purchase and country of origin extrinsic characteristics were found to be among the most helpful. Price was generally regarded as the least helpful quality indicator. Visual intrinsic characteristics such as colour and fat content are the most significant cues, however for most consumers these do not provide a reliable prediction of the eating quality of the meat.

This study undertaken by Glitsch (2000) was repeated by Ngapo *et al.*, (2003) specifically for pork meat, across a range of European countries, and they also found that the four factors considered indicators of good pork quality were fat cover, price, country of origin and place of purchase.

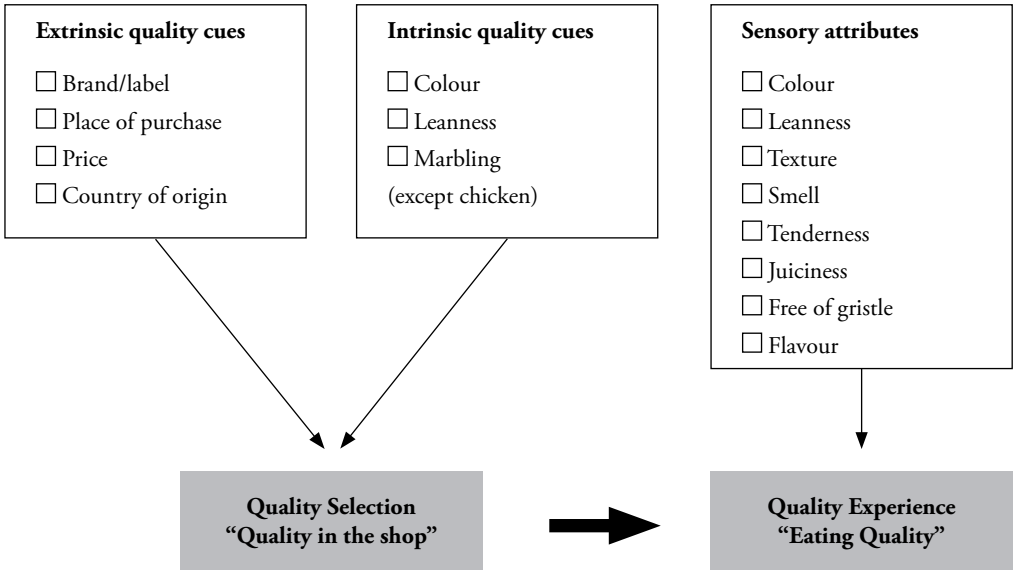

Figure 2. *"Quality in the shop" meat characteristics rated by European Union consumers (after Glitsch, 2000).*

Ngapo *et al.*, (2005) later conducted one of the few global preference studies specific to fresh pork. Digital photographs of pork chops were presented to 12,590 consumers from 23 different countries around the world and they were asked to express their preference based on varying degrees of fat cover, colour, marbling and drip. Across all countries, colour was the most consistently chosen attribute followed by marbling, fat cover and drip. However, the consistency of choice for colour showed the largest variation among countries compared with the other characteristics. The Australian consumers were by far the most consistent with 84% giving consistent choices in contrast to only half of the Yugoslavian consumers. Australian (73%), Irish (67%) and Polish (63%) consumers showed the strongest preference for the light red pork whilst the Taiwanese consumers (66%) showed a strong preference for the dark red pork. These results for pork corroborate well with those obtained in Belgium by Verbeke *et al.*, (2004).

Table 4. *Significant differences in the helpfulness of "quality in the shop" characteristics including results of a t-test for beef and pork (after Glitsch 2000).*

Country...	Germany	Ireland	Italy	Spain	Sweden	United Kingdom
Beef						
1st rank	Origin	Colour	Colour	Place	Colour	Colour
	Place	Place	Place	Colour	Origin	Leanness
		Leanness			Label	
		Origin				
2nd rank	Leanness	Marbling	Origin	Leanness	Marbling	Place
	Colour	Label		Origin		Marbling
				Marbling		Label
				Label		
3rd rank	Marbling	Price	Marbling	Price	Leanness	Price
	Label		Label			Origin
			Leanness			
4th rank	Price		Price		Place	
					Price	
Pork						
1st rank	Place	Colour	Colour	Colour	Colour	Colour
		Leanness	Place	Place	Origin	Leanness
		Place				
2nd rank	Origin	Origin	Origin	Leanness	Label	Place
	Colour		Marbling	Marbling		
	Leanness		Label	Label		
			Leanness	Origin		
3rd rank	Label	Label	Price	Price	Marbling	Marbling
	Marbling	Marbling				Label
						Price
4th rank	Price	Price			Leanness	Origin
5th rank					Place	
6th rank					Price	

In an earlier study specific to pork, Grunert *et al.*, (2002) presented a consumer group with 22 cues and asked them to rank them in terms of their knowledge of the cue and by perceived importance for pork quality. The results indicated that of the top five cues as measured by both knowledge and importance, none of them were related to sensory quality but were, instead, related to the technological, nutritional, and hygienic quality of pork. Grunert (2002) refers to quality uncertainty, which consumers appear to experience while purchasing meat. Consumers would rather trust an expert (the butcher or supermarket) than forming a quality expectation on their own. By implication therefore there is potential to exploit the point of sale information to enhance sale opportunities by means of branding.

Branding

For CQA the consumer substitutes trust for experience. Brand name therefore is a special cue for the quality of foods since it allows consumers to make use of their previous experience (Grunert, 2001). In the absence of branding or labeling the only way consumers would be able to identify an improvement in the eating quality of a meat product is by its visual appearance and this has already been shown not to be a reliable cue. Unbranded products therefore, such as fresh meat, make it much more difficult for the consumer to form quality expectations.

The consumer decision making process involves a series of related and sequential stages of activities. In the case of meat products, the process begins with the recognition of the need to satisfy a want for meat of a perceived quality. It becomes a drive from which the consumer begins a search for information. This search gives rise to various alternatives and finally the purchase decision is made. Finally, the consumer will then evaluate the level of satisfaction in what is termed post purchase behaviour.

This behavior of the consumer is very important for the marketer because the consumer displays brand preference only when that brand lives up to their expectation. Brand preference naturally leads to repeat sales. But, if the used brand does not yield the desired satisfaction, negative feeling will occur and that will lead to the formation of negative attitudes towards the brand. Marketers try to use this phenomenon to attract users of other brands to their own brand. If a branded product develops a history of constant and reliable quality, the brand will be associated with a certain quality positioning in the mind of the consumer and consumers may develop preference for the brand, and brand equity can develop (Erdem and Swait, 1998).

The branding of pork products in Europe has undoubtedly been over-shadowed by the rapid growth in retailer private labels. As a result, it has become extremely difficult for any one company to create a successful branded fresh pork product at a national level. The rise of private label brands by the retailers has been relatively unchallenged in the meat sector due to the lack of competition when compared to certain other grocery sectors. Within the retailer private label category there is usually a choice of products based either on price (value) or quality (premium), thus catering for a wide range of consumers within the same store. This has been an extremely important factor during the current economic climate. A recent study in the United Kingdom (UK), (BPEX, 2009a) has found that despite the current economic downturn, red meat sales have remained robust and pork is performing well above the average. There has, however, been a switch in consumer retailer brand choice based upon price and perceived value for money such that where pork may have been regarded in the past as 'the cheap alternative' to other red meats, it is increasingly being regarded as the value for money meat of choice.

Brand awareness is a prerequisite to strong brands. The other dimensions are loyalty, perceived quality and associations. Brand awareness is reflected in the consumer's ability to identify the brand under different circumstances and is considered to be of particular importance in low involvement product categories such as groceries (Anselmsson *et al.*, 2006). In the case of private label the brand is the retailers name and therefore awareness is usually very high among consumers.

Price premium is considered to be the most useful measure of brand equity (Aaker, 1996), with the motivation that each dimension of the brand equity should have an impact on the price consumers are willing to pay for the brand. Different retailers target different socio-economic groups of consumers and hence the margins will vary according to brand (store) reputation and whether the products are value or premium range. The price premium does not necessarily fully correlate with actual consumer prices, since numerous other factors influence the prices consumers have to pay in the store (Anselmsson *et al.*, 2006). Therefore actual consumer prices are not a satisfactory measure of brand equity. At the farm level it is a common complaint amongst pork producers that they are unable to achieve higher prices based upon the systems of production and type of products they are supplying because private label purchasing erodes the need to pay a premium if there is more than one supplier of the same perceived quality and standard in the market. However, private labels are a double edged sword, as they have helped increase demand for pork and enable some suppliers to build a strong relationship with the retailer which in certain cases has led to higher premiums.

Although national competition for branded pork products is very limited in Europe, there has been a significant growth in regional branding within some retail stores. In the UK this is partly a result of a desire for consumers to source products more locally as well as the successful "pigs are worth it" campaign. Certain retail chains now even sell branded local products alongside their own private label range, to off-set the relative success of small independent butchers, farmer markets and farm shops. In other European countries (eg. France), regional branding of pork products can be very evident. In Latin America, company branded pork products from companies such as Perdigao and Sadia in Brazil, are still very successful due to their dominance of the market and the relatively immature nature of the retail sector in comparison with Europe. However, the majority of pork sold is cured or processed, not fresh.

Product Differentiation – Credence Quality Attributes

Perceived Quality

It is clear there are market opportunities for national or regional branded pork products of reliable and consistent quality but the challenge for the industry is to overcome the perceived variability in eating quality. Numerous private and national quality marks are employed globally in an attempt to provide reliable eating quality of pork to the consumer. One reported successful example of branding a pork quality scheme is "Select Pork" in Western Australia. The Select Pork alliance was formed between a group of producers (10), a processor and a retailer (35 outlets). Results from a benchmarking study indicated that the branded pork was considered by consumers to have better eating quality compared to generic pork (D'Souza *et al.*, 2003). It is understood that Select Pork has attained a 20 percent sales growth and a premium of 12 percent. Select Pork is now the 'generic' pork for the Craig Mostyn Group with expansion of the brand now into Singapore (D.D'Souza, *pers. comm.*).

Food Safety

The global food industry has been beset by serious food alerts ranging from BSE to melamine which have significantly increased consumer awareness of food safety issues. More recently the pork industry in Europe suffered a major crisis with the discovery of dioxin-tainted pork meat in Ireland. Approximately 10 percent of Irish pork was affected and led to the withdrawal of pork products from more than 25 countries around the world at an estimated cost of EUR100 million.

Due to consumer concerns, food safety could be considered as an extrinsic cue for pork products. Using the credence "quality in the shop" (Figure 3), Becker (1999) explored the most significant cues for food safety (Table 5). For the purpose of the study consumers were asked how helpful or otherwise were various cues in assessing the safety of beef, pork and chicken. The intrinsic cue "freshness" was found to be of most important for all meats and all countries, inferring that freshness is perceived as an indication of safety. Animal feed comes next in the case of beef and both feed and origin in the case of pork. Price is not important at all as a safety factor. Although food safety is clearly an important credence quality attribute, consumers like to assume that food is safe and trying to introduce food safety cues would have negative effects for the category as a whole. An added complexity of food safety cues against the backdrop of global pork trade is the variation in risk perception internationally, highlighted by the differences between the EU and USA regarding the use of porcine somatatropin and ractopamine. This in turn leads to a greater reliance on labeling and partly explains why many consumers express a preference for foods from their own countries (Buzby, 2001).

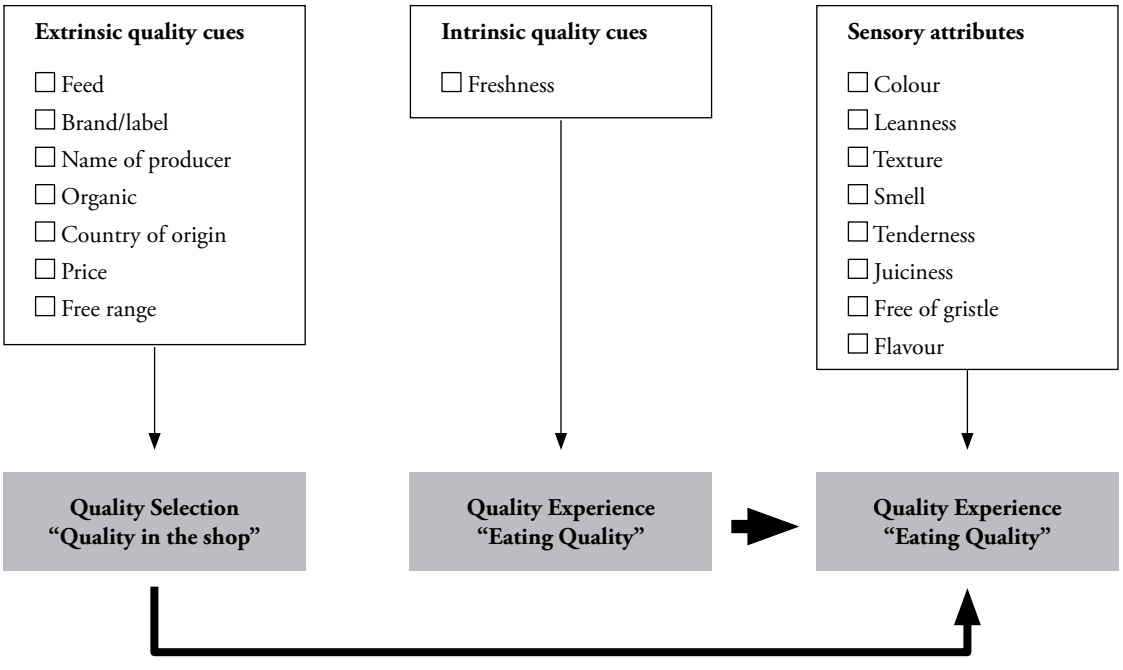

Figure 3. *Credence quality "safety" attributes for meat (after Becker, 1999).*

Health

A more positive attribute associated with food safety is the marketing of the health attributes of meat products. Concerns about health and obesity are widespread in developed countries and EU consumers in the studies referred to earlier have a clear negative perception of fat in meat, which they regard as a sign of poor quality and potentially bad health. There has been an on-going trend in various countries towards lower fat content given the importance of this as an IQA. Likewise the pig and poultry meat sectors have sought to highlight the differences compared to red meat in terms of total fat content and ratio of saturated to unsaturated fatty acids and associated health attributes.

Nutritional manipulation of the feed provided to animals can result in changes in the animal products nutritional profile, providing so called functional foods. Current examples in meat products include enhanced levels of omega-3 fats, vitamins and trace minerals and lower levels of total fat and saturated fats. However, one of the major limiting issues in Europe in promoting such products relates to the health benefit claims of functional foods and the legal restrictions impeding the communication of health benefits to the consumer. Health claims within the EU cannot be made without sound scientific evidence and therefore claims such as "reduces risk of heart disease" or "enhances health and immunity" must be substantiated. The vitamin and health supplement industry in Europe has come in for severe criticism for its advertising of health claims resulting in the withdrawal of many products and labels. Consequently, most health claims for pork are based on its low fat content (pork tenderloin equivalent to skinless chicken breast) and natural levels of minerals (potassium and zinc) and vitamins (pyridoxine (B6), thiamine (B1) and niacin (B3)). This contrasts with the USA where in 1985 the prohibition of diet-disease was relaxed to allow producers to discuss the relationship between diet and disease in advertising and labeling leading to a significant increase in food choices (Grunert, 2005). Current US pork advertising includes claims such as "including protein from lean sources of pork in your diet could help you retain more lean body mass, including muscle, whilst losing weight".

Convenience

Differentiation of product convenience in shopping, meal preparation, eating and disposal of the remains has been of rising importance for the past decades in many markets (Grunert *et al.*, 2004). In the fresh meat area, poultry is the sector that has adapted most to the convenience trend, by developing new cuts and various forms of pre-prepared products. This has developed at the same time as the rapid growth in the percent of meat and meat products sold through supermarkets in Europe. Poultry meat has gained at the expense of pork in convenience foods due predominantly to price. However, there is an opportunity to address imbalances in pork demand, for example between loins and shoulders, by channeling the cheaper shoulder cuts into convenience meals. This is being done successfully by a number of UK pork farm shops that make use of the cheaper cuts to produce a range of frozen ready meals which are also sold in the shop. Another successful strategy, set against the economic downturn, has been challenging celebrity chefs such as Jamie Oliver to promote recipes using cheaper pork cuts. A television-featured Jamie Oliver recipe for boned and rolled shoulder of pork resulted in a sustained increase in the national demand for shoulder meat.

Methods of production

Differentiation by process characteristics does not necessarily directly impact the quality of the product but caters for the growing numbers of consumers that express concerns about the way food is produced. This has resulted in the growth in alternative systems based upon welfare, specific feed content (eg. non-GMO), and organic production.

Concerns about animal welfare have prompted many developed countries to pass laws directed specifically at animal welfare in farming. In most cases these regulations lead to a rise in production costs thus making goods more expensive for domestic consumers. There are implications for global trade flows if imported goods are subjected to similar standards of welfare or in other cases may cause unconcerned consumers to seek cheaper foreign alternatives, potentially leading to trade policy issues (Mitchell, 2001). Such issues can currently be observed in the EU in both the pork and egg industries. It is feared that the impending bans on egg production in cages and sows in stalls will lead to a rise of lower welfare imported eggs and pork from non-EU countries, particularly directed at the food service sectors. To counter the threat of imported pork imports, the UK industry has mounted media campaigns, with the support of influential celebrities, to highlight the point of difference that UK welfare standards represent compared to other countries, both within and outside Europe. Other issues such as food security and the environmental impact of transporting imported pork also feature in the campaign. In the USA similar issues are evident in California which recently imposed a ban on caged layer operations. It is assumed that the layer industry will be forced to leave California as they will not be able to compete. Eggs will likely originate from Mexico which has no such standards. The drive towards improvements in pig welfare throughout many regions of the world, therefore, clearly needs to take account of the impacts upon production costs and the implications for trade if the import of cheaper lower welfare meat is not regulated.

Table 5. *Significant differences in the helpfulness of safety cues including results of a t-test for beef and pork (after Becker 1999).*

Country...	Germany	Ireland	Italy	Spain	Sweden	United Kingdom
Beef						
1st rank	Origin	Freshness	Feed	Freshness	Freshness	Freshness
	Freshness					
2nd rank	Feed	Origin	Freshness	Feed	Origin	Label
				Organic		Feed
				Origin		
3rd rank	Organic	Feed	Origin	Label	Label	Origin
	Producer	Organic	Label			Organic
	Label	Label	Organic			
			Producer			
4th rank	Price	Producer	Price	Producer	Feed	Price
				Price		
5th rank		Price			Organic	Producer
6th rank					Price	
					Producer	
Pork						
1st rank	Freshness	Freshness	Feed	Freshness	Freshness	Freshness
			Freshness			
2nd rank	Feed	Origin	Organic	Feed	Origin	Label
	Origin	Label	Label	Organic		Organic
	Organic	Feed	Origin			Feed
	Label	Organic	Producer			
	Producer					
3rd rank	Price	Producer	Price	Origin	Label	Price
				Label		Origin
4th rank		Price		Producer	Feed	Producer
				Price		
5th rank					Organic	
					Price	
					Producer	

A study in Denmark in 2003 set out to understand how consumers judge rearing systems as a cue for quality in pork and the results revealed a clear perceptual link between the quality of pork and the applied production method, in which extensive outdoor production was generally perceived to result in higher quality than intensive indoor production. The factors which consumers perceived to influence quality included the transportation of the pigs, how the pigs were kept at the farm, what the pigs were fed, the use of growth enhancers, treatment of the live pigs at the slaughterhouse, the general welfare of the pigs, the use of medicine, the breed of pigs, and the level of veterinary control. Despite the predilection for 'welfare' pork, meat from extensive production systems was rarely bought. Although generally regarded as desirable, the focus group participants generally rejected the meat because they perceived it to be either too expensive or too difficult to obtain (Scholderer *et al.*, 2004).

In two follow up studies by the same group, consumers were first asked to state their quality expectations for pork from pigs raised in different production systems and secondly to undertake a taste test. Consumers gave substantially higher ratings to pork from outdoor production systems on all dimensions of expected quality and all quality cues apart from price. Likewise pork chops labeled free-range or organic were consistently perceived to have higher eating quality than pork chops labeled conventional or unlabelled ones, independent of the actual meat type consumers had tasted. When label information effects were adjusted for, the organic pork chops used in this particular study were consistently

perceived to have slightly lower eating quality than the conventional pork chops (Scholderer *et al.*, 2004). The influence of the label cue for systems of production was also confirmed in the study by Ngapo *et al.* (2003) conducted in France, Denmark, UK and Sweden. The eating quality of meat from outdoor production was similar to that from indoor production. There were no differences in consumer appreciation and trained taste panellists found little difference in tenderness, juiciness, odour or flavour between pork from the outdoor and indoor production systems. However, in all four countries studied, when label information was provided, the labels influenced preferences for the fresh pork and in Britain and France also increased the perceived eating quality of the cooked pork.

The UK is generally regarded as at the forefront in terms of animal welfare due to a combination of consumer pressure and demands from retailers. In 1991 the UK went out on its own introducing a law banning dry sow stalls by 1999. High investment in alternative loose housing systems was thus forced on UK breeders years before most of the competition in Europe had to face the EU-wide sow stall ban that doesn't come fully into force before January 2013. Over the past 10 years the UK pig sector has been hit by a profitability squeeze that has been mainly responsible for a halving of the national sow herd resulting in UK self-sufficiency in pig meat plummeting to less than 50 percent. It should be noted that the change in welfare conditions was not the only factor contributing to this decline. The BSE crisis in 1996, currency turbulence, outbreaks of swine fever and foot and mouth disease and Post Weaning Multisystemic Wasting Syndrome (PMWS) have all had an adverse effect on production viability. There are still UK pig farms applying animal welfare standards much stricter than those required by law with, for example, sows and finishing pigs reared outdoors or straw bedding in group feeding units. Such systems result in higher costs of production, but also attract higher returns for the producer. Nor is the welfare approach in the UK catering for a niche market: 40 percent of sows in Britain are kept in outdoor systems and the same percentage of feeding pigs is in straw-bedded systems. But production performance is still comparatively poor at 22 weaners per sow and year, although this has improved continually since 2001 when the figure was only 19 (Benecke, 2008).

Retailers have a very strong influence on British pig production. The development of the outdoor and straw-based systems has predominately been driven by the supermarkets and more is paid for the resultant meat. Many supermarkets established a special market segment for added value pig meat from welfare oriented systems ahead of UK regulations on loose housing of sows. This led to a clear differentiation in product range based on the different demands of a broad customer base. The different product ranges are designed to cater for the demands of both the price-conscious consumer as well as the added-value consumer who are prepared to pay a premium for higher welfare standards. It is this premium range which has enjoyed highest growth in the past 10 years, and which offers most potential for additional profit throughout the supply chain. However, given that the four largest UK supermarkets sell 70 percent of the total pig meat, producers and processors have to fight hard for the premium against the backdrop of overseas competition, particularly other EU countries, most product from which is not produced to the same demanding welfare standards, particularly in the value ranges. The development of private labels, which account for more than 29 percent of UK grocery sales has also added pressure to the premiums available to the processor and producer (Thomassen, 2008). Most UK pig producers say they are more than happy to embrace higher standards of welfare but they expect the consumer to pay to cover the increased cost of production. The desire by pork producers in the UK to gain a fairer payment system that fully covered costs of production led to the "pigs are worth it" campaign aimed at the consumer and supported by celebrity chefs. In the light of the campaign, a large pork processing company in the UK tried to implement a more transparent payment system for their producers, however, the initiative was short lived due to commercial pressures and the company was subsequently taken over by a foreign competitor. Overall however, the campaign has successfully raised consumer awareness of the plight of the pig farmer and placed further pressure on the retailers to ensure the producers receive a "fair" price.

In the European poultry sector there has been a significant shift towards the use of traditional breeds in the extensive systems of broiler meat and egg production. Thus far in the UK this has not been replicated in the pig industry, however, it is the belief of some in the industry that this will be used as a further point of differentiation, given that EU welfare regulations will be more comparable from 2013. Traditional breeds such as Hampshire, Old Spot and Tamworth may see a return which could also provide an intrinsic cue to support the welfare standards. For example it is likely such a move would result in higher marbling values which from earlier studies is preferred as a cue due to associated benefits of juiciness and tenderness. This would be consistent with studies in Australia that indicate that the inclusion of Duroc bloodlines in predominantly 'white' European breeds can also result in improvements in pork eating quality (D'Souza and Mullan, 2001). A study by Dransfield *et al.* (2005) confirmed that there are no intrinsic attributes associated with systems of production to support welfare standards and which could help strengthen consumer acceptance of pork. Information provided on the label therefore is the means by which any preference and price premium will be attained from consumers wishing to express a choice for less intensive systems of production.

Origin Labeling

It has been shown that origin of meat is an important extrinsic cue for perceived product quality (Table 4). In another study in the US over one-third of the respondents drew the linkage between the country of origin of pork meat and intention to buy and a similar amount drew the link between country of origin and the butcher. Country of origin or region of origin is an important tool for differentiating products and explains attempts to build up a national or regional marketing brand. In some cases the importance of country of origin would appear to be more due to health concerns associated with imported meat, for example BSE concerns regarding imported beef. Becker (1999) identified that country of origin is objectively no predictor of eating quality and consumers will often associate issues with this quality cue that are of no relevance for eating quality.

Country image effects are noted strongly in many food choices. Consumer research on country image effects reveals that domestic consumers, especially those in developed countries, prefer foods from their own countries. In some countries the reported attitudes to imported foods are very striking. A survey of Swedish consumers, found they have very negative opinions of all types of imported foods, particularly meat (Ekulund *et al.*, 2004). The study by Dransfield *et al.* (2005) tried to also evaluate what consumers in France, Denmark, Sweden and UK were prepared to pay for both fresh and cooked pork when labeled with country of origin for both indoor and outdoor production. In general terms the consumer willingness to pay varied widely and was higher for those consumers who found more of the characteristics they sought. On average the consumers surveyed offered about 5 percent more for home country and outdoor production labels.

Care is needed in interpreting statements survey respondents may make about their practice of buying domestic. Country-of-origin may not be a salient criterion if no difference is perceived between the foods available for sale from different countries or if labeling is inadequate to identify domestic from imported foods (Heslop, 2007). One of the major reasons cited for failure in "buy domestic" campaigns is a lack of commitment to product consistency. Generalised "buy domestic" programs have not been successful on any level in the countries for which research results have been reported. Both New Zealand and Australia have had domestic branding campaigns to encourage citizens to buy locally sourced products. New Zealand's first campaign involved the fern symbol and the "Buy New Zealand-Made" slogan. The Australian program was more aggressive in linking the buying of Australian goods as necessary to being an Australian (Think Australian – Buy Australian – Be Australian). In both cases it was concluded that the campaigns did not differentially increase sales. In general "buy domestic" programs have not been successful on any level in the countries for which research results have been reported (Heslop, 2007). Regional branding, however, within country, would appear to be more effective. There is growing interest domestically among segments of consumers in "local" produced food. Such interest has sparked a growth in farmer markets and farm gate sales. The interest appears to be rooted in a number of underlying desired food outcomes, including control over sourcing, desire for perceived enhanced taste and nutrition outcomes, and also to outcomes related to support of ethical and environmental values (eg. food miles and fair trade issues).

In the UK there is intense pressure on the government to review product labeling regulations because "produced in UK" has become a euphemism for "made with imported pork". Research into labeling has shown that more than 80 percent of meat products failed specifically to indicate the origin of the main meat ingredient (BPEX, 2009b). The report goes on to say "for those consumers who want to exercise discretionary choice at the point of purchase, clear and unambiguous country of origin information is a necessary prerequisite". Similar concerns are expressed in Australia, where 70 percent of processed pork is sourced from imported product and this is likely to increase further. To combat this Australian Pork Ltd (APL) has re-branded itself in an attempt to enable the consumer to distinguish and differentiate between "made in Australia" and "product of Australia". APL is currently working with pork processors who do not have import licences and retailers in promoting processed pork products that are made from 100 percent Australian pork and pork products.

There is a distinct difference in marketing country of origin for the domestic market as opposed to using the same extrinsic cue for the global market. The image of a country is largely through stereotyping based on established positive pre-conceptions. The general acceptance about the quality of French foods derives from the reputation of food excellence in France, coupled with beliefs about the sophistication and way of life of French consumers. Likewise New Zealand enjoys an image of agriculture associated with being "clean and green" and trustworthy. A study of the importance of trust in the Danish bacon sector determined that "there are different types of trust (generalised trust, system trust, process-based trust and personality-based trust) and that each type of trust is a valuable strategic variable" (Lindgreen, 2003). Furthermore, if one type of trust is missing then it may be possible and necessary to draw on other types. When consumers have developed mistrust of the food industry, and/or of their domestic government agencies, then it may become necessary for foreign producers and importing distribution channel members to restore this trust

by implementing their own trust-based marketing systems. Danish bacon producers installed their own meat assurance schemes for the UK market instead of relying on the British government (Lindgreen, 2003). Similarly, New Zealand food producers have established very elaborate quality assurance (QA) and traceability schemes to provide distribution channel members and end consumers with reason to trust the end product (Knight *et al.*, 2005). In many food markets, particularly food service and further process, country of origin is of much less importance but the requirement for trust and traceability is still paramount as part of the due diligence process.

It is also important to distinguish between a country brand and a country of origin label. For example, "Produce of Australia" is only informing the consumer the product originates from Australia where as "Aussie Pork" as a brand is strongly associated with consumer perception of that country together with the quality of the product and the use of a logo to signal past experiences. Using a brand rather than a country of origin label allows a product image to be created and conveyed that goes beyond merely representing the origins of the product. However, using a country brand that builds on the collective reputation of a country, its citizens, and other products using the brand makes managing it considerably more challenging than managing a traditional private brand due to difficulties in managing both the product-country image and product quality. A country brand will only be successful facing competition from other countries in the international marketplace if its claims are credible and unique. If the claims made by the brand are not unique, it is likely that other countries will copy the strategy and erode any gains made by the branding country's exporters (Innes *et al.*, 2007). In this respect, quality assurance programs have an important role to play in maintaining the credibility of any such quality claims and providing proof of authenticity by means of comprehensive traceability.

The role that labels play in the market for food quality is well documented (Caswell, 1997). However, in the case of meat these products are mostly sold in many countries fresh and not pre-packed, hence the reliance and trust placed in the butcher or supermarket as a key cue identified in Table 4.

Regulation and Communication of Extrinsic cues

There is a wide range of information that can be communicated to consumers through effective labeling (Table 2). The problem for the consumer is that they can quickly become confused with different brands, formal and informal quality marks and a variety of production systems ranging from intensive to organic resulting in a large number of similar products on which they might have little or no information. Some authors have highlighted that the excessive use of labeling based on country or region of origin etc may erode the value that consumers place on them (Henson and Northern, 2000).

The effectiveness of credence quality cues is entirely based upon credibility – how can the consumer trust the information that is being presented. In the UK, the meat industry has succeeded in uniting various quality label and certification schemes under a large national programme offering higher product recognition – Assured British Meats (ABM). The ABM scheme is termed 'Farm Assurance' meaning assurance applied to products with a farm origin and covering the conditions of their production, up to the point of slaughter for livestock products. A farm assurance scheme is a formal framework to ensure the availability, validity and delivery of that assurance information at each stage from supplier to buyer, and to be carried forward so that the interested final consumer can be informed of the provenance of the final product. Consumer concerns and preferences about the food they eat create a need for information relating back to all aspects in the agricultural supply sector (eg. the type of feed), with on-farm characteristics of the production process (eg. outdoor or organic), the method of slaughter, food safety aspects, up to the nature of the final purchased product (eg. food constituents, nutritional values). It is the role of an assurance scheme to provide that information and so allow consumers to better satisfy their specific preferences when making purchasing choices (Wathes, 2005).

Quality Assurance (QA) Schemes

Quality assurance schemes provide a system for assuring and certifying desired product attributes by establishing production and processing standards that relate to the provision of these attributes, inspecting to ensure that standards are being observed, and providing an indicator of these attributes through a mark, label, or certification. In many cases, specific farm assurance schemes are not targeted at final consumers but at intermediate customers in the supply chain, namely abattoirs (which are the ultimate buyers of livestock) and their customers (such as multiple food retailers, butchers and also export markets). In the USA the new "PQA-Plus" program does now include aspects of animal welfare and requires on farm audits rather than the former requirement for the producer to be "educated" about the scheme rather than changing behavior. However, in contrast to the UK schemes, the "PQA-Plus" scheme tends to be limited to on-farm quality assurance, rather than providing assurance throughout the supply chain.

The two key features of any assurance scheme are the need for credible standards and the need for a credible system of inspecting those standards. There are a large number of farm schemes operating in the UK, most of which

were implemented in the early 1990s in response to growing concerns about animal welfare (Spriggs *et al.*, 1999). Retailers were instrumental in the growth of these schemes due to concerns about food safety and the methods of production. Farm level quality assurance schemes include both generic schemes, which have been developed with broad public participation, and proprietary schemes developed and operated by food retailing chains and large processing firms. The standards for the generic schemes which cover cattle, sheep, pigs and poultry are set by technical committees and typically aim to secure the management of the supply chain particularly in the following areas:

- Animal welfare
- Animal husbandry
- Animal health
- Animal feed
- Transport, handling, slaughter and processing
- Traceability.

The benefits of farm assurance schemes can be identified at three levels. First they provide credibility to farmers for the production process which helps inspire buyer confidence to both gain and retain a market for the products produced. Secondly, farm assurance and traceability are essential for both food processor and retailer in order that they comply with legal requirements and ensure that the quality standards they wish to be associated with their products can be validly claimed and demonstrated. Finally, farm assurance is desired by those consumers who have a specific focus on food supply issues. Many food retail chains demand livestock that has come from farm assurance scheme members. In addition, many chains also run their own (proprietary) farm-level schemes, which go well beyond the requirements. This can be due to a combination of reasons including, the requirement for higher standards than the assurance schemes provide, development of brands with competitive advantage and closer cooperation and control of the supply chain (Bredahl *et al.*, 2001). Essential to the success of such schemes is that they become accepted as the standard for the industry or the cost of doing business, which is certainly the case in the UK. The commercial success of the UK schemes is attributed to the branding of the various sector schemes under the "little red tractor logo". Consumer recognition of the red tractor is extremely high and conveys a strong element of confidence and trust.

Quality assurance schemes may convey a competitive advantage to domestic producers covered by the program. For example, all of the large retail food chains in the UK require farm assured livestock. Clearly, in order to source this primary market, quality assurance scheme membership has become de facto mandatory, conveying an advantage to suppliers participating in the schemes, and a disadvantage to those who do not. These schemes may come to convey the same advantage for their members as other national systems that aim to create a competitive advantage for some domestic producers based on the sensory attributes of food, or even on the location of production, such as that used for wine and cheese. Taking the example of the Assured British Pigs (ABP) farm-assurance scheme, several trade effects are suggested for countries exporting pork to the UK. The demand for farm-assured pigs with animal welfare and trace-back attributes in the UK is well developed. Many retail food chains (the likely buyers of most imported meat) demand farm-assured livestock, hence quality assurance schemes such as ABP have become mandatory for supplying the primary retail market. Although retail food chains may be prepared to accept pork from comparable schemes in other countries, the animal welfare and traceability elements of such schemes are likely to have been developed for their own domestic market and may therefore need significant revision to satisfy the UK market. In addition, the mechanism by which the foreign scheme is inspected may not be sufficiently rigorous. However, where foreign schemes are acceptable to UK buyers, the presence of the quality label should be sufficient to indicate the necessary quality and/or safety of the meat and allow for reduced transaction costs of UK buyers. This in turn may encourage a greater trade of meat between countries.

In Australia, where independently audited systems are operated, they have not become the industry standard which means a number of processors are able to accept pigs from farms that are either not QA approved or the QA certificates have not been renewed. The Australian Pork Industry Quality Program (APIQ) is undergoing a review of the scheme with the objective of ensuring acceptance of the scheme by all sectors of the industry. Although most Australian retailers stipulate that all pork is APIQ or equivalent this information is not currently conveyed on the label, in contrast to the UK red tractor logo, and as such the Australian consumer is unlikely to appreciate the standards under which the pork is produced. This point is particularly important at the time when APL is working to highlight the benefits of Australian produced pork and pork products for labeling purposes.

As previously noted, farm assurance schemes must have inspection protocols which ensure that members attain and maintain the required standards and that verify the sometimes complex chain of traceability. When first implemented, farm assurance schemes often lacked credibility because the inspection process was not independent of the scheme membership. That has been resolved with the inspection process being carried out by certification bodies that are accredited either directly by the national authorities or by private companies accredited by a national accreditation body.

Traceability technology information systems are rapidly advancing enabling a growing number of consumers to access details about food products at the point of purchase using bar codes, radio-frequency identification (RFID) chips and mobile phone scanning. This is used by an increasing number of consumers as a means to check systems of production, environmental and ethical concerns, for example the distance the product has traveled, origin of the product or ingredients used in the feed and fair trade practices. Such technology provides a new dynamic to the methods available to display transparency and verify claims associated with extrinsic cues.

Ultimately, assurance schemes convey the information to the consumer that provides confidence and satisfies concerns ranging from welfare and antibiotics to feed ingredients and the environment. For this cue to be effective, consumer awareness and product labeling are essential.

Summary

The global consumption of pork is still higher than other meat types, however ,there is intense price pressure and the global pork industry is having to fight hard to retain customers and increase market share. Pork quality is a very subjective and dynamic concept and the perception of pork quality is changing fast. Rather than rely on traditional intrinsic cues, consumers today pay more attention to credence quality attributes such as safety, healthiness, convenience, origin and method of production. These attributes focus primarily on quality of the production process, and not on the product itself and this increases the importance of trust in the information provided and confidence in the source of the information. At point of purchase, the consumer is often presented with an overwhelming number of choices that must be evaluated quickly. Extrinsic information cues, such as brand name, price, and label information, are used as a means of reducing the time pressures and simplifying the purchase decision making process. These extrinsic cues rely upon trust-based assumptions about the brand, its producer, the store selling the meat, the price, the certification or assurance scheme that verifies the production methods and label information relating to claims about nutrient content and any associated health benefits. The purchase will then depend upon which cues the consumers feels are relevant based on the cue's predictive values, as determined by previous experience and knowledge, and confidence values, as determined by the trust in the information source or assurance label.

With increasing globalisation of food products, food labeling has become a highly effective extrinsic cue to create differentiation and consumer assurance about both intrinsic and credence product characteristics. However, due to the fact that in many countries a high proportion of pork products are still sold fresh and without packaging, the place of purchase remains an important extrinsic cue that consumers rely upon to substitute for their own lack of experience and confidence in evaluating intrinsic cues. This is important when considering the significant growth globally in the percent of meat products sold in supermarkets compared to private butchers and the trend towards private labels. The reliance on extrinsic cues in the consumer decision making process for pork is therefore likely to increase and farm assurance schemes and the use of sophisticated traceability technology will help satisfy an even greater desire for transparency between the producer and the consumer.

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Selenium Enriched Pork May Reduce Colon Carcinogenesis

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Extensive experimental evidence indicates that selenium (Se) supplementation reduces the incidence of cancer in animals (Hu *et al.*, 2008). However, the delivery of Se is challenging due to its toxicity, especially when consumed in an inorganic form. The consumption of Se enriched pork where the Se is bound in an organic protein matrix could provide a means of delivering direct health benefits for humans (Biesalski, 2002). This study investigated the effectiveness of Se enriched pork in the suppression of aberrant crypt foci (ACF) formation, the putative precursors of colon cancer (Bird and Good, 2000), using a rodent azoxymethane (AOM) induced colon cancer model.

Ninety-six male Sprague Dawley rats (28 d old) were offered *ad libitum* access to one of four experimental diets (n=24): 1) Control, American Institute of Nutrition (AIN, Reeves *et al.*, 1993) 93G diet (Se 0.2 ppm); 2) AIN 93G diet + non-Se enriched pork (Se 0.2 ppm); 3) AIN 93G diet + Se enriched pork (Se 0.7 ppm); and 4) AIN 93G diet + selenised yeast (Diamond V, Cedar Rapids, Iowa, USA; Se 0.7ppm). After four weeks of feeding the respective diets, the rats were injected once a week for 2 weeks with AOM (15 mg/kg) to induce DNA damage (Hu *et al.*, 2008). The dietary treatments continued for the following 15 weeks to allow for ACF formation without allowing carcinogenesis to progress to the adenoma or tumour stage. At the end of the study rats were euthanased, colons were collected, fixed in formalin and stained with methylene blue for histologic examinations for the presence ACF. Data were analyzed using analysis of variance.

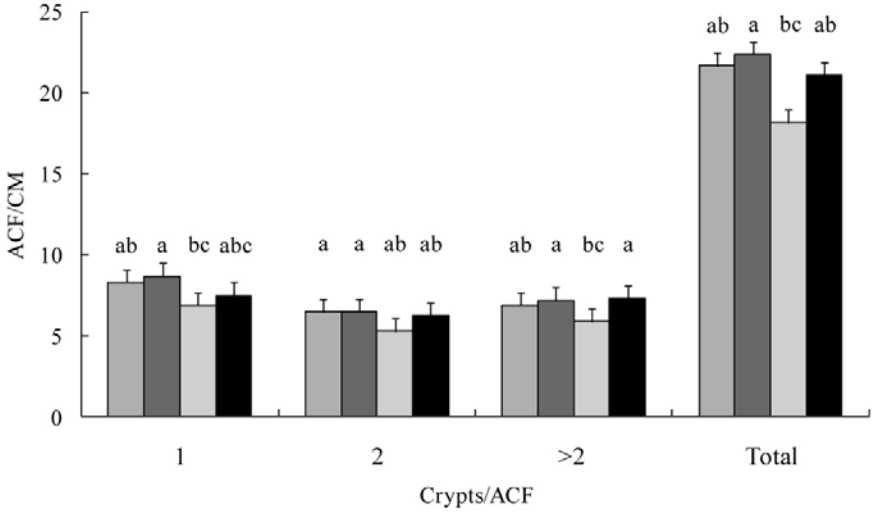

Figure 1. *Aberrant crypt foci (ACF) in the distal colon of AOM induced Sprague Dawley rats fed AIN 93G diet (■), AIN 93G diet with pork (■), AIN 93G diet with selenium enriched pork (■) and the AIN 93G diet with selenised yeast (■).*

[abc]Means with different superscripts differ significantly (P<0.05)

Feeding rats a diet containing Se enriched pork reduced (P=0.05) the number of ACF in AOM-induced rats compared to those fed the other experimental diets. Selenised yeast did not reduce the incidence of ACF in rats, despite the same concentration of Se being present as in the Se-enriched pork diet. This suggests that the Se-enriched pork appears to have a protective effect against early stage of colon carcinogenesis in the rodent model.

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Supported in part by the Pork CRC Ltd.

Feeding a Lower Protein Diet Reduces Nitrogen Content in the Intestinal Tract but Does not Influence Apparent Nitrogen Digestibility

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Post-weaning diarrhoea (PWD) reduces production efficiency through increased morbidity and mortality and poorer efficiency of growth (Halas *et al*., 2007). Dietary proteins that are not digested and absorbed in the small intestine are fermented by the intestinal microbiota to produce a number of potentially toxic epithelial irritants such as ammonia, which are thought to increase the incidence of PWD. Limiting the amount of protein available for microbial fermentation has been proposed as a strategy to reduce the risk of PWD in weaner pigs without using in-feed antibiotics (Halas *et al*., 2007). In this experiment, we hypothesised that feeding a lower protein diet for a short period of time after weaning would reduce PWD by reducing the amount of protein entering the hindgut from the small intestine, thereby reducing protein fermentation in the colon.

Forty-eight 21 d old male pigs (Landrace × Large White) weighing 6.9±0.11 kg (mean±SEM) were used in a 2x2x2 factorial experiment (n=6) with the respective factors being (i) infected vs. non-infected, (ii) high protein (HP, 239 g/kg CP) vs. low protein (LP, 190 g/kg CP) and (iii) feeding duration (7 vs. 14 d after weaning). Pigs in the infection group were challenged with enterotoxigenic *Escherichia coli* (ETEC; 8 ml of soy broth containing $1.84x10^8$ colony-forming units/ml of ETEC serotype O149; K91; K88) at 72, 96 and 120 h after arrival. All diets were formulated to at least contain an ideal pattern of ileal digestible amino acids. Pigs were euthanased at the end of each feeding regimen for harvesting of digesta, and thereafter the apparent nitrogen (N) digestibility was measured at the terminal ileum and ammonia-N (NH_3-N) was measured at the ileum and colon. Ileal N flow of dietary origin was calculated based on daily N intake and the apparent ileal N digestibility. PWD was observed for the 14 d after weaning and is expressed as the mean proportion of days with diarrhoea. Data were analysed using the GLM procedure of SPSS (SPSS Inc., Chicago, Illinois, USA).

Table 1. *Effect of feeding a lower protein diet on total nitrogen (N) intake, apparent ileal digestibility (AID) of N, ileal N flow of dietary origin, ammonia-N (NH_3-N) in the intestine, and post-weaning diarrhoea (PWD).*

Item	Non-Infected				Infected					P-value		
	HP7	HP14	LP7	LP14	HP7	HP14	LP7	LP14	SEM	PL	I	FD
Total N intake (g/d)[1]	53	118	43	95	51	122	41	97	4.7	***	NS	***
AID of N (%)	56	65	53	62	47	60	46	58	1.5	NS	*	***
Ileal N (g/d)[1,2]	26	41	23	36	32	45	27	40	1.6	*	*	***
Ileum (mg/kg)[3]	47	57	32	38	55	65	35	43	1.9	***	*	***
Colon (mg/kg)[3]	273	350	186	233	362	406	246	289	11.5	***	***	***
PWD[4] (%)	1.2^a	0.0^a	0.0^a	2.4^a	7.1^c	3.6^b	1.2^a	1.2^a	0.44	*	**	NS

SEM, Pooled standard error of mean; NS, Not significant; * P<0.05; ** P<0.01; *** P<0.001; PL, protein level; I, infection; FD, feeding duration; [1]Calculated on pen basis; [2]Dietary origin N flow; [3]NH_3-N contents; [4]Interactive effect (PLxI and PLxFD, P<0.05); [abc]Mean values within a row with different superscripts differ significantly (P<0.05).

Feeding an LP diet decreased total N intake, ileal dietary-origin N flow and NH_3-N contents at the ileum and colon but did not alter (P>0.05) the AID of N at either 7 or 14 d after weaning. Although ETEC infection decreased overall AID of N, feeding the LP diet consistently reduced ileal N flow along with ileal and colonic NH3-N contents. The ETEC infection increased PWD only in pigs fed a HP diet, and feeding a HP diet increased the incidence of PWD at day 7 only (Table 1). These data suggest that feeding an LP diet immediately after weaning reduces the flow of N of dietary origin into the large intestine, thereby decreasing protein fermentation. This in turn was associated with a reduction in the incidence of PWD.

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Supported in part by the Australian Research Council.

Piglets in Werribee Farrowing Pens Explore More But Eat Less Than Those in Farrowing Crates

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Piglets often have reduced feed intake after weaning and this has serious implications for growth. However, piglets reared outdoors display more exploratory and feeding behaviour both before and after weaning than piglets reared indoors (Cox and Cooper, 2001; Webster and Dawkins, 2000). We thought that the increased freedom to engage in natural behaviours might encourage piglets in large farrowing pens to mimic some of the behavioural patterns seen in outdoor systems. In this study, we tested whether piglets reared in large pens during lactation would interact more with their environment than piglets reared in farrowing crates and whether this behaviour was associated with increased feed intake before and after weaning. Since the term exploratory behaviour usually refers to a response to novel stimuli, we have chosen to use the term environmental interactions.

Twenty-three litters (range 8 to 11 piglets) from crossbred sows were reared in either large pens (n=10) or conventional farrowing crates (n=13). The sows in pens had access to straw and double the floor area of the crate, allowing the sows to nest and have greater control over suckling than sows in crates. In the pens, the piglets were also able to follow the sow to the feeder. Six days after farrowing, the piglets in both treatments were offered increasing quantities (5-10g) of dry creep feed twice daily. The piglets were videoed for 41 h before and 41 h after the removal of the sow at weaning (21 d of age). Piglets remained in the pens and crates after weaning. Behaviour was measured every 30 minutes by classifying the percentage of each litter engaged in fighting/play fighting, interactions with the environment, sucking from the sow, feeding, or inactive. Piglets were classified as expressing feeding behaviour when they were observed to investigate or eat feed from the creep dish or the sow's feeder. Environmental interaction was any active behaviour not included in the previous categories (eg. rooting behaviour or interacting with pen fittings). Behavioural data were analysed using repeated measures analysis of variance, paired and unpaired t-tests. Feed removed from the creep dish was used to estimate feed intake and these data were analysed by paired and unpaired t-tests. All data analysed were normally distributed.

Table 1. *Environmental interactions, feeding behaviour, and estimated feed intake (mean ± standard deviation) of piglets reared in farrowing crates or pens before and after weaning.*

	Environmental (% litter)		Feeding behaviour (% litter)		Estimated feed intake (g)	
	Pre-weaning	Post-weaning	Pre-weaning	Post-weaning	Pre-weaning	Post-weaning
Crate	7.5 ± 0.37[a]	13.3 ± 1.57[c]	1.7 ± 0.32[a]	4.6 ± 0.69[b]	48.1 ± 5.76[a]	170.1 ± 9.44[b]
Pen	10.7 ± 0.90[b]	19.0 ± 1.11[d]	0.9 ± 0.16[a]	2.9 ± 0.39[c]	57.2 ± 6.76[a]	121.7 ± 7.95[c]

[abcd]Means in a category with different superscripts differ significantly (P<0.05)

Piglets reared in pens displayed 40% more environmental interactions than those reared in farrowing crates, both before and after weaning (Table 1; P<0.01). By contrast, piglets reared in farrowing crates engaged in more feeding behaviour both before and after weaning (Table 1; P<0.05) and had greater estimated feed intake after weaning than piglets reared in pens (Table 1; P<0.001). In conclusion, piglets reared in pens did interact more with their environment than those reared in farrowing crates but, contrary to our expectations, this behaviour was not associated with increased feeding behaviour or estimated feed intake either before or after weaning.

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Supported in part by the Pork CRC Ltd.

Intestinal Responses to Dehulling and Level of Inclusion of Australian Sweet Lupins (*Lupinus angustifolius*) in Weaner Pig Diets

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The change from sow's milk to solid feed at weaning causes marked alterations in the structure and function of the gastrointestinal tract (GIT), and makes pigs more susceptible to the proliferation of enteric pathogens such as enterotoxigenic *Escherichia coli*, which can cause post-weaning colibacillosis (PWC). Diet composition and form have major effects on PWC (Pluske *et al*., 2002), hence it is important to consider the effects of ingredients on nutrient digestibility, since a diet of lower digestibility can result in an increase in the supply of nutrients to pathogenic bacteria in the hind gut. Previous research has demonstrated that a small amount of insoluble fibre ameliorates the incidence of PWC (Kim *et al*., 2008), while some soluble fibres lead to proliferation of enteric pathogens (Pluske *et al*. 2002). We hypothesise that increasing concentrations of whole or dehulled Australian sweet lupins in place of milk products in weaner pig diets will alter the GIT responses and plasma metabolites.

A total of 180 entire male pigs weighing 6.4±0.1 kg at weaning were used in the experiment. The experimental design, diet formulations and specifications, and other experimental methods were described by Kim *et al*,. 2009. All diets contained 2,500 ppm of zinc oxide (ZnO). The acid detergent fibre:neutral detergent fibre ratio was increased as whole lupin concentration increased (0.22, 0.33, 0.39, 0.44 and 0.48) and it was decreased as the dehulled lupin concentration increased (0.22, 0.21, 0.19, 0.18 and 0.17). Blood samples were collected on d 6 and 20 for determination of plasma urea nitrogen (PUN). The β-haemolytic *E. coli* shedding score was determined on days 0, 3, 5, 7, 9, 11 and 13 by taking swabs from the anus. Faecal score and the incidence of diarrhoea were visually assessed daily (Kim *et al*., 2008). Antibiotic treatments and timings were recorded as treatment days. Data were analysed using analysis of variance (SPSS, v. 16, SPSS Inc., Chicago, Illinois). The *E. coli* shedding score data were log-transformed for normalisation before statistical evaluation.

Table 1. *Effects of dehulling and concentration of lupins on intestinal parameters of weaner pigs.*

		Whole lupin, g/kg				Dehulled, g/kg				
Item	Control	60	120	180	240	60	120	180	240	SEM
E. coli, $\log_{10}$, d 3	0.04[a]	0.00[a]	0.00[a]	0.10[a]	0.06[a]	0.07[a]	0.00[a]	0.33[b]	0.21[b]	0.025
PWD, d 1-14	1.1	0.7	0.4	0.4	1.8	1.8	1.4	1.1	1.1	0.23
Antibiotic treatment days	0.7	0.7	0.4	0.0	1.8	1.8	1.4	1.1	1.1	0.22
Faecal consistency, %	22.3	23.1	22.3	21.1	23.1	23.7	22.6	23.5	22.4	0.28
PUN (mmol/L), d 6	5.0[a]	4.7[a]	4.9[a]	5.5[a]	6.5[b]	5.1[a]	5.4[a]	5.9[b]	6.7[b]	0.09
PUN (mmol/L), d 20	5.6[b]	5.21[b]	5.0[a]	5.4[b]	6.3[c]	5.5[a]	5.4[a]	6.3[c]	6.7[c]	0.08

[abc]Mean values in a row with different superscripts differ significantly (P<0.05); PWD, post-weaning diarrhoea; PUN, plasma urea nitrogen; SEM, standard error of mean.

Faecal consistency, antibiotic treatment days, and the incidence of PWC were generally low and unaffected by up to 240 g/kg inclusion of whole or dehulled lupins in the diet. The low incidence of diarrhoea was most likely attributable to the inclusion of dietary ZnO. However, piglets fed diets containing more than 180 g/kg of dehulled lupins had a higher faecal β-haemolytic *E. coli* score on day 3 after weaning (P<0.05). Moreover, inclusion of 240 g/kg of whole lupin or more than 180 g/kg of dehulled lupins significantly increased PUN levels, possibly indicating less efficient utilisation of amino acids for body protein retention. These data indicate that inclusion of dehulled lupin in piglet diets immediately after weaning should be limited to a maximum of 150 g/kg, supporting the recommendations by Kim *et al*., (2009).

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Supported in part by the WA Agricultural Produce Commision Pig Producers' Committee.

Efficacy of Protected Organic Acids, Alone or in Combination with Essential Oils, on the Growth Performance of Piglets

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Use of organic acids in weaner pig diets has long been accepted to improve animal performance and reduce post-weaning scours. Organic acids modify the gastrointestinal tract (GIT) bacteria and if they are delivered in their undissociated form their efficacy increases 50-100 fold (Presser *et al*., 1997). In addition, recent research with essential oils (EO) has focused mainly on their antimicrobial properties in modifying the GIT microflora. However, *in vivo*, EO is predominantly and almost completely absorbed in the stomach and proximal small intestine (Michiels *et al*., 2008). As a consequence, there is a renewed focus on protecting a combination of protected organic acids (POA) and EO (POA+EO) to provide greater efficacy (Piva *et al*., 1997). The aim of this preliminary experiment was to investigate if added POA could improve the performance of weaner pigs fed a high quality weaner diet and if lower quality weaner diets with added POA+EO could maintain similar levels of performance.

Two hundred and eighty-eight male and female piglets (commercial hybrid genotype) were allocated to 24 pens with 12 pigs/pen in a randomised complete block design. Piglets were weaned at 15-17 d of age with an average weight of 5.9kg. Three treatments were applied with eight replicates/treatment. The treatments comprised A) a control weaner diet (15.0 MJ digestible energy (DE)/kg and 0.84 g available lysine (AvL)/MJ DE) based on corn and soybean meal with added dried blood plasma, whey powder, low antigen soy protein isolate and oat groats with no added POA or EO, B) the control weaner diet with added POA (Tetracid 500™ (fumaric, malic, citric, phosphoric acid, JEFO Nutrition Inc., Quebec, Canada) at 2kg/T, and C) a lower quality weaner diet based on corn and soybean meal only (15.0 MJ DE/kg and 0.80 g AvL/MJ DE) with POA+EO (Porcinat+™; fumaric, citric, malic, sorbic acid, thymol, eugenol, vanillin; JEFO Nutrition Inc., Quebec, Canada) added at 1 kg/T. Diets were offered *ad libitum* with water freely available via nipple drinkers. The data was analysed using analysis of variance then a multiple comparison test and Fisher's least squares.

Table 1. *Feed intake, average daily gain (ADG), average final body weight (AFBW) and feed conversion ratio (FCR) of weaner pigs fed to 35 d of age after weaning on a control diet (Treatment A), the control diet with added protected organic acids (POA; Treatment B) or a lower quality weaner diet with added POA and essential oils (POA+EO; Treatment C) (mean ±SEM).*

Treatments	Feed Intake	ADG	AFBW	FCR
A – No acid	410.9^{b} ± 16.7	328.6^{b} ± 13.2	17.3^{b} ± 0.303	1.26^{b} ± 0.018
B – POA	436.9^{ab} ± 12.3	363.1^{a} ± 11.4	18.5^{ab} ± 0.262	1.21^{a} ± 0.016
C – POA+EO	469.8^{a} ± 8.78	386.9^{a} ± 8.17	19.3^{a} ± 0.226	1.22^{ab} ± 0.010

[ab]Means in a column with different superscripts differ significantly (P<0.05). SEM, standard error of mean.

Addition of POA to the control diet and POA+EO to the low quality weaner diet significantly improved (P<0.05) feed intake in the weaner piglets compared to the control (Table 1). The addition of the POA+EO to the low quality weaner diet was also able to maintain ADG at a level similar to the control with added POA, with both treatments promoting significantly better ADG compared with the control diet. Addition of POA+EO to the low quality weaner diet resulted in a significantly higher piglet body weight at 35 d compared with the control. This preliminary data suggests that protecting organic acids and essential oils may result in synergistic benefits that can confer additional benefits to POA alone. Further research is required to establish the efficacy of POA versus POA+EO in diets with the same base composition.

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CHAPTER 4

Reproduction

Effect of Dam Parity on Maternal Transfer of Specific IgG Into Colostrum and Milk Following Vaccination With Tetanus Toxoid

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Gilt progeny are more susceptible to disease than the progeny of older parity sows (Miller, 2008). This may be due to reduced transfer of passive maternal antibody (via colostrum and milk) from gilts relative to older parity sows. Older parity sows are more likely to have higher antibody concentrations than gilts due to repeated exposure to on-farm pathogens. It is unknown, however, if the gilt is capable of producing the same antibody response as the sow. Our hypothesis was that the antibody response and maternal transfer of antibodies by sows is greater than that of gilts.

A total of 64 gilts (parity 0) and 64 sows (parity 2-5; Landrace x Large White) from two consecutive mating weeks were given tetanus toxoid (Equivac T vaccine; Pfizer Animal Health, West Ryde, NSW) 7 and 4 weeks prior to farrowing. Tetanus toxoid was chosen as a novel vaccine antigen to test the level of antibody immune response in naïve dams. Tetanus toxoid vaccine is commonly used to investigate antibody immune responses (Piersma *et al*., 2004). A blood sample was collected from each dam just prior to their first vaccination and 2 weeks after their second vaccination. Colostrum and milk samples were collected from randomly selected gilts (16) and sows (16) on d 1, 8 and 22 post-farrowing. Positive and negative controls were generated in a pilot study from vaccinated and non-vaccinated sows, respectively. An indirect enzyme-linked immunosorbent assay (ELISA) was developed to measure IgG tetanus toxoid-specific antibodies in serum and colostrum/milk (Miller, 2008). Tetanus toxoid antibody concentrations were determined using optical density (OD) and sample: positive (SP) ratios were calculated to account for plate and day differences.

SP ratio = (sample OD - negative control OD) / (positive sample OD – negative sample OD) x 100

Linear regression (REML) models were used to analyse the association between dam parity and IgG concentrations in dams using Genstat Release 10. All 2-way interactions were investigated. The IgG concentrations in serum post-vaccination were analysed using pre-vaccination IgG concentration, parity (gilt or sow) and mating week (1 or 2) as fixed effects and the individual sow as a random effect. Milk and colostrum IgG concentrations were analysed separately, due to the marked difference in antibody concentrations between colostrum and milk, with parity and mating week as fixed effects and individual sow as a random effect.

Tetanus toxoid-specific IgG antibodies were not detected in the serum of gilts or sows prior to vaccination. Post-vaccination, gilts had a higher concentration of tetanus toxoid IgG serum antibodies than sows (66% and 58% respectively; ± 3.37% standard error of differences (SED); $P<0.05$). Parity had no effect on the concentration of tetanus toxoid-specific IgG antibodies in either colostrum or milk samples ($P>0.05$).

These results suggest that gilts are capable of producing a greater antibody response to vaccination than older parity sows. This is likely to be due to the younger age of the gilts relative to the sows. Since 90% of colostral antibodies are directly derived from serum (Bourne and Curtis, 1973), these results suggest that gilts are less able to transfer IgG antibodies to colostrum/milk than sows although the cause is currently unknown. This effect of parity on antibody transfer similarly occurs in cattle (Lui *et al*., 2008) although the cause is also currently unknown. A reduced ability of gilts to transfer antibodies into colostrum will contribute to a greater susceptibility to disease, and so increased incidence of disease among gilt progeny compared to sow progeny.

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Supported in part by the Pork CRC Ltd and Australian Pork Ltd.

Relationships Between Injuries and Locomotion and Productive Parameters of Sows

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Sows in intensive production are often housed on hard floors which may affect the strength and health of the feet. Slipperiness and roughness can also increase the risk of injury. In addition, agonistic behaviour may increase the risk of injury after mixing unfamiliar pigs or when stall-housed sows are allocated new neighbours. The literature suggests that lameness can reduce the productivity of farm animals. Green *et al.* (2002) concluded that feet/leg problems reduce milk production in cows. We tested the hypothesis that sows with higher injury scores and more locomotion difficulties had fewer piglets than 'sound' sows.

Two hundred and eighty-eight sows were studied across two housing treatments: groups of 80 sows on bedding; or individual housing in stalls. Successive groups entered treatment weekly over eight weeks and, within each group, data were collected from 18 sows balanced on parity (ie.6 parity 1, 6 parity 2 and 6 parity 3 and older). Measurements included number of scratches and abrasions at weeks 1, 9 and 15 of gestation; saliva cortisol concentrations at weeks 1 and 9 of gestation and locomotion scoring at weeks 9 and 15 of gestation. Liveweight and reproductive performance were also measured. Non-parametric correlations and linear regression were conducted using SPSS statistical package to examine the relationships between injuries, locomotion and cortisol concentrations during gestation and reproductive parameters. These relationships were examined using the means of each parity group within each treatment within each week of the study (n=48).

Table 1. *Correlation coefficients between injuries, locomotion scores and productivity.*

	Locomotion score		Piglets born alive		Piglets weaned	
	Correlation	P value	Correlation	P value	Correlation	P value
Locomotion score			0.019	.900	-0.372	.009
Scratches	-0.626	.000	0.056	.777	0.371	.009
Abrasions	0.611	.000	0.035	.813	-0.318	.028
Cortisol			-0.155	.293	0.067	.652

Table 2. *Regression coefficients predicting piglets weaned.*

Predictor variables	Standardised regression coefficient	P value
Locomotion score	-0.603	0.000
Housing (stall or group)	0.219	0.068
Parity (1, 2 or 3 and more)	0.199	0.095

Sows with a poor locomotion score weaned less (P<0.01) piglets and had more (P<0.05) abrasions while sows with a better locomotion score had more scratches (Table 1). The model that best predicted the number of piglets weaned per sow included the significant (P<0.01) average locomotion score at weeks 9 and 15, housing and parity. This model accounted for about 37% of the variance in number of weaned piglets (adjusted R2 = 0.366, F3,44 = 10.058, P = 0.000, using the backward method). The regression coefficient indicated that poor locomotion score, stall housing and young parity were associated with reduced piglet numbers (Table 2).

These data provide limited support for the hypothesis that sows with a poor locomotion score had fewer piglets weaned. These sows also had more abrasions suggesting that they may have spent more time lying down and therefore they had fewer scratches as a result of less interaction with other sows. However, more detailed research is clearly needed to confirm the relationships between fitness, injury and productivity of sows.

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Supported in part by Australian Pork Ltd.

Effects of Semen Age and Storage Time Prior to Artificial Insemination on Pregnancy Rate and Litter Size

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After collection, boar semen is diluted and stored in a variety of extenders until use for artificial insemination (AI). With classical extenders like BTS (Beltsville Thawing Solution, Minitube, Sebastopol, VIC), it is widely accepted that beyond 48 h, pregnancy rate and litter size decrease rapidly with storage time (Soede *et al*., 2003). However, in today's pig industry, semen is widely used up to five days after collection, a practice which is justified by the use of so called 'long-term extenders'. There is, however, little independent scientific evidence to support this justification and even a few reports that question the use of semen stored in long term extenders beyond 2-3 d (e.g. Kuster and Althouse, 1999). This paper presents effects of storage time and semen age at AI on pregnancy rates and litter size under South Australian conditions. It was expected that beyond 48 h of storage, fertility would be affected.

The data in this paper were obtained from three farms in South Australia, during winter/spring. The pooled semen (3 boars per dose) used in the study was collected within 48 h, 48 to 72 h, or 72 to 84 h prior to AI and diluted using Androhep® extender (Minitube, Germany). The collection and delivery schedule was designed such that on each day of AI, all three farms had semen of each category available for AI. Hence, all AI's on any day could be distributed equally over the three storage times and sows and gilts that were inseminated more than once could be inseminated with the same semen class on each occasion. Semen was transported to the farms in temperature controlled containers. The semen in the three different storage classes was packed in colour coded tubes, without the AI operators knowing which colour represented which class. Sows were checked for pregnancy using ultrasound at 4-5 weeks after AI. Data were analysed using GLM in SAS. For litter size, farm and parity (sow/gilt) were included as factors. There were no interactions. Pregnancy rate was analysed using Chi-square analysis.

Table 1. *Effects of semen storage time and age at artificial insemination (AI) on pregnancy rate and litter size.*

Storage time	Sows mated	% Pregnant	Total born	Born alive
< 48 h	190	92	12.2 ± 0.3	11.3 ± 0.2
48-72 h	171	88	12.1 ± 0.3	10.9 ± 0.3
72-84 h1	170	89	12.1 ± 0.3	11.1 ± 0.3

[1]Majority of AIs were performed in the morning. Hence, semen used was 72-84 h rather than close to 96 h old.

There was no effect of semen storage time and age at AI on pregnancy rate (P>0.10) and litter size (P>0.10; Table 1). For the three farms separate, there was also no effect of semen storage time. The three farms differed (P<0.05) in litter size: total born was 12.9±0.2, 12.0±0.2, and 11.6±0.3, respectively. This study was conducted in a time of the year (Jul-Nov 2008) when weather conditions were favourable to storage and transport of semen, and to reproductive performance in general. It would be interesting to study effects of storage time on reproductive performance in the summer time and also to extend the storage time beyond 4 d in future studies.

In conclusion, storage of semen for up to 84 h (over three days) before AI did not seem to affect pregnancy rate and litter size under the conditions in this study.

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Supported in part by the South Australian Pig Industry Fund.

Progeny Outcomes Following Maternal Treatment With Porcine Somatotropin During Pregnancy

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Low birth weight reduces piglet neonatal survival rates and postnatal growth and feed conversion efficiency. In gilts, maternal porcine somatotropin (pST) injections increase progeny birth weight when treatment is continued throughout most of pregnancy (d 25 to 100), but not if stopped in mid-pregnancy at d 50 (Gatford *et al*., 2004). Maternal pST treatment from d 25 to 50 of pregnancy increases fetal growth at d 50 in sows as well as gilts (Gatford *et al*., 2009), and we therefore hypothesised that a 75 d period of maternal pST treatment would increase progeny birth weight and postnatal performance in sow progeny as well as gilt progeny. The aim of this experiment was to demonstrate the effects of maternal pST treatment from d 25 to 100 on progeny finisher performance and carcase size.

Landrace x Large White (PrimeGro™ Genetics, Corowa, NSW) gilts and sows were uninjected (controls), or injected daily with pST (Reporcin® OzBioPharm, Knoxfield, VIC; gilts 2.5 $mg.d^{-1}$; sows 4.0 $mg.d^{-1}$,~15 $\mu g.kg^{-1}.d^{-1}$ in each), from d 25 to 50 or d 25 to 100 of pregnancy (n=120 per parity and treatment, 2 x 3 factorial design). Growth and individual feed intakes using electronic feeders were measured during the finisher phase, and carcase weight and P2 were recorded at slaughter, in littermates from the lightest, middle and heaviest third of birth weight for their litter, within each parity, treatment and progeny sex. Outcomes were analysed by repeated measures analysis of variance, with data from each piglet treated as a repeated measure on the dam.

Table 1. *Effects of maternal pST treatment and parity on progeny finisher and carcase weights (mean±SEM).*

	Gilt progeny			Sow progeny			Significance		
	Control	pST d25-50	pST d25-100	Control	pST d25-50	pST d25-100	Treatment (T)	Parity (P)	T*P
LW, finisher entry (kg)	62.5 ± 0.8	63.0 ± 0.7	64.6 ± 0.8	64.5 ± 0.7	65.6 ± 0.7	69.1 ± 0.6	<0.001	<0.001	0.207
LW, finisher exit (kg)	85.8 ± 0.9	85.1 ± 0.8	87.1 ± 0.9	86.6 ± 0.8	88.0 ± 0.7	91.2 ± 0.7	0.011	<0.001	0.377
Hot carcase weight (kg)	62.7 ± 1.1	63.6 ± 1.0	64.9 ± 1.1	65.1 ± 0.8	65.5 ± 1.0	69.5 ± 1.1	0.006	0.001	0.439

pST, porcine somatotropin; LW, liveweight; SEM, standard error of mean.

Progeny growth rates, daily feed intake and feed conversion efficiency as finishers, and carcase P2 fat depth were not altered by maternal treatments (data not shown). Maternal treatment with pST from d 25 to 100, but not from d 25 to 50 of pregnancy, increased progeny liveweight (LW) at entry and exit from the finisher period and increased progeny carcase weight compared to control progeny (+3 kg, P=0.007; Table 1).

Increased size at birth led to persistent improvements in progeny performance, resulting in ~3 kg heavier carcases from progeny of dams treated with pST from d 25 to 100 of pregnancy. Maternal pST treatment from d 25 to 50 did not increase birth weight or subsequent progeny performance which probably reflects maternal constraint in later pregnancy. Evaluation of a shorter period of maternal pST treatment in late gestation (d 75 to 100 of pregnancy) for increasing birth weight and progeny performance in gilts and sows is underway.

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Supported in part by the Pork CRC Ltd.

Comparison of Sialic Acid Content in Gilt and Sow Colostrum and Milk

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Sialyl-oligosaccharides provide important dietary monosaccharide units for brain gangliosides and glycoproteins that are integral to the development of cognitive function in the brain. They are also associated with the mucins forming the mucosal surface of the small intestine as well as other tissues. (Wang and Brand-Miller, 2003). Sialic acid (SIA) is also a major component of human milk oligosaccharides principally as N-acetylneuraminic acid (Neu5Ac) while bovine milk also contains a small amount of SIA in the form of N-glycolylneuraminic acid (Neu5Gc). Sialylated oligosaccharides associated with mucins act as highly specific receptors for viruses, bacteria and parasites to prevent infectious disease. We have therefore investigated if there are differences in SIA content of colostrum and milk from gilts and sows that may influence pig health and production.

Colostrum samples were collected by manual palpation from primiparous gilts and multiparous (parity 2-5) sows from a single farrowing (October, 2007) after the birth of the second piglet. Milk samples were collected on d 21 from the same animals during natural milk letdown, and both colostrum and milk were lyophilized and stored at -80°C. All animals were Large White x Landrace pigs in a commercial farrowing shed (Rivalea Australia Pty Ltd, Corowa, NSW). Samples were analysed in duplicate for the Neu5AC subclasses 3'Sialyllactose (3'SL) and 6'Sialyllactose (6'SL) by high-performance anion-exchange chromatography with pulsed amperometric detection (HPAEC-PAD) on CarboPac PA200 with an amino trap column guard. Neu5Ac and Neu5Gc were analysed by high-performance liquid chromatography (HPLC) with a fluorescence detector. Results were analysed using a one-way analysis of variance with SPSS for Macintosh 16.0 (SPSS Inc, Chicago, USA).

Table 1. *Concentrations (Mean (SEM)) of Neu5Gc and Neu5Ac and its 3'SL and 6'SL subclasses in gilt and sow colostrum (Col; mg/100g dry matter (DM)) and d 21 milk (d 21; mg/100g DM). N for each group is included (n=Gilt/Sow).*

	Neu5Gc		Neu5Ac		6'SL		3'SL	
	Col (n=10/5)	d 21 (n=10/7)	Col (n=10/5)	d 21 (n=9/7)	Col (n=5/5)	d 21 (n=5/5)	Col (n=5/5)	d 21 (n=5/5)
Gilt	38 (1.7)	6 (0.7)	1260 (72)	432 (15)	67 (13)	65 (9.8)	1012 (75)	240 (19)
Sow	47 (3.5)	6 (0.5)	1313 (128)	443 (19)	120 (13)	60 (5.4)	1081 (121)	243 (16)

Neu5Ac is the dominant SIA (~97%) in porcine colostrum and d 21 milk. Both Neu5Ac, Neu5Gc and 3'SL were expressed at significantly higher ($P<0.001$) levels in colostrum than in d 21 milk with 3'SL representing the major SL component in all samples. In comparing the effect of parity, total SIA (Neu5Ac + Neu5Gc) was approximately 4% higher in sow than in gilt colostrum/milk but the difference was not significant. However the higher levels of Neu5Gc expressed in sow colostrum compared to gilt colostrum were significant ($P<0.018$) although a similar difference was not observed in d 21 milk. Although 3'SL status did not differ between sows and gilts, the concentration of 6'SL was significantly higher ($P<0.05$) in sow colostrum relative to that from the gilt: this difference, however, was not apparent in d 21 milk.

Differences in observed SIA content may have a number of impacts on piglet growth as it is conceivable that SIA availability may potentially influence gastrointestinal resistance to pathogenic infection as well as cognitive processes and therefore important behaviours like suckling. The differences reported here suggest that SIA content in colostrum and milk may be worthy of further investigation including assessment of the impact of dietary SIA supplementation of gilt progeny at farrowing on disease resistance and subsequent growth to weaning.

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Supported in part by the Pork CRC Ltd.

Risk Factors Associated With Pigs That Have Reduced Post-Weaning Growth Performance and/or Survivability

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Weaner pigs commonly have a post-weaning growth check due to a low feed intake for approximately 10 days post-weaning. Failing to eat after weaning has a profound and long lasting effect on growth, as the digestive tract and the body reserves of the piglet are compromised (Bruininx *et al.*, 2001). Furthermore, approximately 4% of pigs weaned do not survive through to the end of the weaner phase. It is hypothesized that there are pre-weaning factors that affect rate of gain and survival in the post-weaning period. Therefore, the aim of this experiment was to identify the risk factors that are associated with pigs that have poor rate of gain and survivability within 13 d post-weaning.

One thousand, five hundred and forty pigs (Large White x Landrace, PrimeGro™ Genetics, Corowa, NSW) pigs were monitored from birth to 150 d of age. Individual live weight measures were taken at birth, 26 (weaning) and 39 d of age (13 d post-weaning). The teat order (1=anterior teat pair down to 8=posterior teat pair) of piglets was recorded at 21 d of age. The feeding behaviour of all pigs was observed continuously for 24 hr post-weaning and the time taken for each individual piglet to feed post-weaning was measured. A subset of the pigs (192 pigs) were intensively observed. In addition, their birth viability score, time taken to initiate sucking, rectal temperature 60 min post-birth, 24 hr liveweight and piglet plasma immunoglobulin G (IgG) 24 hrs post-birth were measured. The association between these factors measured and rate of gain (ROG) for 13 d post-weaning, and survivability up until 150 d of age were analysed by Pearson's bivariate correlation, two-tailed analysis (SPSS, Version 17).

Table 1. *Pearson correlation coefficients between piglet characteristics, rate of gain (ROG) and survivability (N in brackets).*

	ROG 0 to 13 d post-weaning	Survivability (Died) between 26 and 150 d of age
Birth weight	0.233** (1124)	-0.013 (1526)
Viability score	0.275** (126)	-0.136 (191)
Time to first suck	-0.002 (126)	0.343** (191)
Rectal temperature (60 min post-birth)	0.208* (125)	-0.273** (189)
24 hr weight	0.272** (125)	-0.355** (178)
IgG (24 hrs post-birth)	0.257** (115)	-0.143 (163)
Teat order	0.117* (467)	0.022 (148)
Weaning weight	0.04 (1101)	-0.057* (1485)
Time taken to feed post weaning	-0.088** (909)	0.038 (939)

*, P<0.05; **, P<0.01.

There are pre-weaning factors that affect ROG and survival in the first 13 d post-weaning. Pigs are at risk of having a poor ROG in the first 13 d post-weaning if they have a low birth weight, low viability score at birth, low rectal temperature 60 min post birth, low 24 hr liveweight, low IgG concentrations (indicating inadequate colostrum intake), have sucked from anterior teats of the sow and have a long duration to feed post-weaning. Pigs are at risk of not surviving post-weaning if they have a long duration to first suck post-birth, low rectal temperature 60 min post-birth, low 24 hr post-birth weight and a low weaning weight. Strategies to increase birth weight, decrease time to first suck post-birth, increase weaning weight, and decrease time taken to feed post-weaning need to be investigated.

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Supported in part by the Pork CRC Ltd.

Longevity to the Second Parity Requires Good Attention to Sow Health In The First

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Difficult parturition, infection, and the use of hormones (such as oxytocin) are postulated as causes of sow stress at farrowing. These stressors can reduce the probability of a sow completing a full lactation or farrowing in the next parity. It is the purpose of this study to assess whether sows treated for health issues have a reduced probability of farrowing in the second parity. The presence of such stressors can be inferred from individual medication data. Approximately 2000 records for farrowed primiparous sows were collected from two maternal lines (Primegro GeneticsTM, Corowa, NSW) between January 2007 and June 2008. Production and medication records for individual sows were available in the study data. The medication events were broken down to the categories of 1) oxytocin, 2) antibiotics 3) analgesics plus anti-inflammatories and 4) other treatment. A binary trait, FAR2, identified whether sows farrowed in parity 2 (0=no; 1=yes). All factors significantly affecting the incidence of FAR2 were then identified using logistic regression (Proc LOGISTIC, SAS Institute). Information on medication events were added as potential risk factors to previous models developed by Bunter *et al.* (2008). Significant factors were identified by fitting a full model containing many effects, then eliminating non-significant effects sequentially based on their Wald test statistic to obtain the final model. Factors that contribute to FAR2 and the odds-ratios for binary effects are presented in Table 1. The odds-ratio compares the ratio of incidence for animals with and without the risk factor (where the odds-ratio = 1); a value of <1 indicated a reduced incidence relative to the reference level.

Table 1. *Significant (P<0.10) risk factors that affect the ability of the sow to farrow in her second parity.*

Risk factor	P value	Odds-ratio	Compared to
Seasonal (Year/Quarter)	<0.001	–	
Gestation gain (kg)	0.02	–	
Shortened lactation (0/1)	<0.001	0.159	Normal lactation
Lactation length (d)	0.02	–	
Average fat depth (mm)	<0.001	–	
Sow weight d 110 (kg)	<0.001	–	
Antibiotic alone	0.07	0.783	No antibiotics
Antibiotic+analgesic+anti-inflammatory	0.06	1.473	Antibiotic use

Of 1885 weaned primiparous sows, 73% of these went on to farrow in parity 2 and 5% were transferred while pregnant. Seasonal effects, weight gain during gestation, sow fatness prior to farrowing and shortened lactation length were effects significantly (P<0.05) associated with FAR2. In addition to these known important factors, there was also a tendency (P<0.10) for sows requiring antibiotic treatment to have reduced survival to parity 2 even when this treatment was combined with non-steroidal anti-inflammatories and analgesics. Sows requiring antibiotics at or after parturition or during lactation were 22% (95% Wald confidence interval for odds-ratio = 0.59-1.02) less likely to farrow in parity 2. However, this outcome was improved with additional analgesics. Hoy (2006) suggested that swift treatment of post-farrowing health issues, particularly in primiparous sows, reduced sow and piglet losses and improved reproductive performance in the subsequent parity. Oxytocin use in this dataset was partly confounded with season and thus no inferences can be drawn, while the other treatment category was also not significant. This study suggests developing strategies to prevent sow health issues at farrowing may yield improved results for sow longevity, since treated sows were less likely to be retained in the herd.

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Supported in part by the Pork CRC Ltd.

Technical Aspects of Unilateral Ovariectomy in Gilts

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Embryo mortality in pigs ranges from 10 to 40% of the fertilized oocytes. Progesterone (P_4) is an important driver of endometrial function, and as such is important for early embryo survival. Most studies assess P_4 concentration in peripheral blood circulation during early pregnancy. However, evidence suggests that P_4 is transferred directly from the ovary to the uterus by counter-current exchange (Stefanczyk-Krzymowska *et al*., 1998) resulting in a 'local' supply of P_4 to the uterus. The significance of this 'local' supply of P_4 remains unclear and in order to investigate its role in embryo survival a unilateral ovariectomy (ULO) model was used. The ULO model allows any potential differences between one uterine horn that relies solely on peripheral P_4 and one that is supplied by both local and peripheral P_4 to be seen. The remaining ovary compensates for the lost ovary in terms of ovulations thus resulting in an equal number of potential embryos making it comparable to intact animals (Kramer and Lamberson, 1991). This compensation should result in an equal supply of P_4 in peripheral blood circulation as there is also an equal number of corpora lutea. Distribution of embryos is also assumed to be equal across horns as pig embryos are known to migrate throughout the entire uterus before implantation, irrespective of the oviduct fertilization occurs in (Dhindsa *et al*., 1967). This technical paper compares ULO gilts to intact gilts in order to identify whether ULO is a suitable model for assessing the effects of local P_4 and does not have any adverse effects on ovulation rate and peripheral P_4 concentration.

During their first oestrous cycle, thirty crossbred gilts were subjected to ULO within the first 10 d of the luteal phase in order to allow sufficient time for ovarian compensation before the next oestrus period. Ten gilts were kept intact and served as controls (CTR). Gilts underwent anaesthesia and the ULO was performed by mid-ventral laparotomy. The right ovary was removed in half of the gilts and the left ovary in the other half. Gilts were mated during the next oestrus. CTR gilts were fed at 1.8 x maintenance (M), whilst gilts in the ULO treatment received a 2.4M or 1.2M (half each). Differences in feeding level were used on the basis that a high feeding level may exaggerate the difference in local P_4 supply between horns. Peripheral blood samples were taken on d 5, 10, 15 and 30 of pregnancy. Gilts were slaughtered on d 35 of pregnancy.

Table 1: *Ovulation rate (#CLtot) and peripheral progesterone (P4) concentration (mean±SE) in gilts.*

			Peripheral P_4 concentration (ng/ml)			
Treatment	n	#CLtot	Day 5	Day 10	Day 15	Day 30
CTR	10	15.9±0.08	14.2±1.41	22.3±2.70	19.6±2.03	16.3±1.94
ULO	30	15.8±0.04	17.2±1.60	26.4±1.90	23.6±2.10	16.4±1.48
P value[1]		NS	NS	NS	NS	NS

[1]Data analysed by analysis of variance; NS, not significant (P>0.05); CTR, control; ULO, unilateral ovarectomy

ULO gilts did not differ significantly from that of control gilts in terms of number of ovulations and peripheral P4 concentration. In ULO gilts the mean distance of all embryos from the tip of the ovariectomised horn was 68±1.7 cm, and in CTR gilts it was 77.5±4.2 cm (P>0.05). In ULO gilts, the mean number of embryos in the proximal 60cm of the ovariectomised horn was 2.5±0.14, and in CTR gilts it was 2.4±0.18 (P>0.05). These results indicate that the ULO model has no adverse effects on these parameters making it comparable to that of an intact animal for use in studies comparing the effect of local P_4 versus peripheral P_4 on embryo survival.

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Supported in part by the Pork CRC Ltd.

Evaluation of the Supplementation of Complexed Trace Minerals on the Number of Claw Lesions in Breeding Sows

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Lameness is a major reason for decreased sow longevity in pig breeding herds. Claw lesions, especially severe white line and side wall lesions are reported to be associated with lameness in sows. Despite the high prevalence of claw lesions, minimal research has focused on claw lesions in pigs and continues to be a limiting factor in development of management practices to reduce claw lesions and lameness. Although housing conditions and management on the farm are important for the development of claws and prevention of claw lesions in pigs, nutrition, especially of trace minerals, may also act as a predisposing factor. Nutrition is vital in developing the hoof structure and the importance of trace minerals in the keratinisation process has been reported previously (Tomlinson *et al*., 2004). Feeding complexed trace minerals reduced the number of dairy cows culled before week 36 postpartum and improved claw integrity compared to cows fed a sulphate trace mineral diet (Siciliano-Jones *et al*., 2008). This study, hypothesised that dietary supplementation of complexed trace minerals (CTM, bonding individual trace minerals to single amino acids) would reduce the prevalence of claw lesions in breeding female pigs. The present study was conducted to determine the effect of a partial substitution of CTM of Zn, Mn and Cu for ordinary inorganic sulphate trace minerals (ITM) in breeding female pigs. The key response variable, number of claw lesions, was measured across two consecutive locations and the intervening gestation.

This study used 237 commercial cross sows of mixed parity, randomly allotted to one of two treatments and housed in conventional gestation stalls at the research station of the University of Minnesota. The sows were fed either a control diet containing ITM (N=124; Zn 125 ppm, Mn, 40 ppm and Cu, 15 ppm) or a diet containing CTM (N= 113) as a partial substitution of inorganic minerals (Zn, 50 ppm; Mn, 20 ppm; Cu, 10 ppm) fed at equal levels of mineral supplementation. The lesions in different claw areas (side wall, heel, white line, heel-sole junction and sole) of these sows were counted by a trained person in two consecutive parities at mid-gestation using a mechanical chute designed for the purpose. The total numbers of lesions in different claw areas, in lateral and medial claws and in front and hind limbs were obtained by adding up the component counts. The associations of supplementing trace minerals with the number of lesions were analysed (Univariate analyses, Proc Genmod, SAS V 9.1) using Poisson regression or negative binomial regression with sow as a repeated variable (Table 1).

Table 1. *The associations of supplementing complexed trace minerals with the number of claw lesions in stall-housed sows (ITM, n= 124; CTM, n= 113).*

Variables	Parameter estimate	P value
Total number of hind limb lesions	0.1611	0.041
Total number of lateral claw lesions	0.1445	0.059
Total number of lesions	0.1352	0.064
Total number of sole lesions[a]	0.4461	0.043

[a] Poisson regression. ITM, inorganic sulphate trace minerals; CTM, complexed trace minerals; n, number.

Results demonstrate that the sows in the ITM group had 17% more (P<0.05) lesions on the hind limbs than the sows in the CTM group. Both the total number of lesions as well as the number of lesions on lateral claws tended to be higher (P<0.07; 14 and 16% respectively) among sows fed ITM. Sows fed ITM had 56% more (P<0.05) lesions on the sole than sows fed CTM. The results of this study support the beneficial effect of feeding CTM to decrease claw lesions in breeding female pigs.

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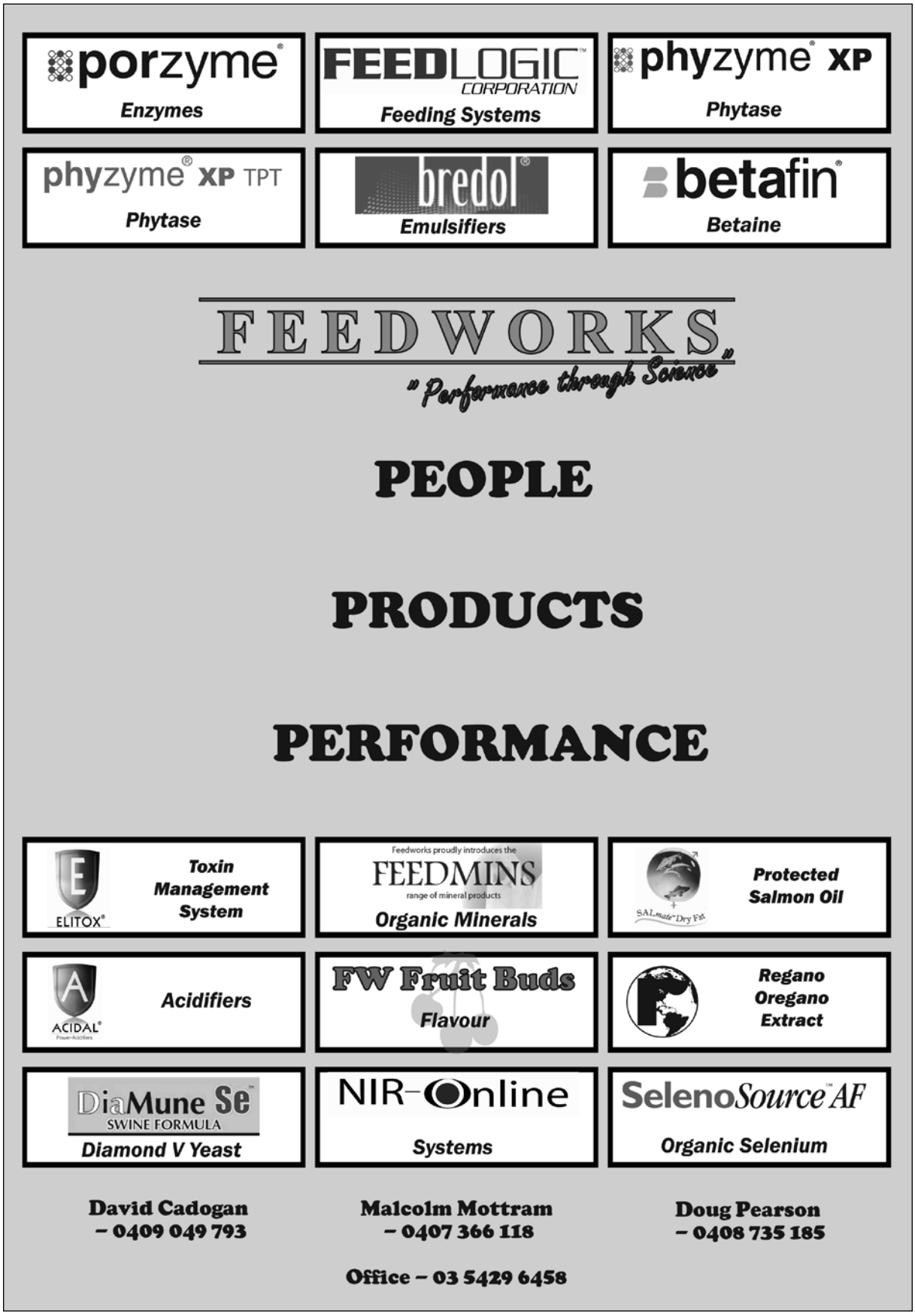
CHAPTER 5

Nutrition and Feed Evaluation


porzyme
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Feeding Systems
phyzyme XP
Phytase
phyzyme XP TPT
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bredol
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Betaine
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Influence of Feed Access and Bedding Material Type on Diet Composition and Diet Dry Matter Digestibility in Growing Pigs

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The Australian pig industry has rapidly adopted deep-litter housing systems for both the growing herd and to a lesser extent the breeding herd. However, the consumption of an edible bedding material (eg. straw, rice hulls) may result in reduced overall nutrient and energy digestibility of the diet. With diets formulated to meet specific pig requirements, the dilution effect of bedding material is likely to result in effects on growth and carcase quality. The aim of this experiment was to define the influence of fresh bedding material consumption on the digestibility of a formulated diet and any additional effects from diet interruption.

Forty male finisher pigs (commercial genotype, average weight 62 kg) were allocated to individual pens in a randomised complete block design, Pens were one-third solid, two-thirds clay slat (2.8 m2/pig) within a climate-controlled research facility. A frame was constructed around the solid part of the pen to facilitate the presentation of bedding material (barley straw or rice hulls) with spoiled material removed daily and replenished. Pigs were offered a finisher diet (13.5 MJ digestible energy (DE)/kg, 0.55 g available lysine/MJ DE) including 200 mg/kg of n-hexatriacontane (C-36) as an alkane marker. There were two dietary treatments: *ad libitum*, or an interrupted treatment, where feed was offered *ad libitum* on d 1 and at half the amount consumed on d 1 on the subsequent day, with this two-day cycle continuing for 21 d. Faecal samples were collected on a weekly basis and to avoid cross-contamination pens were washed and the next voided sample was collected. Alkane profiles in the bedding material, diet and faeces were determined by gas chromatography (Dove and Mayes, 2006). Diet composition and dry matter digestibility was estimated from the alkane profiles of the diets, bedding materials and faeces (*EatWhat*; Dove and Moore, 1995), after correction of faecal profiles for incomplete alkane recovery (Wilson *et al.*, 1999). Data were subjected to analysis of variance and separated by least significant differences (P<0.05).

Table 1. *Average daily feed intake of diet, dietary bedding material content and diet dry matter digestibility of finisher pigs offered bedding material and subjected to an ad libitum or interrupted feeding regimen.*

Bedding material	Feeding regimen	Diet average daily feed intake (kg/d)	Bedding material intake (% of diet)	Dry matter digestibility (%)
Nil	*Ad libitum*	2.80[ab]	–	84.8[a]
Barley straw	*Ad libitum*	3.00[b]	4.1[a]	80.2[b]
Barley straw	Interrupted	2.69[a]	5.2[a]	79.5[b]
Rice hulls	*Ad libitum*	2.90[ab]	14.2[b]	79.6[b]
Rice hulls	Interrupted	2.69[a]	13.3[b]	80.0[b]
P value		0.020	<0.001	<0.001

[ab]Means in a column with different superscripts differ significantly.

The intake of formulated diet under the interrupted regimen was significantly lower than those fed *ad libitum* with access to barley straw (P=0.020, Table 1). In general, pigs fed *ad libitum* consumed more feed when given access to bedding material. Rice hulls formed a significantly greater proportion of the diet than did barley straw (P<0.001), irrespective of the feeding regime, which did not influence consumption of the finisher diet. Consumption of both barley straw and rice hulls reduced diet dry matter digestibility (P<0.001), but the extent of the decrease was similar despite barley straw consumption being approximately one-third of rice hull consumption. These results suggest that feed interruption will not have a significant effect on the level of bedding material intake, and regardless of bedding material type or intake, diet dry matter digestibility will reduce by approximately 5%.

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Supported in part by Australian Pork Ltd.

Performance of Pigs Fed Cassava Starch Residue in Diets

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Cassava in Vietnam, aside from its use in animal feeding, is also an important crop for production of cassava flour for human nutrition. Correspondingly, there are numerous processing plants which process cassava root to extract high value cassava starch. The wet cassava residue, or the material otherwise known as pulp or bagasse, resulting from starch extraction in these processing plants then undergoes sun-drying, both to remove cyanide (HCN) and to produce a storable dry product. Despite the nutritive value (616 g/kg starch and 11.5 MJ digestible energy (DE)/kg content) and low HCN risk (Kopinski *et al.*, 2007) and relative cost of cassava residues, feed mills have been reluctant to increase the inclusion levels above 8-10% in pig diets. To address this, the current study was conducted to examine the performance of pigs fed diets containing various inclusion levels of cassava residues.

A total of 192 Yorkshire x Landrace pigs with an average initial body weight of 21±0.11 kg were allocated randomly to four treatment diets containing various cassava residue inclusion levels, with four replicates and 12 pigs/pen as the experimental units. Pigs were fed pelleted diets formulated to the nutrient specifications for Vietnamese pigs (grower diets containing 13.64 MJ DE/kg, 6.6g lysine/MJ DE and finisher diets of 12.76 MJ DE/kg, 6.3g lysine/MJ DE). Treatment 1 was a control diet based on corn, rice bran, wheat bran, soybean meal and fishmeal with 0% cassava residue inclusion. Treatment 2 was a similar balanced diet with wheat bran and corn replaced by cassava residue inclusion at 100 g/kg in the grower diet and at 150 g/kg in the finisher diet. In Treatment 3, the cassava residue inclusion was at 150 g/kg in the grower diet and at 250 g/kg in the finisher diet. In treatment 4, the grower diet had an inclusion level of 200 g/kg cassava residue and the finisher diet had a 35% cassava residue inclusion. Experimental data was statistically analyzed by analysis of variance using MINITAB® 13.3.

Table 1. *Performance of pigs fed various inclusion levels of cassava residue in grower and finisher diets.*

	Cassava residue (g/kg)		ADG (g/day)		ADFI (kg/day)		FCE (g/g)		FC/G
Treatment[1]	Grower	Finisher	Grower	Finisher	Grower	Finisher	Grower	Finisher	(VND)
1	0	0	578[a]	773	1.48	2.42	2.55[a]	3.13	9,213[a]
2	100	150	568[ab]	765	1.48	2.43	2.60[a]	3.18	9,089[ab]
3	150	250	559[b]	776	1.47	2.42	2.62[a]	3.12	8,909[b]
4	200	350	533[c]	774	1.48	2.41	2.77[b]	3.11	9,035[b]
SEM			5.7	6.1	0.016	0.019	0.032	0.028	54

[abc]Means within columns with different superscripts differ significantly (P< 0.05); ADG, average daily gain; ADFI, average daily feed intake; FCE, feed conversion efficiency; FC/G, Feed cost per gain; VND, Vietnam Dong; [1]Experimental treatments described in text above.

Feeding cassava starch residue in diets up to inclusion levels of 100 g/kg for grower pigs and at up to 350 g/kg for finisher pigs resulted in no adverse effects on growth, feed intake or feed efficiency (Table 1). Inclusion of more than 100 g/kg cassava starch residue in grower diets (at 150 g/kg inclusion level) significantly reduced (P>0.05) growth but not feed efficiency. Despite significantly reducing growth during the grower phase when cassava is included in grower diets above 100 g/kg, there are significant cost savings (P<0.05) if cassava is included up to 200 g/kg in grower and 350 g/kg in finisher diets.

KOPINSKI, J.S., KINH, L.V., VINH, D., NINH, P.H. and BURREN, B. (2007.) In "Manipulating Pig Production XI", p.118, eds J.E. Patterson and J.A. Barker. (Australasian Pig Science Association: Werribee).

Supported in part by the Australian Centre for International Agricultural Research.

Ileal Digestibility of Grains Also Includes Fermentation as Indicated by End-Products

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Measurement of ileal digestibility assumes that the energy losses from microbial fermentation in the small intestine are negligible. However, the pig has an active microbial population present in the small intestine (Leser *et al.*, 2002). Given that grains are often the largest component of the pig diet, the aim of this experiment was to evaluate whether there were significant differences between four grain types, in terms of some fermentation characteristics found at the terminal ileum of pigs fed the grains.

Ileal digesta was collected from male pigs (commercial genotype; ~35kg, n=40), fitted with a simple T-piece cannula 15 cm anterior to the ileo-caecal valve. The design was based on a non-resolvable incomplete block with four runs over 16 weeks. Each pig was used four times within a run and the 32 diet treatments were replicated five times. The diets comprised mainly the test grain (~94%) combined with vitamins, minerals and an acid-insoluble ash marker. Seven barley, ten sorghum, five triticale and nine wheat grains were tested. One sorghum diet was repeated with the additive Zingibain (a protease extracted from ginger; Natbio Pty Ltd., Annerley, QLD). Samples were collected 1 hour after feeding on d7 after introduction of the diet, and analysed for characteristics of fermentation such as short-chain fatty acids (SCFA), ammonia (NH3), and dry matter. A linear mixed model was used to analyse the data in ASReml-R (Butler *et al.*, 2007), which had fixed effects for sample site, grain type, variety and Zingibain and their interactions, and random effects for pig, run and cage.

Table 1. *Comparison of four grain types for their ileal fermentability characteristics.*

	Barley	Sorghum	Triticale	Wheat	P Value
DryMatter (%)	12.4	12.5	12.6	11.9	NS
Ash (%, DM)	21.3[a]	26.1c	23.4[b]	26.6[c]	0.026
NH_3(µg)	393	439	409	456	NS
Acetic (g/kg, DM)	7.5	9.1	7.9	8.7	NS
Propionic (g/kg, DM)	0.34	0.54	0.31	0.50	NS
n-Butyric (g/kg, DM)	1.19	0.83	0.99	0.99	NS
Total SCFA (g/kg, DM)	10.2	11.0	9.8	11.2	NS
Lactic acid (g/kg, DM)	13.5	13.2	16.6	11.8	NS

[abcd] Means in the same row with different superscripts differ significantly (P<0.05); NS, not significant; DM, dry matter..

Evidence of fermentation was detected at the terminal ileum for all grain types (Table 1). Variation in SCFA profiles were not statistically significant (P>0.05), particularly at the low concentrations detected, and given the large variation between individual pigs. We tentatively conclude that these grain species did not differ in their small intestinal fermentability, so while losses to digestibility values do occur, the losses should be similar between grains. Similar values for total SCFA and lactic acid indicate an active lactic-acid producing microbial population. Further work is required to quantify which fraction of grain is fermented, rather than digested by enzymes.

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BUTLER, D., CULLIS, B., GILMOUR, A. and GOGEL, B. (2007). ASReml-R Reference Manual. (Queensland Department of Primary Industries and Fisheries).

Supported in part by the Pork CRC Ltd.

Manipulation of the Digestible Energy Content of Sorghum Through Fermentation

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[3]Barneveld Nutrition Pty Ltd, Springwood, QLD 4127.

Countries, such as those in the European Union, have regulated the use of in-feed antibiotics and have focused on alternative methods, such as fermented liquid feed (FLF), as a means of controlling diseases, while maintaining growth performance. However, few studies have examined the influence of fermentation of cereals in FLF systems on the digestible energy (DE) content for growing pigs, especially in grains such as sorghum. The aim of this experiment was to determine DE content of the fermented cereal component of liquid diets, with or without additives aimed at manipulating the ferment, for growing pigs.

Twelve crossbred entire male pigs (49±1kg) housed individually, were allocated in a randomised complete block design to compare the DE content of sorghum with four treatments: (1) fermented sorghum from commercial fermentation tanks; (2) fermented sorghum; (3) fermented sorghum with molasses at 2% of the diet, and (4) fermented sorghum with sarsaponin (DK Sarsaponin Liquid (*Yucca Schidigera*), Feedworks Pty Ltd, Romsey, VIC) at 500ppm of the diet. Treatments 2, 3 and 4 were fermented in small drums to replicate the commercial FLF system used on farm (from which treatment 1 was derived), so greater control could be exercised over the fermentation process (eg. to assist with back-slopping residue). The diets were comprised of approximately 830 g/kg of sorghum, with the remainder a combination of protein meals, amino acids, vitamins and minerals. All four diets were tested simultaneously with 3 replicate pigs per treatment. Following a 7 d adaptation period, total collection of faeces and measurement of feed intake was undertaken for 6 d. The DE content of the test diet as formulated was 13.5 MJ/kg. This was used as a basis to determine the amount of feed for each pig at 3 x maintenance using the equation: (3 x 0.5 $LW^{0.75}$)/DE. Total feed intake was calculated using the dry matter (DM) intake multiplied by 3.7, as each diet was mixed to a cereal to water ratio of 1:3.7. Analysis of variance was used to determine the effect of different dietary treatments on the energy digestibility (%), diet DE (MJ/kg DM) and DE (MJ/kg DM) of fermented sorghum.

Table 1. *Diet energy digestibility (%), diet digestible energy (DE;MJ/kg DM) and sorghum DE (MJ/kg DM).*

Treatment	Diet energy digestibility	Diet DE	Sorghum DE
Sorghum CF	84.28	15.37	16.03
Sorghum EF	79.05[b]	14.57[b]	15.03[b]
Sorghum EF + Molasses	86.18[a]	15.68[a]	16.40[a]
Sorghum EF + Sarsaponin	84.18[a]	15.43[a]	16.10[a]
SEM	1.263	0.203	0.285
P value[1]	0.018	0.033	0.032

[ab]Means within the same column with different superscripts differ significantly (P< 0.05); SEM, standard error of mean; DM, dry matter; CF, commercial fermentation; EF, experimental fermentation; [1]Treatment 1 was excluded from statistical analysis given the fermentation was not controlled.

Fermented sorghum DE was comparable to the average DE of 16.6 MJ/kg DM of sorghum grain reported by van Barneveld (1999) suggesting that fermenting sorghum might have minimal influence on DE. However, the addition of molasses or sarsaponin significantly increased the DE of sorghum compared to sorghum fermented alone (Table 1). Molasses likely aided fermentation by providing a readily available source of carbohydrates, whereas sarsaponin may have helped to aid in hydrating the sorghum grains so that endogenous enzymes could increase the nutrient availability of the feed. While further evidence is required to establish the DE of fermented versus unfermented sorghum, these results suggest that use of additives during the fermentation process can enhance the DE content of sorghum.

VAN BARNEVELD. R.J, (1999). *Australian Journal of Agriculture Research*. **50**:667-687.

Supported in part by Australian Pork Ltd.

Effect of Particle Size on Hydration Properties of Barley and Sorghum

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[3]Department of Industry and Investment, Orange, NSW 2800.

The hydration properties of animal feed are important because water content (i) facilitates starch gelatinisation, (ii) controls particle sedimentation in liquid feeding systems, (iii) determines exposure of the starch for digestion by α-amylase, and (iv) allows the release of low molecular weight amylase hydrolysis products so that they can be absorbed (Doucet *et al*., 2007). Two quantitative parameters that evaluate the swelling and solubility behaviour of the starch component of cereal flours in excess water are water absorption index (WAI; the volume occupied by the hydrated starch following swelling in excess water) and water solubility index (WSI; the amount of soluble polysaccharide released from the granules to the aqueous phase) (Seker *et al*., 2003). During hydrothermal treatment, such as steam pelleting, there is limited water available to induce gelatinisation and the distribution of particle size can affect starch gelatinisation. It is hypothesised that starch gelatinisation will be lower for big particles as a result of lower WAI and that smaller particles have a higher WAI. Our aim was to demonstrate that within samples of milled grain (barley or sorghum) different particle size ranges show major differences in their hydration and solubility properties.

Barley and sorghum were separately hammer milled through a 4 mm sieve. WAI and WSI measurements (Seker *et al*., 2003) were made on either the unsieved ground material, or milled grain fractionated with sieves (4.7, 2.8, 1.7, 1.0, 0.50, 0.25, 0.125 and 0.045 mm). A random incomplete block design with two replicates was used, where a period of two days formed a replicate (Table 1). The data was analysed in ASReml-R using linear mixed model methodology with fixed effects of grain type and sieve size and their interaction and random terms of replicate and day.

Table 1. *Fraction yield and predicted WAI and WSI for different particle sizes of barley and sorghum.*

		Particle size (mm)								
		0.045	0.125	0.25	0.50	1.0	1.7	2.8	4.7	Unsieved
Barley	Yield (%)[1]	2.3	2.8	7.2	19.7	39.8	25.5	2.4	0	
	WAI (g/g)	9.0^{f}	11.5^{g}	8.8^{f}	6.7^{e}	3.5^{c}	2.1^{b}	0.9^{a}	-	4.5^{d}
	WSI (g/g)	2.5^{b}	2.9^{c}	3.9^{f}	3.4^{e}	2.8^{c}	2.6^{b}	2.1^{a}	-	3.2^{d}
Sorghum	Yield (%)[1]	1.9	5.2	16.2	38.6	29.1	6.6	1.3	0	
	WAI (g/g)	4.8d^{e}	4.8d^{e}	5.3^{e}	4.6^{d}	2.7^{b}	1.8^{a}	1.6^{a}	-	4.0^{c}
	WSI (g/g)	2.5b^{c}	2.5^{b}	2.7^{d}	2.8^{d}	2.4^{b}	2.5^{b}	1.9^{a}	-	2.7^{cd}

^{abcdefg} Means in the same row with different superscripts differ significantly (P<0.05). [1]Yields do not sum to 100% due to minor losses during sieve fractionation; WAI, water absorption index; WSI, water solubility index.

Particle size fraction was shown to have a highly significant effect on WAI (P<0.001) and WSI (P<0.001) (Table 1). As a consequence, conventional milling of grains leads inevitably to highly heterogeneous hydration properties (WAI and WSI) as individual particles vary greatly in size and chemical composition (data not shown). The data suggests that the hydration properties of unsieved materials give incomplete information about hydration properties. It can be concluded that uniformity of particle size distribution can minimise heterogeneity of hydration properties of ground grains and could affect pellet quality after processing.

DOUCET, F.J., WHITE, G., WISEMAN, J. and HILL, S.E. (2007). In "Recent Advances In Animal Nutrition 2006", pp. 313–330, eds P.C. Gamsworthy and J Wiseman. (Nottingham University Press, Nottingham, UK).

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Supported in part by the Pork CRC Ltd.

Processing Influences the Nutritional Composition of Pig Grower Diets

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Variations in pellet quality are an ongoing source of frustration for both stock feed manufacturers and pig producers and occur despite increasingly sophisticated procedures for process control and ingredient description and selection. Industry generally characterizes the feeding value of ingredients from analyses of the unprocessed material while animal feeds are complex mixtures of usually heat-processed feed ingredients. In addition to the potential implications for on-farm feed use efficiency, the extent to which processing conditions influence feed characteristics are of key concern in the application of new technologies such as microwave and near infrared spectroscopy to the on-line control of feed manufacture systems. This paper reports on some chemical characteristics of feed mixtures before and after processing in a survey of processing conditions and ingredient inclusions in commercially manufactured pig grower feeds.

Grower feeds formulated to contain similar raw materials and provide 13.8 MJ digestible energy (DE)/kg and 0.68g available lysine/MJ DE were manufactured at two stock feed mills with different conditioning and pelleting systems. Incomplete block designs with two replicates were randomized separately for use at each mill. Samples were collected after mixing (milled) and after processing (pellet). Data from each mill were analysed separately because of differences in grain source and treatments. A linear mixed model was used to analyse the data which had fixed effects for sample site and treatment and their interaction and random effects for replicate and day within replicate. Protein, fat and fibre were determined using methods of the AOAC (2007). Starch and damaged starch (DS) were determined using glucometry (Megazyme International Ireland Ltd, Wicklow, Ireland).

Table 1. *Chemical components of pig grower feeds before (Milled) and after processing (Pellet).*

	Mill 1			Mill 2		
Component	Milled	Pellet	P Value	Milled	Pellet	P Value
Protein (g/kg)	177	172	*	186	181	NS
Moisture (g/kg)	108	114	**	86	81	NS
Fat (g/kg)	26	32	***	38	37	NS
Fibre (g/kg)	31	31	NS	31	29	**
Starch (g/kg, DM)	527	515	NS	521	512	NS
DS (g/100g starch)	3.7	7.2	***	2.7	4.1	***

NS, non significant; * P<0.05; ** P<0.01; *** P<0.001; DS, damaged starch; DM, dry matter.

Within Mill 1, the protein, moisture, fat, and damaged starch contents differed significantly due to processing (Table 1). Only protein and damaged starch contents were affected in Mill 2. Irrespective of the mill, processing increased damaged starch, and this might improve animal performance (Tester *et al.*, 2006). Generally, feed processing is affected by throughput, conditioning, moisture, and additives. These parameters, individually or collectively, influenced the measured changes in the feed components. Although similar raw materials were used in both mills, differences between the mills likely reflect environmental and processing differences. Differences in feed components can affect on-line process control, feed properties and on-farm feed performances, and future studies are required to investigate the inter-dependencies.

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS (AOAC) (2007). *Official Methods of Analysis 18th Edition,* editors W. Horwitz and G. Latimer.

TESTER, R.G., QI, X. and KARKALAS J. (2006). *Animal Feed Science and technology*. **130**:39-54.

Supported in part by the Pork CRC Ltd.

Specific Mechanical Energy, Pasting And Digestibility Properties of Sorghum: Implications for Feed Processing Involving Expanders

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Specific mechanical energy (SME) is a process response that combines screw speed, torque, feed rate, and drive motor rating in extrusion and expansion, which are common in pig feed manufacture. Expanders and extruders work on the same principles, but in spite of the importance of SME (Batterman-Azcona *et al.*, 1999) in defining these processes, studies are limited on how SME defines functional and digestion properties of finished feed. Knowledge of such relationships could help develop pig feeds with specific end-uses. Our hypothesis was that there are correlations between SME, pasting and digestibility for processed sorghum.

Sorghum (*Buster var.*) was extruded using a replicated randomised full-factorial experimental design (3 moisture levels x 3 screw speeds). SME was calculated as $[(SS \times \Gamma \times P_R)/(100 \times SS_{max} \times G)]$, where SS = screw speed, SS_{max} = maximum screw speed, Γ = torque (%), PR = power rating of motor, G = feed rate. Extrudates were analysed for pasting and *in vitro* starch digestibility (Mahasukhonthachat *et al.*, 2010), and statistical analysis was by Minitab® 15. The RVA final viscosity (FV) was an index of pasting properties, and very rapidly digested starch (Do) and digestion rate constant (K) were obtained from a modified first-order kinetic model.

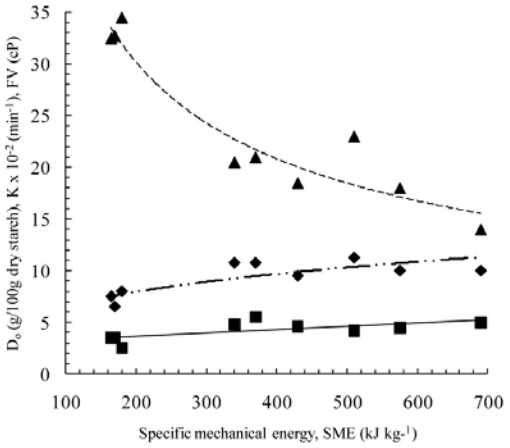

Figure 1. *Relationship between pasting, digestibility and specific mechanical energy (SME) (▲- final viscosity (FV)-SME, ◆- digested starch (Do)-SME, ■- digestion rate constant(K)-SME).*

SME significantly ($P<0.05$) depended on the extrusion conditions because of the effects on degree of fill, heat capacity, viscoelasticity, and frictional heat. In the extrudates, the RVA revealed high but incomplete gelatinisation, with starch exhibiting less restriction to swelling than in non-extrudates, due to desirable structural and molecular changes, which enhanced starch digestibility. Significant ($P<0.05$) power-law relationships exist between SME, pasting and digestibility properties (Figure. 1; $FV = 520\ (SME)^{-0.54}$, $D_o = 2.1\ (SME)^{0.25}$, $K = 0.005\ (SME)^{0.36}$, $r^2>0.56$) suggesting high SME is beneficial for high starch digestibility and optimal energy delivery from finished pig feeds. By analogy with findings for humans, this could lead to increased intake as rapid feed digestion leads to more rapid onset of subsequent hunger. Consequently, extruders and expanders should be operated for the highest SME possible to yield high starch digestibility.

BATTERMAN-AZCONA, S.J., LAWTON, J.W. and HAMAKER, B.R. (1999). *Cereal Chemistry*. **76**:316-320.

MAHASUKHONTHACHAT, K., SOPADE, P.A. and GIDLEY, M.J. (2010). *Journal of Food Engineering*. **96**:18-28.

Supported in part by the Pork CRC Ltd.

Functional and Digestibility Properties of Pig Feeds: Pasting Properties Using Rapid Visco-Analysis (RVA)

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[1]University of Queensland, St Lucia, QLD 4072, [2]NSW Department of Industry and Investment, Orange, NSW 2800. [3]QLD Department of Primary Industries and Fisheries, Wacol, QLD 4076. [4]University of Sydney, Narrabri, NSW 2390. [5]John L Black Consulting Pty Ltd, Warrimoo, NSW 2774.

End-uses, nutritional value and pellet quality of pig feeds depend on their physicochemical characteristics, which are influenced by the base materials (eg. cereals), ingredients, additives, and processing. Starch and protein, the major energy components of cereals, are respectively gelatinised and denatured to degrees that are dependent on processing and feed characteristics. Understanding both the rate and extent of energy delivery from pig feeds and biological responses of pigs to feeds would be enhanced by understanding the physicochemical properties of the feeds (White *et al.*, 2008). The null hypotheses of this paper is that the pasting properties of pig feeds are not dependent on the type and variety of cereals, or enzyme treatments.

Varieties of barley (7), sorghum (10), triticale (5), and wheat (9) were cold-pelleted in a pilot mill. One sorghum variety was treated with zingibain (ZT, Natbio Pty Ltd, Annerley, QLD), ginger protease prior to pelletisation. The 32 pellets were formulated to contain about 940 g/kg of the cereal, essential amino acids, minerals, and vitamins. The pellets were hammer-milled (1 mm sieve), and their pasting properties determined (Mahasukhonthachat *et al.*, 2010) using a randomised incomplete block design with two replicates over seven days. The data were analysed using linear mixed models with the statistical package ASReml (VSN International Ltd). The model included fixed effects for type, and variety of grain, and ZT, as well as random effects for replicate and day.

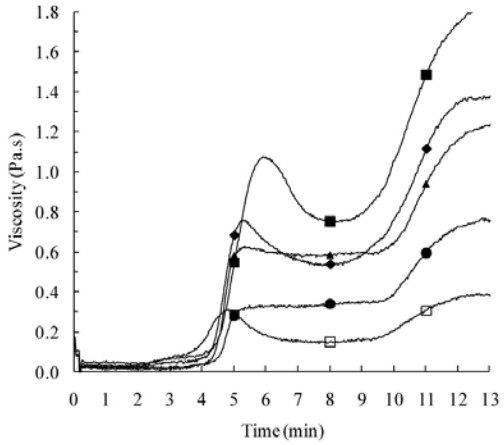

Figure 1: *Typical viscograms of the feeds; barley (■), wheat (◆), ZT-sorghum (▲), sorghum (●), and triticale (□).*

Starch was not fully gelatinised in any of the 32 pellets (Figure 1), which exhibited three types of viscographic behaviour; high shear-thinning (triticale), moderate shear-thinning (barley and wheat); shear-thickening akin to restricted swelling (sorghum). These behaviours were also reflected in the peak time (min); triticale <5.0, barley-wheat 5.0-6.0, sorghum >6.0. The pasting parameters were significantly ($P<0.05$) affected by the type and variety of grain. The effects of ZT were only significant after heating (>50°C), possibly due to hydrothermal-induced disruptions of starch-protein interactions in the sorghum. ZT significantly reduced the peak time and increased peak viscosity to indicate improved swelling of sorghum starch. The results suggest that barley- and wheat-based feeds can be processed under identical conditions, triticale would need a lower temperature:energy ratio, and sorghum more intense processing, supplemented by treating with proteases.

MAHASUKHONTHACHAT, K., SOPADE, P.A. and GIDLEY, M.J. (2010). *Journal of Food Engineering*. **96**:18-28.

WHITE, G.A., DOUCET, F.J., HILL, S.E. and WISEMAN, J. (2008). *Animal*. **2**:867–878.

Supported in part by the Pork CRC Ltd.

Functional and Digestibility Properties of Pig Feeds: *In vitro* Starch Digestion Characteristics Using Glucometry

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[1]University of Queensland, St Lucia, QLD 4072. [2]NSW Department of Industry and Innovation, Orange, NSW 2800. [3]Queensland Department of Primary Industries and Fisheries, Wacol, QLD 4076. [4]University of Sydney, Narrabri, NSW 2390. [5]John L Black Consulting Pty Ltd, Warrimoo, NSW 2774.

From its Atwater factor, the energy potential of starch is 17 MJ/kg if completely digested, making starch digestibility important in pig feeds, where cereals are the base material. Digestibility properties can be assessed by *in vitro* and *in vivo* techniques, with good correlations between the two established for humans (Sopade and Gidley, 2009). *In vitro* techniques are simple and inexpensive, and gaining importance in characterisation of animal feeds (White *et al.*, 2008). Here, we report *in vitro* amylolytic digestion of pig feeds, with the null hypotheses being *in vitro* starch digestion is independent of the cereals, varieties and enzyme treatments.

Barley (7 varieties), sorghum (10 plus one treated with ginger protease zingibain (ZT, Natbio Pty Ltd, Annerley, QLD)), triticale (5), and wheat (9), formulated to contain about 940 g/kg of the cereal, were cold-pelleted in a pilot mill. The 32 pellets were hammer-milled (1 mm sieve) and analysed with seven other pellets (not shown) for *in vitro* starch digestion using a duplicated randomised incomplete block design over four runs. The novel *in vitro* digestion procedure of Sopade and Gidley (2009) was used; 37°C, 85 rpm bath, Accu-Chek Performa® glucometer, 4hr digestion; 12 data points. The data were analysed using linear mixed models with experiment, grain type, variety, time, ZT, and their interactions as fixed terms, while replicate and run constituted the random effects. The time covariate was fitted with a linear trend, a spline (to model curvature) and a lack of fit component.

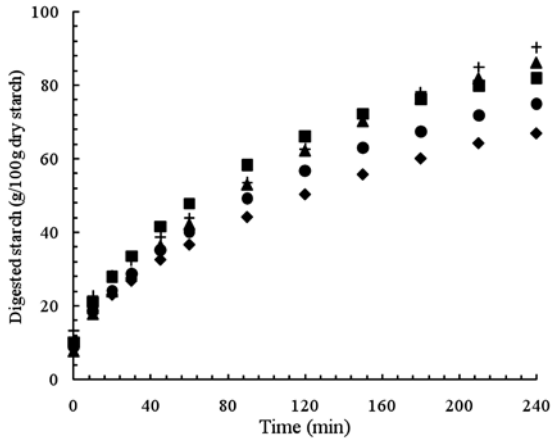

Figure 1: *Typical digestograms of the tested feeds (◆, sorghum, ●, wheat, ■, ZT sorghum, ▲, barley, +, triticale).*

Irrespective of the grain type, variety or enzyme treatment, all pellets exhibited a monophasic digestogram suggesting the absence of an initial barrier to enzyme-starch contacts (Figure 1). Digestion significantly increased with time in a non-linear (exponential) manner, consistent with a first order process, and there were significant effects of grain type, variety, ZT, and all their interactions. The rate and extent of starch digestion varied between and within grain species, and variations in starch contents of cereals need to be taken into account when determining relative starch digestibility. In addition, starch structures and grain constituents (eg. amylose content and interactions with protein) influence digestibility, with barley appearing to be the most digested of the grains.

SOPADE, P.A. and GIDLEY, M.J. (2009). *Starch/Stärke.* **61**:245-255.

WHITE, G.A., DOUCET, F.J., HILL, S.E. and WISEMAN, J. (2008). *Animal*. **2**:867–878

Supported in part by the Pork CRC Ltd.

CHAPTER 6

Pig Health

Porcine Circovirus Type-2 (PCV2), Postweaning Multisystemic Wasting Syndrome (PMWS), Vaccines and the Immune System - What's Going On?

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The immune system of the pig plays a key role in controlling infection by Porcine Circovirus Type-2 (PCV2), keeping it subclinical in most cases. However, a variable proportion of pigs in a farm may develop Postweaning Multisystemic Wasting Syndrome (PMWS), a multi-factorial acquired immune deficiency syndrome. Unfortunately, the precise immunological mechanisms by which a pig gets a subclinical infection or develops PMWS are still poorly known. Curiously, PCV2 vaccines seem to be extremely efficacious for controlling the disease. The objective of this review is to summarise the current knowledge on PCV2 immunology and the immunological basis of PCV2 vaccination.

Immunopathogenesis of PCV2 infections

Immunomodulatory activity of PCV2

The notion that PMWS-affected pigs suffer from an acquired immunodeficiency (Darwich *et al.*, 2004) led to speculation that PCV2 infection might modulate the host immune defences. Several *in vitro* studies have recently supported this hypothesis and clarified some aspects of the complex interaction between PCV2 and the cells of the immune system.

In dendritic cells (DC), PCV2 infection induces functional impairment of their activity depending on this cell type subpopulation. PCV2 infection of myeloid DC (mDC) does not alter their ability to process and present antigen to T lymphocytes, nor did it interfere with DC maturation (Vincent *et al.*, 2003, 2005). Conversely, the interaction of PCV2 with plasmocitoid DC (pDC), also known as natural interferon producing cells (NIPC), induce impaired responsiveness to danger signals. Due to the importance of DC cells in mediating innate defences, the ability of PCV2 to interfere with their functionality might represent a major barrier to the development of an adequate immune response, either against PCV2 itself or against any other pathogen (Vincent *et al.*, 2007).

When PCV2 is added to *in vitro* cultured alveolar macrophages (AM), an altered production of certain cytokines and/or chemokines is observed (Chang *et al.*, 2006). It has been speculated that this alteration of the functionality of PCV2-infected AM may favour spread of PCV2, as well as render pigs more susceptible to opportunistic and secondary pulmonary infections.

Addition of PCV2 to peripheral blood mononuclear cells (PBMC) obtained from both healthy and diseased pigs alters their cytokine profile (Darwich *et al.*, 2003a). Interestingly, contrary to what was observed for pDC, PCV2 induced the production of interferon-α (IFN-α) in peripheral blood mononuclear cells (PBMC; Wikstrom *et al.*, 2007). In addition, PCV2 seems to modulate the specific-immune responses developed by pigs to other pathogens, since the cytokines released by PBMC upon recall responses to pseudorabies virus are down-regulated by PCV2 (Kekarainen *et al.*, 2008b). The inhibitory effect on some of these cytokine responses was mediated by the release of PCV2-induced interleukin-10 (IL-10). Ex vivo, increased levels of this cytokine in the serum of PCV2-infected pigs has been associated with development of PMWS (Darwich *et al.*, 2003b; Stevenson *et al.*, 2006).

The implication of different components of PCV2 in the modulation of the immune response has also been investigated. Vincent *et al.* (2007) found that PCV2-induced impairment of DC function did not require viral replication and was mediated by the viral DNA. The same authors demonstrated that a minimum concentration of double strained (ds) DNA (replicative form) was necessary to mediate such inhibition. In PBMC, the PCV2-induced suppression of cytokines released upon recall antigen was associated with the whole virus and certain DNA sequences derived from its genome. In contrast, PCV2 virus-like particles (VLP) did not show any suppressive effect, neither did they modulate IFN-α responses (Kekarainen *et al.*, 2008a). Regarding the IL-10 inducing ability of PCV2, it was only maintained as far as the whole virus was used for stimulating the cells. Neither VLPs nor any of the studied CpG-oligodeoxynucleotides (ODNs) were found to be IL-10 inducers (Kekarainen *et al.*, 2008a).

Altogether, these data suggest that PCV2 has the potential to evade the immune control and mediate immunosuppression by impairing the host immune mechanisms. At present, however, it is still not known why only a small proportion of PCV2-infected pigs become immune-compromised and unable to counteract the immune-modulatory effect of PCV2.

Immunosuppression in PMWS-affected pigs

The most striking evidence of immunosuppression is given by the extensive lesions observed in lymphoid tissues of PMWS-affected pigs. These include depletion of B and T lymphocytes combined with an increase in the number of macrophages and loss or redistribution of interfollicular dendritic cells (Chianini *et al.*, 2003). In lymphoid tissues, depletion of T lymphocytes was found to involve mainly $CD4^+$ cells and, to a lesser extent, $CD8^+$ cells (Sarli *et al.*, 2001).

Another feature of immunosuppression in PMWS-affected pigs is the alteration of PBMC subsets. In a cross-sectional study in which natural cases of PMWS were compared with healthy pigs, a decrease in B and T ($CD8^+$ and $CD4^+/CD8^+$) cell subpopulations was related to disease (Darwich *et al.*, 2002). The kinetics of such lymphopenia as well as the phenotype of the cells involved was further characterized by Nielsen *et al.* (2003) under experimental conditions. Thus, depletion of B and T lymphocytes was observed only in PCV2-inoculated pigs that later developed PMWS, starting from d 7 post-inoculation (PI), and becoming severe at the time of occurrence of clinical signs. Changes in T cell subsets involved mainly $CD4^+CD8^+$ memory T cells. Conversely, in those PCV2-inoculated pigs that did not show clinical signs, the number of cytotoxic ($CD4^-CD8^+$) and γδ ($CD4^-CD8^-$) T lymphocytes was increased in comparison to that of control pigs, thereby suggesting an active response to PCV2 infection.

Lymphoid depletion and lymphopenia are consistent features of PMWS affected pigs. However, it is still unknown whether the loss of lymphocytes is a direct effect of PCV2 infection or an indirect consequence of responses to PCV2 infection. Some authors postulated that lymphoid depletion was a result of virus-induced apoptosis (Shibahara *et al.*, 2000; Kiupel *et al.*, 2005). However, contradictory results have been found by others (Mandrioli *et al.*, 2004; Resendes *et al.*, 2004). In a recent study it was observed that PCV2-infected PBMC showed morphological changes typical of cellular degeneration. Those changes were correlated with an increase in viral titres, suggesting that PCV2 infection of PBMC may lead to cell death (Lefebvre *et al.*, 2008). It has been shown *in vivo* that B and T lymphocytes support PCV2 replication (Pérez-Martín *et al.*, 2007; Yu *et al.*, 2007). Whether this latter fact underlies the severe lymphoid depletion observed in PMWS-affected pigs remains to be elucidated.

Protective immunity developed upon PCV2 infection

Humoral responses

Most of the published serological surveys for PCV2 are based on the detection of total anti-PCV2 antibodies (TA), without determining their neutralising activity. In the field, seroconversion for TA occurs in both sub-clinically- and PMWS-affected pigs (Rodríguez-Arrioja *et al.*, 2002; Larochelle *et al.*, 2003; Sibila *et al.*, 2004; Grau-Roma *et al.*, 2009). Whereas some studies found no differences between non-PMWS and PMWS-affected pigs regarding titres of TA (Larochelle *et al.*, 2003), other works reported weaker responses in diseased pigs (Meerts *et al.*, 2006; Grau-Roma *et al.*, 2009). Under experimental conditions, delayed responses or low titres of TA have been related to the expression of PMWS (Bolin *et al.*, 2001; Ladekjaer-Mikkelsen *et al.*, 2002; Rovira *et al.*, 2002; Okuda *et al.*, 2003; Meerts *et al.*, 2006). Several field and experimental studies have shown that PCV2 might persist in tissues and blood in the presence of high titres of TA (Rodríguez-Arrioja *et al.*, 2002; Larochelle *et al.*, 2003; Sibila *et al.*, 2004; McIntosh *et al.*, 2006; Krakowka *et al.*, 2002; Magar *et al.*, 2000), however, those studies did not discriminate between neutralizing and non-neutralising antibodies.

It has been demonstrated that PCV2-infected pigs develop PCV2-specific neutralising antibodies (NA) (Pogranichnyy *et al.*, 2000; Meerts *et al.*, 2005; Meerts *et al.*, 2006; Fort *et al.*, 2007). Under experimental conditions, NA develop between d 10 to 28 PI (Pogranichnyy *et al.*, 2000; Meerts *et al.*, 2006; Fort *et al.*, 2007) and low titres have been related to an increased PCV2 replication and development of PMWS (Meerts *et al.*, 2006). So far, only one study has investigated the dynamics of NA in naturally-infected pigs (Meerts *et al.*, 2006). It was shown that maternally derived NA were passively transferred to all piglets and none of the pigs that developed PMWS seroconverted for NA. In addition, another study showed that the levels of NA were correlated with the clinico-pathological status of naturally-infected pigs (Fort *et al.*, 2007). Thus, PCV2- positive pigs with NA titres equal or beyond 1:512 were found to be more likely sub-clinically infected and those with titres ≤ 1:16 had a higher probability to suffer from PMWS. It is important to note that not all pigs with low NA titres had low levels of TA (Meerts *et al.*, 2006; Fort *et al.*, 2007).

This latter fact suggests that either some animals develop a humoral response lacking NA or that NA develop later than non-NA. A delay in NA responses has been reported in PCV2 sub-clinically infected pigs (Pogranichnyy *et al.*, 2000; Fort *et al.*, 2007). In addition, there is one study reporting the coexistence of high NA titre and a high viral load in serum and tissues (Fort *et al.*, 2007). Taken together, these data suggest that the sole presence of PCV2 antibodies does not fully guarantee viral clearance when infection has taken place and points out the potential role of other immune mechanisms independent of humoral responses.

Cell-mediated responses

The role of adaptive cell-mediated responses in controlling PCV2 infection and disease have not been studied in depth. However, the fact that PMWS-affected pigs have impaired T cell responses (Darwich *et al.*, 2002; Nielsen *et al.*, 2003) is suggestive of their contribution to the protective immunity against PCV2 infection. In addition, it has been shown that artificially induced immunosuppression may potentiate viral replication (Krakowka *et al.*, 2002; Kawashima *et al.*, 2003; Meerts *et al.*, 2005).

At least three studies have reported data on cell-meditated immune responses in PCV2-infected pigs (Meerts 2005; Fort *et al.*, 2009a; Steiner *et al.*, submitted). PCV2 subclinically-infected pigs develop specific humoral and T cell responses, although with a relatively slow kinetics. The kinetics of the helper and cytotoxic T cell responses, measured by the number of IFN-γ-secreting cells (SC), are dependent on the individual animal and also on the time PI at which the cells are tested. Interestingly, VLPs based on PCV2 capsid (Cap) protein are also capable of stimulating cytotoxic T cells, suggesting that those PCV2-specific T cells can recognise antigen processed from VLPs as well as from live virus. Unfortunately, such cell-mediated response studies are yet to be performed in pigs developing PMWS in comparison to PCV2 subclinically-infected animals.

Present knowledge on adaptive immune response against PCV2 infection suggests that cell-mediated response, measurable as IFN-γ-SC, together with a significant neutralising antibody response, is mostly responsible for viral clearance in infected animals (Fort *et al.*, 2009a). It is hypothesized that a failure in one or the other or both responses might result in PMWS development.

PCV2 vaccination and protection

At least four commercial vaccines for use in growing pigs and breeding-aged animals are currently available in all major swine producing regions worldwide. The first vaccine on the market was CIRCOVAC® (Merial, Spain), an inactivated PCV2, oil-adjuvanted vaccine for use in sows and gilts 2-4 weeks prior to farrowing. CIRCOVAC® was first used in Europe under temporary license in 2004, and by 2006-07 was already available in most European countries and Canada. The other three commercial products are recombinant vaccines designed for use in growing pigs, around 3-4 weeks of age. Suvaxyn PCV2 One Dose® (Fort Dodge Iowa, USA) is based on a chimeric infectious virus containing the immunogenic ORF2 Cap gene of PCV2 into the non-pathogenic genomic backbone of PCV1 (Fenaux *et al.*, 2003). Ingelvac CircoFLEX® (Boehringer Ingelheim, Germany) and Porcilis PCV® and Circumvent® (Intervet-Schering Plough, The Netherlands) are sub-unit vaccines based on the product of the ORF2 expressed on baculovirus. All four vaccines are based on PCV2a strains.

Data from field studies have demonstrated that all vaccine products show remarkable efficacy. A drastic reduction in PCV2-associated productive losses has been observed in growing pigs, either vaccinated or originated from vaccinated breeding herds. Thus, improved average daily gain and feed conversion, decreased mortality rates and reduced medication cost are some of the benefits observed in vaccinated herds (Fachinger *et al.*, 2008; Kixmoller *et al.*, 2008). Vaccination of sows has been demonstrated to have a beneficial effect on reproductive performance, demonstrated by the improvement of reproductive parameters in vaccinated breeding stocks. Thus, sow and gilt vaccination has been reported to increase the number of live born pigs and the number of pigs per sow per year, and to reduce the number of mummies per sow (Thacker *et al.*, 2008; Villa, 2008). Recently, the potential protective effect of dam vaccination on preventing PCV2 foetal infection and reproductive failure was investigated under experimental conditions (Madson *et al.*, 2009). PCV2-naïve pregnant sows were either vaccinated or given placebo on d 28 of gestation, and by d 56 were inoculated with a PCV2b isolate. Reproductive failure could not be reproduced, but PCV2 infection of naïve pregnant sows resulted in foetal infection, from which sow vaccination did not protect. Vaccination of the dam did not prevent colostral shedding of PCV2, suggesting that sow vaccination might not prevent vertical transmission.

To date, few studies have dealt with the mechanism(s) underlying vaccine-induced protection. It is generally assumed that the main basis of vaccine efficacy relies on the protective effect of PCV2 antibodies, either passively acquired (sow vaccination) or actively induced (piglet vaccination). However, low antibody responses or lacking antibody development after vaccination apparently does not always rule out protection. Fenaux *et al.* (2004) found

that after the immunisation with a chimeric PCV1-2 virus, although not all pigs seroconverted to PCV2, they were still protected from developing PCV2-viremia and clinical signs after challenge with PCV2. The authors of that study suggested a potential role of cell-mediated immunity in vaccine-induced protection. Recently, it was reported that colostrum of vaccinated specific pathogen free (SPF) sows contained PCV2-specific IFN-γ-SC (Goubier *et al.*, 2008). The transfer of those cells to their offspring was demonstrated, but their protective effect could not be elucidated since IFN-γ-SC were only detected in newborn piglets within a very short period of time.

The immunogenicity and efficacy of a commercial PCV2 sub-unit vaccine used in one- and two-dose schedules have been recently evaluated in conventional piglets (Fort *et al.*, 2008, 2009b). Results from these studies demonstrated that vaccination induced the development of humoral and cell-mediated responses (measured by the production of IFN-γ-SC) and significantly reduced viremia, shedding and viral load in tissues upon challenge with either PCV2a or PCV2b isolates. It was also found that maternally-derived PCV2 antibodies (MDA) protect against PCV2 infection and influence the humoral response developed after vaccination. In fact, it has been suggested that pigs with antibody titres measured by immunoperoxidase monolayer assay (IPMA) below 5 $\log_2$ are potentially more susceptible to PCV2 infection. Besides, IPMA titres beyond 10 $\log_2$ were seen to interfere with the development of antibodies following PCV2 vaccination. Based on these observations, a "vaccination window" has been proposed, defined as the range of antibody titres at which piglets should be vaccinated to minimize interference with MDA and, at the same time, ensure the development of protective immunity before PCV2 exposure (Fort *et al.*, 2009b).

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Hematological Parameters And Serum Proteins in Pigs With Porcine Circovirus Type 2-Associated Disease (PCVAD)

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Clinical features of infection with Porcine Circovirus Type 2 (PCV2) include reproductive disorders and disease complexes such as Porcine Multisystemic Wasting Syndrome (PMWS), Porcine Dermatitis and Nephropathy Syndrome (PDNS) and Porcine Respiratory Disease Complex (PRDC) in weaned pigs (Segalés *et al.*, 2004). The characteristic depletion of lymphocytes and infiltration of macrophages and multinucleated giant cells in lymph nodes in pigs with PCV2-associated disease (PCVAD) lead to the hypothesis that pigs with PCVAD have altered hematological parameters and serum proteins compared with clinically healthy pigs.

About 50 weaned pigs from eight herds with apparent PCVAD were sampled. Twenty-four pigs were confirmed to have PCVAD through detection of PCV2 in association with characteristic histopathological findings were subsequently included in the study. One hundred and four clinically healthy pigs at the same age were used as controls (Klem *et al.*, 2009). Blood samples added ethylenediaminetetraacetic acid (EDTA) were assayed using an ADVIA 2120 haematology system in the MultiSpecies™ System Software, while the proteins fractions in serum were determined by electrophoresis (Capillarys™ 2 Sebia). Statistical analysis was carried out using JMP Statistical Discovery Software Version 7.0.

Table 1. *Hematological parameters (mean±SEM) and serum proteins in pigs with Porcine Circovirus Type-2 Associated Disease and clinically healthy pigs.*

Parameter	PCVAD (n=24)	Healthy pigs (n=104)	Significance level
Erythrocytes (#/l)	6.9x1012±0.2 x10^{12}	7.3x1012±0.06x10^{12}[a]	*
Hematocrit (l/l)	0.33±0.01	0.39±0.003[a]	***
Leucocytes (#/l)	24.2x109±2.8x10^{9}	27.8x109 ±0.8x109[a]	NS
Neutrophils (#/l)	16.4x109±2.3x10^{9}	10.2x109±0.4x109[a]	**
Eosinophils (#/l)	0.32x109±0.05x10^{9}	0.71x109 ±0.07x109[a]	***
Lymphocytes (#/l)	5.4x109±0.9x10^{9}	14.4x109±0.6x109[a]	***
Monocytes (#/l)	1.3x109±0.2x10^{9}	1.8x109 ±0.08x109[a]	*
Total proteins (g/l)	54.0±2.8	58.2±0.4	NS
Albumin (g/l)	18.6±0.8	24.3±0.2	***
Globulin (g/l)	35.4±2.5	34.0±0.4	NS
α-1-globulin (g/l)	5.5±0.3[b]	4.3±0.1[b]	**
α-2-globulin (g/l)	8.3±0.4[b]	7.3±0.08[b]	*
β-1-globulin (g/l)	6.1±0.4[b]	4.5±0.09[b]	***
β-2-globulin (g/l)	5.1±0.3[b]	6.7±0.1[b]	***
γ-globulin (g/l)	10.4±2.4[b]	11.1±0.3[b]	NS

[#], number; l, litre; SEM, standard error of the mean; [a]the number of erythrocytes and leucocytes were determined in 102 pigs, [b]the globulin fractions were determined in 16 pigs with PCVAD and 101 healthy pigs; *, P<0.05; **, P<0.01; ***, P<0.001; NS, not significant.

Pigs with PCVAD had significantly (P<0.05) lower numbers of erythrocytes, eosinophils, lymphocytes, monocytes and a lower hematocrit than healthy pigs (Table 1). In addition, they had a significantly (P<0.05) higher number of neutrophils. Pigs with PCVAD had a significantly lower level of albumin than healthy pigs, but there is no significant difference in the total amount of globulin. However, pigs with PCVAD had a significantly higher level of α-globulin and β-1-globulin and a significantly lower level of β-2-globulin than healthy pigs, while there is no significant difference in the level of γ-globulin. These findings are important for understanding the susceptibility for other infections and the response to vaccination.

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A Preliminary Study of Porcine Circovirus Type 2 in Outbreaks of Diarrhoea in Growing Pigs in Denmark

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Porcine Circovirus type 2 (PCV2) is endemic in pig herds in most countries. Initially, PCV2 was linked to post-weaning multi-systemic wasting syndrome (PMWS). More recently, other disease syndromes have been associated with PCV2. PCV2 has been reported as a differential diagnosis for *Lawsonia intracellularis* (LI) infections in pigs (Jensen *et al*., 2006). Our hypothesis was that intestinal PCV2 infection occurs where grower (>10 weeks) pigs are experiencing diarrhoea in the absence of other major intestinal pathogens.

Six farms in Denmark (3 in Zealand, 2 in Jutland, 1 in Funen) experiencing diarrhoea in grower pigs (12-17 weeks) were selected. Blood samples were collected on d 1 from 20 diarrhoeic and 20 in-contact non-diarrhoeic grower pigs and tested using ELISAs for antibodies to determine the proportion of pigs within the sample population that were test-positive to PCV2 (Kristensen *et al*., 2009) and LI (Boesen *et al*., 2005). Three diarrhoeic pigs from each farm were euthanized on d 4 and samples submitted for laboratory diagnosis. Intestinal PCV2 infection was defined as lymphoid depletion, coupled with granulocytosis +/- giant cells/inclusion bodies within lymphoid organs (mesenteric lymph nodes and/or Peyers Patches) on histology and PCV2-specific immunohistochemistry to demonstrate antigen within intestinal lesions.

Lymphoid depletion, coupled with granulocytosis, was observed in the intestinal lymphoid tissue in one pig on two farms. Low-moderate amounts of PCV2 antigen were detected in the intestine and/or lymphoid tissue of at least one pig on three farms. A diagnosis of *Brachyspira pilosicoli* colitis was confirmed on five of the six farms, with LI on three farms, based on intestinal lesions detected during histological examination and the demonstration of nucleic acid/ antigen in affected tissue sections via *in situ* hybridisation/ immunohistochemistry, respectively. Two farms had duel infections with LI and *B. pilosicoli*.

Table 1. *Proportions of Porcine Circovirus Type-2 (PCV2),* Lawsonia intracellularis *(LI) and* Brachyspira pilosicoli *test-positive diarrhoeic grower pigs from 6 farms in Denmark. Proportions of PCV2 and LI circulating antibody test-positive pigs in the study sample are presented.*

Farm	PCV2 intestine	PCV2 lymph node	LI	B. pilosicoli	PCV2 antibody	LI antibody
1	0/3	0/3	3/3	0/3	21/40	9/40
2	2/3	3/3	0/3	3/3	34/40	26/40
3	1/3	1/3	2/3	3/3	40/40	37/40
4	0/3	0/3	1/3	3/3	20/40	16/40
5	0/3	1/3	0/3	3/3	38/40	3/40
6	0/3	0/3	0/3	3/3	37/39	7/39

ELISA results suggested that PCV2 and LI were endemic (Table 1). The proportions of LI and PCV2 antibody test-positive pigs was similar for diarrhoeic (48/120; 97/120) and non-diarrhoeic (50/120; 93/120) pigs, respectively. The odds ratios for LI and PCV2 antibodies in pigs with diarrhoea were 0.96 and 1.21, respectively ($p>0.05$), suggesting that there were no associations between antibody production and diarrhoea.

Our results suggest that PCV2 did not play a major role in causing intestinal disease in euthanised pigs, as giant cells/viral inclusion bodies were not detected, with low-moderate amounts of PCV2 antigen. Further testing is underway to compare PCV2 viral load in diarrhoeic and non-diarrhoeic pigs.

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Supported in part by Australian Pork Ltd.

Reduced Digestive Enzyme Activity in the Ileum of Pigs Severely Affected With Proliferative Enteropathy

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Proliferative enteropathy (PE), caused by *Lawsonia intracellularis* (LI), is a significant wasting disease, which causes acute intestinal haemorrhage and death in adult pigs, and diarrhoea and reduced growth rates in growing pigs. As normal crypt cells in the intestinal epithelium mature they undergo differentiation and become specialised for the digestion and absorption of nutrients. PE causes abnormal proliferation of immature crypt cells in the ileum, which may interfere with the digestion and absorption of nutrients. The aim of this pilot study was to determine if pigs affected with PE showed reduced levels of digestive enzyme activity in the ileum compared with uninfected animals.

Four hybrid finisher pigs (Large White x Landrace) were orally dosed with mucosal homogenate from a PE-affected pig containing 5 x 109 LI and housed separately to two control pigs which were not dosed with LI. Pigs were monitored for clinical signs of PE and LI infection (faecal shedding of LI and IgG antibodies to LI). Pigs were euthanased 22 d post oral dosing and two sections of ileal tissue were processed for histopathology. The mean percentage area of tissue affected with microscopic lesions of PE (presence of LI and abnormal crypt cell proliferation) was determined. Protein was extracted from two adjacent lengths of PE affected ileal mucosa (stored at -70°C) and enzyme activity was measured in triplicate for each protein extract. Sucrase activity (Enzyme Commission number (EC) 3.2.1.48) was determined with a Biovision Glucose assay kit (Biocore, Alexandria, NSW), after incubating protein extracts with sucrose (Dahlqvist, 1964). Alkaline phosphatase (EC 3.1.3.1) and aminopeptidase (EC 3.4.11.2) activity were determined using the Beer-Lambert Law, with a molar extinction coefficient of 17,700 M-1cm-1 and 9,900 M-1cm-1 for p-nitrophenol and 4-nitroaniline respectively (Fan *et al.*, 2001).

Table 1. *Severity of PE (faecal shedding, mean antibody titre and lesion scores) and mean ileal enzyme activity.*

Disease status	PCR positive (d PI)	Mean % ileum with lesions	Antibody titre (d 22 PI)	Alkaline phosphatase (nmol/min/mg)	Aminopeptidase (nmol/min/mg)	Sucrase (nmol/min/mg)
High	10-22	97.5[a]	480	12.6[a]	2.0[a]	1.1[a]
Low	14-22	30[ab]	240	78[b]	20.5[b]	27.8[b]
Control	0	0[b]	0	91[b]	14[b]	31.7[b]

[ab]Means in the same column with different superscripts differ significantly (P<0.05). Significance was determined by Student's *t* test; PE, proliferative enteropathy; PCR, polymerase chain reaction; PI, post infection.

Mild clinical signs of PE and evidence of LI infection were detected in all four pigs dosed with LI (faecal shedding of LI, specific antibodies and histological lesions). However, significant variation in the severity of intestinal lesions were observed in the pigs given the same dose of LI giving rise to two distinct groups of pigs with high and low severity of PE. Pigs with the highest lesion scores and antibody titres (high disease status) showed significantly reduced levels of enzyme activity compared with the moderately affected and control pigs. No evidence of LI infection was observed in the two control pigs (Table 1).

Reductions in the activity of intestinal brush border enzymes in pigs severely affected with PE may explain the poor growth observed, as aminopeptidase, alkaline phosphatase and sucrase are required to digest and absorb proteins, fats and carbohydrates from the diets of pigs. Partial protection or recovery from PE may explain the variation in lesion severity and the absence of reduced enzyme activity in mildly affected pigs. More extensive studies are needed to definitively correlate PE severity and reduced digestive enzyme activity.

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Potential Interference of Anti-Coccidial Medication With *Lawsonia intracellularis* Vaccination in Suckling Pigs

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Enterisol® Ileitis vaccine (Boehringer Ingelheim, North Ryde, NSW) is registered for the control of proliferative enteropathy (PE) caused by *Lawsonia intracellularis* in weaned pigs over 3 weeks of age. Vaccination of suckling piglets may be preferred to administration post-weaning due to ease of handling (Holyoake *et al*., 2009). In Australia, piglets are commonly medicated prophylactically against coccidial scours (*Isospora suis*) in the first week of life. Our hypothesis was that concurrent anti-coccidial medication would affect Enterisol® Ileitis vaccine efficacy.

Fifty-six healthy piglets were randomly selected on a commercial farm and orally dosed with 2ml of Enterisol® Ileitis at 4±2 d of age. Anti-coccidial medication (Baycox® 5% Piglet Suspension, Bayer Animal Health, Pymble, NSW) was administered at 5 d of age. Pigs were weaned off-site and at 7 weeks of age were challenged with 3.0x109 viable L. *intracellularis* bacteria. Pigs were necropsied 21 d post-challenge and sections of ileum, jejunum and colon tissues were examined histologically for PE lesions and *L. intracellularis* antigen was detected in tissue using an *L. intracellularis* specific antibody (McOrist *et al*., 1989). Lesion severity was used as the primary measure of vaccine efficacy. Statistical analyses were conducted using a Restricted Maximum Likelihood linear regression model in Genstat (VSN International).

Pigs were placed in one of three groups based on the time interval between vaccination and Baycox® administration. There were no significant differences (P>0.05) in weaning weights and weight gains from weaning to challenge and challenge to necropsy among treatment groups. All pigs were naïve to *L. intracellularis* prior to experimental challenge based on an absence of bacterial shedding (PCR) and circulating *L. intracellularis*-specific antibodies (ELISA) at weaning and challenge. Pigs vaccinated on the same day as receiving Baycox® developed more severe PE lesions post-challenge than pigs vaccinated 1 or 2 days before or after Baycox® administration (P<0.01; Table 1).

Table 1. *Means (±SEM) for the prevalence of proliferative enteritis (PE) lesions and Lawsonia intracellularis antigen in piglets administered Enterisol® Ileitis vaccine and Baycox® Piglet suspension concurrently.*

		Small intestine		Colon
E-B interval (age)	N	*% lesions*[1]	*% LI antigen*[2]	*% LI antigen*[2]
0 d (5 d)	12	26.89 ± 7.58[a]	17.19 ± 9.60[a]	2.88 ± 2.31[a]
1 d (4 and 6 d)	13	7.06 ± 1.89[b]	1.12 ± 0.60[b]	0.02 ± 0.01[b]
2 d (2 and 3 d)	31	8.41 ± 1.54[b]	0.94 ± 0.34[b]	0.07 ± 0.04[b]

[ab]Means within a column with different superscripts differ signficantly (P<0.01); [1]% lesions, proportion of intestinal crypts with PE lesions; [2]% LI antigen, proportion of intestinal crypts with *L. intracellularis* antigen; N, number of pigs; SEM, standard error of mean; E-B interval, Enterisol®-Baycox® interval.

Our results indicate that components of the anti-coccidial medication may have interfered with, or inactivated the live vaccine when both were present in the intestinal lumen of the piglet. These findings suggest that vaccination with Enterisol® Ileitis on the same day as anti-coccidial medication should be approached with caution or avoided where possible.

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Supported in part by the Australian Research Council.

Manipulating the Environment in the Porcine Large Intestine Using Fermentable Carbohydrates to Control Swine Dysentery

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Swine dysentery (SD) is a contagious mucohaemorrhagic diarrhoeal disease with severe impacts on production efficiency in grower/finisher pigs. The causative agent of SD is the intestinal spirochaete *Brachyspira hyodysenteriae* that induces inflammation and necrosis of the caecum and colon (Hampson *et al*., 2006). Recently, Thomsen *et al*. (2007) found that an organic diet containing sweet lupins and dried chicory root completely prevented SD following experimental challenge with *B. hyodysenteriae*. However, based on the study by Thomsen *et al*. (2007) it wasn't possible to determine whether the dietary protection against SD was due to the galactans supplied by the sweet lupins or inulin from the dried chicory roots or if both carbohydrate sources are needed. It was hypothesised that diets (barley and triticale based) containing galactans (as lupins) and fructans (as inulin) could prevent the occurrence of swine dysentery (SD) after experimental infection with *B. hyodysenteriae*.

A 2x2 factorial experiment was undertaken with the main effects being protein source (185g/kg canola meal (low in galactans) versus 220g/kg lupins (high in galactans)) and inulin supplementation (+/- 80g/kg inclusion). Forty Large White x Landrace pigs, 10 pigs per diet, weighing 21±2.8 kg were allowed to adapt to the diets for two weeks and then each pig was challenged orally four times on consecutive days with 80 mL of broth containing ~108 viable cells (*B.hyodysenteriaie*). Pigs were euthanised when they showed clinical signs of SD or at the end of the experiment six weeks post-infection.

Table 1. *Number of positive pigs, relative risk (RR)[1] of a pig showing clinical signs of swine dysentery (SD) and average number of days until pigs developed clinical SD or were slaughtered. Pigs were euthanised when they developed clinical SD or at the end of the experiment 42 d post-infection.*

Inulin (g/kg)...	0		80				
Protein source, Lupin (g/kg)...	0	220	0	220	SEM	Inulin[2]	Lupin[3]
Pigs challenged	10	10	10	10		Inulin: 1	Lupin: 1
Pigs with clinical SD	7	3	0	3		No inulin: 8.3	Canola meal: 1.4
RR of clinical SD	12.3	1	0	1		(1.7 – 58.0)	(0.3 – 7.3)
No. of days to slaughter	18.3[a]	34.5[b]	37.1[b]	36.7[b]	1.50	P=0.017	P=0.687

[1]The relative risk for the medical outcome in the group of interest compared with the reference group. [2,3]Relative risk of pig showing clinical SD when fed (1) diets with or without inulin, or (2) diets containing lupin versus canola meal. Relative risk and 95% confidence intervals are given. [ab]Significant interaction between Inulin and Lupin. Means in the same row with different superscripts differ significantly (P < 0.05).

Pigs fed diets without inulin had a 8.3 times higher risk of developing clinical SD (Table 1) and were 16 times more likely (P=0.004) to have colon contents that were culture positive for *B hyodysenteriae*, compared with the pigs fed a diet with 80g/kg inulin. Diets containing lupins didn't significantly protect the pigs in this experiment from developing clinical SD, but lupin and/or inulin inclusion in the diets delayed the onset of disease compared with the diet based mainly on canola meal.

This experiment demonstrates that diets supplemented with highly fermentable carbohydrates from inulin and sweet lupins might protects pigs against developing SD by possibly modifying the microbiota in the gastrointestinal tract. Pigs fed inulin had reduced risk of developing SD and the onset of disease was delayed in pigs fed lupin.

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Supported in part by the Pork CRC Ltd.

Relationship Between *Streptococcus suis* Isolated From Suspected Zoonotic Human Cases and Pigs From the Same Farm

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Streptococcus suis is a Gram positive, facultative anaerobic organism that has been associated with a wide range of clinical disease syndromes in swine, such as meningitis, abortions and septicaemia, but it is also very common in apparently clinically healthy animals. *S. suis* appears in a number of different serotypes, although serotype 2 is most often associated with disease (Staats *et al*., 1997). Historically *S. suis* has been considered a sporadic zoonotic in humans but in 2006 a large scale outbreak of zoonotic *S. suis* was reported in China and recently *S. suis* has been shown to be the leading cause of bacterial meningitis in adults in southern Vietnam. In Australia, clinical *S. suis* in humans was first reported in 1993 and no further cases were reported in the scientific literature until 2008, when two articles reported three individual cases (Kennedy *et al*., 2008; Tramonta *et al*., 2008). Two of these cases involved piggery workers having contact with the same herd.

To date, despite these three previously reported isolations and possible contact with swine, there have been no direct epidemiological links to demonstrate pigs as being the source of infection. It is generally accepted in the literature that there is little proof for human to human spread of *S. suis* and that pigs serve as the main reservoir (Segura, 2009). This possibility may be directly tested by sampling pigs from the farm previously associated with two of the human isolations. An identical *S. suis* DNA fingerprint obtained from both isolates from on-farm pigs as well as the human isolates would support the contention that pigs can be a zoonotic source of pathogenic *S. suis* strains in Australia. Our hypothesis is that given that human to human spread has never been reported and two human cases occurred at the same farm at different times, that a strain with the ability to cross from pigs to humans has the ability to take up residence in a pig herd.

Forty-eight pigs ranging in age from 18 days to 18 weeks were swabbed from both nostrils using Amies medium transport swabs and these swabs were sent to the Elizabeth Macarthur Agricultural Institute for analysis. Both swabs from the same animal were resuspended into the same vial of Brain Heart Infusion Broth with 20% glycerol and frozen at -80°C until further analysis. Material was inoculated onto NNCC medium and three isolates showing the same colony morphology as the strains isolated from the human cases were picked and grown individually for further analysis. The swab suspension and each isolate were tested by *S. suis* specific PCR. Two molecular fingerprints were obtained from all *S. suis* isolates as well as those from both human cases using Random Amplification of Polymorphic DNA (RAPD) with two different primers.

All but one (47/48) swab suspensions tested positive for the presence of *S. suis* and 64 individual isolates were obtained representing 29 animals. Of the animals with at least one confirmed *S. suis* isolate, 7 out of 29 had an isolate showing the same RAPD-type as the human isolates (12 out of 64 total *S. suis* isolates).

These results strongly suggest that the strain implicated in two human cases was a strain that crossed from pigs to humans. The first human case associated with this herd was in 2006, while the swabs in this study were taken in 2008. Together with the fact that *S. suis* has never been implicated in human to human transmission, these findings imply that this *S. suis* strain may have zoonotic potential and the ability to establish and maintain itself within a pig herd.

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Human isolates were kindly provided by Dr. A.R Tramontana and Professor P.J. Collignon

Virulence Gene Profiling of Clinical and Non-clinical Australian Streptococcus suis Isolates by Multiplex PCR

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World wide, *Streptococcus suis* is an important swine pathogen. It costs the American pork industry alone an estimated $USD300 million annually. It is believed to be widespread through Australian pig herds and it is of concern to the Australian pork industry. In recent decades, *S. suis* emerged as a health risk to people in pork production and processing (Sriskandan and Slater, 2006; Segura, 2009). Not all *S. suis* strains are pathogenic to pigs and humans. There is no clear consensus on exactly which characteristics identify virulent strains. Virulence of *S. suis* appears to depend largely on the carriage of certain combinations of virulence factors such as capsular polysaccharide (cps) types, or serotypes, and presence of a number of virulence genes (VGs). Silva *et al*. (2006) developed a nine gene multiplex polymerase chain reaction (MP-PCR) that allows for the detection of a *S. suis* specific gene (*gdh*); differentiation of the serotypes most associated with pathogenicity (types 1, 2, 1/2, 7 and 9); and detection of the virulence-associated genes *arcA, mrp, sly,* and *epf*. The aim of this research was to employ this MP-PCR to validate its ability to characterise *S. suis* strains present in the Australian pig population (both in clinically diseased and non-symptomatic animals) and compare these with three recent human isolates which all had links to pork production and processing. We hypothesise that 1) the PCR method can adequately characterise Australian isolates; and 2) strains from humans reflect the virulence gene profiles affecting the pig population.

Three human clinical isolates were collected, representing three temporally separate cases with occupational exposure to pigs or pork, two of which were from the same farm. Eighteen clinical strains of *S. suis* were obtained from the NSW Department of Primary Industries, Menangle, NSW. Nasal swabs were also collected from 48 healthy pigs from a farm with a history of *S. suis*-associated with two of the human clinical samples. Sixty-one separate isolates were obtained from 28 of the pigs and were subcultured to obtain triple cloned isolates. DNA was extracted from all isolates and characterised using the nine gene MP-PCR. Data was tabulated in order to show the resulting VG profiles and their distribution amongst the 82 total isolates (Table 1).

Table 1. *Virulence gene profiles and their relative percentages within human, clinical and non-clinical isolates.*

Profile	Genotype of VG profile	Human strains (n=3)	Clinical strains (n=18)	Non-clinical pig strains (n=61)
I	*cps1, arcA, sly*	0.0%	5.6%	0.0%
II	*cps2, arcA, mrp*	100.0%	16.7%	3.3%
III	*cps2, arcA, mrp, sly, epf*	0.0%	11.1%	0.0%
IV	*cps9, arcA*	0.0%	27.8%	3.3%
V	nt[a], *arcA, mrp*	0.0%	27.8%	16.4%
VI	nt[a], *arcA*	0.0%	5.6%	65.6%
VII	nt[a]	0.0%	5.6%	11.5%

[a]nt, non-typeable (neither cps 1, 2, 1/2, 7 or 9); VG, virulence gene.

Using the MP-PCR we successfully characterised seven different VG profiles among the known pathogenic and zoonotic clinical *S. suis* isolates. Three VG profiles were of unknown serotype, and no isolates were of serotypes 1/2 or 7. Sixty-one percent of the clinical isolates possessed cps 1, 2 or 9 genes, whilst only 6.6% of the non-clinical isolates had these genes (Table 1). The human clinical isolates possessed the same VG profile as 16.7% of the 18 clinical and 3.3% of the 61 non-clinical pig strains. This VG profile is typically found in strains causing invasive and pneumonic disease in pigs (Silva *et al*., 2006) and similar to those associated with meningitis in humans in Vietnam. These findings were in line with the experimental hypotheses.

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Supported by the Pork CRC Ltd and Australian Pork Limited.

Impact of Probiotic Use on *Escherichia coli* Virulence and Antimicrobial Resistance Genes

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The commensal *Escherichia coli* population of the pig gut can be used as the indicator species in monitoring background antimicrobial resistance levels within a herd (Sorum and Sunde, 2001). Antimicrobial resistance in the microbial community has ramifications for the pig industry in terms of disease treatment and prevention. One strategy to combat disease without the use of antimicrobials is probiotics. Our focus is the development of probiotic formulations that specifically target porcine enterotoxigenic *E. coli* (ETEC) and show antagonistic properties toward O8G7, O141 and O149 types. These formulations are attempting to modify the gut microflora to aid in the protection against intestinal disease. It was hypothesised that by using a Lactobacillus-based probiotic formulation (ColiGuard®, International Animal Health Products, Huntingwood, NSW) specifically designed to target porcine ETEC, we can influence the background virulence and antimicrobial resistance gene profiles of the *E. coli* community in the porcine intestine.

A field trial was undertaken using two groups (Probiotic and Control) each comprised of six gilts. The treatment group received probiotic as a top dressing from two weeks prior to farrowing until their piglets were weaned at approximately 21 d. The formulation was then provided to the treatment group piglets (n=48) starting with an oral drench at 24 h of age, then daily as top dressing on creep feed from weaning until 10 d post-weaning. The control group (n=50) received a placebo. Rectal swab samples collected at 10 d post-weaning were enriched in MacConkey broth to enhance the growth of *E. coli*. Total DNA from each broth was extracted and analysed for the presence of 35 *E. coli* specific virulence genes (VGs) including those associated with porcine ETEC (LT, STa and STb) (Chin and Chapman, 2008). Principal component analysis was used to investigate the relationship between the presence and absence of VGs in preparations from the two groups.

The resulting principle coordinate analysis (PCO) demonstrated a clear segregation in VG carriage between the two groups. When examining the presence and absence of the ETEC VGs on an animal basis there were 31 animals in the control group versus only 11 animals in the probiotic group carrying one or more of the ETEC VGs. Antimicrobial resistance analysis was based on single colonies of typical *E. coli* from randomly selected rectal swab samples from the control group (n=217 *E. coli* from 24 pigs) and the probiotic supplemented group (n=199 *E. coli* from 25 pigs). Extracted DNA was confirmed as *E. coli* using polymerase chain reaction (PCR) to identify the uspA gene. The DNA was then subjected to three multiplex PCR assays for the detection of 19 antimicrobial resistance genes (ARGs). The results revealed a significant difference between the two groups for 9 of the 19 ARGs. Of these, six were significantly ($P<0.05$) reduced in the probiotic group (*cmlA*, TEM, *aphA1*, *sull*, MOXM and *dhfrv*). The remaining 3 ARGs were more frequently seen in *E. coli* from the probiotic group (CAT1, acc3(IV) and FloR). These finding suggest probiotics can be used to reshape the *E. coli* population of the weaner gut, while also having an impact on the carriage of antimicrobial resistance genes.

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Supported in part by the Pork CRC Ltd.

Comparative Sensitivity, Specificity and Lung Detection Rate of Conventional PCR Assays for *Mycoplasma hyopneumoniae*

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Several published polymerase chain reaction (PCR) assays for *Mycoplasma hyopneumoniae* (*Mhp*) targeting different genes have been applied to clinical samples such as lungs or nasal swabs. However, most lack assessment for specificity against more than a single strain of mycoplasmas that inhabit the porcine respiratory tract and are closely related to *Mhp*, namely *M. flocculare* (*Mflocc*) and *M. hyorhinis* (*Mhr*). These organisms can occur in pneumonic lesions with *Mhp*, so complicate diagnosis. We hypothesised that differences in specificity and sensitivity exist between published assays, and increasing annealing temperatures could reduce cross-reactivity with non-*Mhp* organisms, but retain reactivity with both *Mhp* strains and infected lung samples. This study evaluated specificity of seven PCR assays using an expanded set of mycoplasmal isolates (n=25), including several reference strains, whose identity was based on agreement among several published PCRs that target 16S rRNA or p37 genes. DNA extraction from 21 lungs was also compared using two commercial kits.

Quantitative and diagnostic sensitivity were studied using *Mhp* strain 232 DNA and 26 lungs with histopathological lesions typical of mycoplasmal pneumonia, respectively. Four nested PCRs (Verdin, Kurth, Calsamiglia, Stark) and two single-step PCRs tests targeting *Mhp* (Baumeister, Mattsson) were compared with a multiplex PCR (Stakenborg) for *Mhp*, *Mhr* and *Mflocc* (Kurth *et al*., 2002; Stakenborg *et al*., 2006).

Table 1. *PCR assay reactivity of* Mycoplasma hyopneumoniae *(Mhp), M. flocculare (Mflocc) and M. hyorhinis (Mhr) isolates, and of lungs with lesions of mycoplasmal pneumonia.*

PCR assay	Incr T_A	*Mhp* isolates	*Mflocc* isolates	*Mhr* isolates	Lungs X 5	Lungs x 21 Q	Lungs x 21 Instg	*Mhp* DNA limit (fg/µl)
Verdin	Yes	7/7	0/7	1/11	5/5	20/21	19/21	100-500
Kurth	Yes	7/7	5/7	6/11	5/5	15/21	15/21	10
Baumeister	Yes	5/7	2/7c	1/11	5/5	6/21	12/21	100-1000
Stark	No	7/7	4/7	7/11	5/5	11/21	18/21	1-5
Calsamiglia	Yes	7/7	7/7	5/11	5/5	21/21	18/21	10
Stakenborg *Mhp*	No	7/7	0/7	0/11	5/5	15/21	15/21	10000
Stakenborg *Mflocc*	No	0/7	7/7	0/11	NA	NA	NA	NA
Stakenborg *Mhr*	No	0/7	0/7	11/11	NA	NA	NA	NA
Mattsson	No	7/7	0/7	0/11	NT	NT	19/21	100-500

Quantitative sensitivity for *Mhp* strain 232 DNA is also shown. Annealing temperatures (T_A) were increased to reduce cross-reactivity. Inct T_A, Increasing Annealing temperatures; Q, Qiagen DNeasy; Instg, Instagene.

The first five assays, as originally described, showed some or many false positive results when tested against *Mflocc* or *Mhr* isolates. A first stage primer in the Calsamiglia assay was also modified to better target the known *Mhp* DNA sequence. Some PCR assays showed no improvement (Stark PCR), or some improvement (Kurth, Calsamiglia, Baumeister) in specificity without loss in sensitivity. The optimised Verdin PCR had high specificity and retained sensitivity for detection of infected lung samples. The multiplex Stakenborg PCR and Mattson PCR also showed high specificity without modification. Only the optimised Verdin, and the Mattsson and Stakenborg assays can be recommended for diagnostic application, with the former two being the most sensitive for *Mhp* and able to detect more infected lung samples. The two DNA extraction systems (QIAGEN DNeasy, QIAGEN Pty Ltd, Doncaster, VIC; Instagene, Bio-Rad Laboratories Pty Ltd, Gladesville, NSW) showed no significant difference in detection rate.

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Supported in part by Australian Pork Ltd.

CHAPTER 7

Health and Nutrition

Piglet Survival in Farrowing Pens in a Hoop Structure Versus in Farrowing Crates in an Environmentally Controlled Building

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The use of the farrowing crate is being increasingly questioned, and has been banned or restricted to the first week of lactation in some countries. The Werribee Farrowing Pen has been developed as an alternative to the farrowing crate (Cronin *et al*., 2000). However, it requires twice the floor space of a crate. The use of a low-cost hoop structure to contain large farrowing pens may reduce the capital cost of additional floor space, but may also compromise piglet survival. The aim of this experiment was to compare piglet survival in farrowing pens in a hoop structure versus farrowing crates in an environmentally-controlled building to test the null hypothesis of no difference in piglet survival between the two housing systems.

Three hundred and twelve commercial hybrid sows (PIC Australia, Grong Grong, NSW) were paired for parity and anticipated farrowing date and were randomly allocated at 112 d gestation to either housing system in 26 fortnightly blocks of 12 sows. The pens were installed in two rows of six in a hoop structure with ends partially enclosed with shade cloth. Each pen was 3.9 m x 2.4 m with a solid floor that sloped towards a shallow drain at the rear of the pen. The 2.4 m x 2.1 m 'nest' area of the pen contained a sow feeder, and a 1.2 m x 0.6 m heated creep box. Under-floor electric heating, activated when the sow began nesting behaviour and de-activated 48 h after parturition, was provided in the 'nest' area not covered by the creep box. Sow and piglet drinkers were provided over the drain. The crates were contained in fan ventilated rooms maintained at 24±2°C. Each crate measured 2.4x1.8 m and was equipped with tri-bar flooring, a sow feeder, sow and piglet drinkers, and a 1.2x0.6 m heated creep box. Sows were fed a lactation sow diet, restricted to 2 kg on the day of farrowing, increasing gradually to *ad libitum* after d 7 of lactation. Piglets on both treatments were offered creep feed in small pans from d 7 after birth. Sows and piglets were managed according to usual farm practices, with weaning occurring around d 21 of age. Sows in pens were provided with about 1 kg of straw on entry and were confined in a section of the 'nest' area for about 24 h around farrowing. Data were analysed using analysis of variance procedures (Genstat 9.1), using blocks of six pens or crates as experimental units.

Table 1. *Piglet production and survival in farrowing pens in a hoop structure versus crates in an environmentally-controlled building.*

	Pen	Crate	SED	P value
Sow parity	4.3	4.3	0.25	0.938
Total born	12.0	12.2	0.36	0.477
Born alive	11.0	11.0	0.29	0.949
Weaned	9.8	10.3	0.20	0.016
Survival of born alive to weaning (%)	89.5	93.3	1.163	0.003

SED, standard error of difference.

Piglet survival to weaning was lower (P=0.001) in pens than in crates (Table 1) in contrast to the findings of Cronin *et al*. (2000) in which pens and crates were contained in the same building. This suggests the uncontrolled thermal environment in the hoop structure may have reduced piglet survival. Piglet survival in crates was similar across seasons, whereas it declined in pens from an average of 92.1% in autumn, winter and spring to 84.5% during summer. Possibly, heat-induced behavioural changes in sows and decreased use of creep areas in summer caused more piglets to be overlaid. The use of pens in a low-cost hoop-structure decreased piglet survival but we could not determine if this was due to the effects of the farrowing pen or the environment.

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Supported in part by Australian Pork Ltd.

Maternal Dietary Arginine Supplementation During Early Gestation Improves Reproductive Efficiency in Pigs

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The supply of arginine (a non-essential amino acid) and conversion to nitric oxide (NO) appears to be essential for and may limit vascular development in reproductive tissues. NO regulates angiogenesis, the formation of new blood vessels, and is a potent vasodilator, relaxing blood vessels and reducing their resistance in the placenta and uterus during pregnancy in the pig and other species. This action may increase the rate of delivery of oxygen and nutrients to support foetal growth and survival. In the pig, concentrations of arginine peak in uterine fluids in early pregnancy (d 30-40) then again at 110 d (Wu *et al.*, 2006). In parallel, an early surge in placental angiogenesis occurs from 25-44 d of gestation, with another increase in late gestation, from d 90 to term, in this species (Vonnahme *et al.*, 2001). It is therefore possible that increased NO production induced by maternal arginine supplementation (MAS) may enhance these gestational specific changes in utero-placental vascularity and blood flow in pigs. It has been reported that MAS from d14 to 28 or 30 with a product containing 25% arginine, increases litter size (+0.8 pigs) and number live born (+1.08 pigs) in gilts and sows (Progenos, Trouw Nutrition, The Netherlands). We therefore sought to confirm this under commercial conditions in Australia. We hypothesised that MAS in the pig during early gestation, when placental angiogenesis and vascularity increase, would improve reproductive outcomes in their progeny, such as numbers born alive and litter and piglet birth weight.

Large White (LW) and Landrace (LR) gilts (parity 0) and sows (parity 3), were fed either a control (Con; LW gilts: N=53; LR gilts: N=46; LW sows: N=24; LR sows: N=39) or arginine (Arg; LW gilts: N=40; LR gilts: N=55; LW sows: N=25; LR sows: N=48) supplemented (+25g/d arginine, Progenos premix, Trouw Nutrition, The Netherlands) diet (2.5kg/d) for 16 d in early gestation starting at either 16 (Con: n=30; Arg: n=30), 17 (Con: n=64; Arg: n=58) or 18 (Con: n=68; Arg: n=80) d of gestation. Total number born, number born alive, number of still born and mummified, birth weight and d 10 weights of progeny were measured. Data were analysed using Univariate analysis of variance, with total born included as a covariate except for total born analysis.

MAS overall (regardless of gestational start day), increased total born in LW gilts (Con: 10.20; Arg: 12.00; +1.8 pigs, P<0.05) and LR sows (Con: 12.37; Arg: 13.34; +0.97 pigs, P<0.05). Total born were increased with MAS commencing from d 18 of gestation in all pigs (Con: 11.28; Arg: 12.66; +1.38 pigs, P<0.05) or from d 17 in LR pigs (Con: 11.97; Arg: 13.47; +1.50 pigs, P<0.05). MAS increased the number born alive in LW gilts (Con: 9.50; Arg: 10.61; +1.11 pigs, P<0.05) and LR sows (Con: 11.29; Arg: 12.47; +1.18 pigs, P<0.05) and when MAS started from d 18 of gestation (Con: 10.41; Arg: 11.48; +1.07 pigs, P<0.05) or d 17 in LW gilts (Con: 9.34; Arg: 11.0; +1.66 pigs, P<0.05). MAS increased litter birth weight in LR gilts (Con: 16.69; Arg: 18.03; +1.34 kg, P<0.05) and in LR gilts when MAS commenced on d 16 of gestation (Con: 17.02; Arg: 18.51; +1.49 kg, P<0.05). Similarly, MAS increased average piglet birth weight in LR gilts (Con: 1.46; Arg: 1.58; +0.12 kg, P<0.05) and LR gilts when MAS commenced from d 16 of gestation (Con: 1.44; Arg: 1.59; +0.15 kg, P<0.05). MAS from d 17 of gestation also increased average piglet day 10 weight in LW (Con: 2.57; Arg: 3.25; +0.68 kg, P<0.05).

Maternal arginine supplementation during early gestation under commercial conditions improves reproductive outcomes, particularly in LR gilts. This may occur by increasing NO abundance to enhance placental-foetal blood flow and nutrient transfer, thereby improving foetal growth, survival and reproductive outcomes

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Supported in part by the Pork CRC Ltd.

Supplementing Gestation Diets With Betaine Increases Litter Size of Summer Mated Sows

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Prolonged exposure to high ambient temperatures and the resultant heat stress can impair embryo development, increase incidences of foetal loss and compromise pregnancy outcomes (Wolfenson *et al.*, 2000). Heat stress is, therefore, likely to be at least partially responsible for the depression in fertility commonly observed in domestic sows mated during summer. Betaine, a potent organic osmolyte and methyl donor, has been shown to improve thermotolerance as well as reduce circulating homocysteine concentrations, and elevated homocysteine levels are associated with increased incidences of foetal abnormalities (Eklund *et al.*, 2005; Rees *et al.*, 2006). In light of this, the current study tested the hypothesis that adding betaine to the gestation diets of sows mated during summer would increase litter size.

A total of 450 primiparous and multiparous sows were used in this study, with sows selected from 10 mating days between 11 January and 11 February, 2008. Sows were stratified according to parity and allocated to receive either a standard gestation diet (n = 221) or a betaine supplemented gestation diet (n = 229). All sows were fed at the same level during gestation: receiving 1.9 kg/d on d 2 to 42 of gestation; 2.5 kg/d on d 43 to 84 of gestation; and 3.0 kg/d between d 85 of gestation and farrowing. The betaine diet was first fed from d 3 ± 1 of gestation, with dietary betaine content altered during gestation to ensure a daily intake of between 7.6 and 9.0 g/sow. At farrowing, total litter size, number of piglets born alive, number of still borns and number of mummified foetuses were recorded. Within treatment, sows were blocked according to two parity groups (parities 1 and 2 versus parities 3 – 6), and a general analysis of variance model, with block built-in, was used to study the effects of dietary treatment and parity group on litter size data.

Table 1. *Litter size data (mean ± SEM) for Control and Betaine Parity 1 and 2 and Parity 3 to 6 sows.*

	Standard diet		Betaine diet	
	Parities 1 and 2 (n= 79)	Parities 3 to 6 (n=95)	Parities 1 and 2 (n=93)	Parities 3 to 6 (n=88)
Total litter size	12.3 ± 0.38[a]	12.0 ± 0.30a	11.9 ± 0.34[a]	13.6 ± 0.35[b]
Piglets born alive	11.4 ± 0.33	10.8 ± 0.30	11.2 ± 0.30	12.0 ± 0.30

[ab]Means in the same row with different superscripts differ significantly (P < 0.05); n, number.

Total litter size was significantly higher (P<0.01) and the number of piglets born alive tended (P = 0.06) to be higher for betaine-fed parity 3–6 sows compared to standard-fed parity 3–6 sows. Despite this, litter size of parity 1 and 2 sows was unaffected by betaine supplementation (Table 1). Betaine acts a source of methyl groups for the conversion of homocysteine to methionine, it may be that betaine supplementation of gestating sow diets reduces levels of homocysteine, a known teratogen, while increasing methionine and choline availability for foetal tissue growth. Requirements for choline, and methyl groups likely reflect the number of embryos present in the uterus, and it is plausible that maternal methionine intake may be inadequate during gestation, particularly in older, heavier sows, in which pre-natal mortality typically occurs later during gestation. In conclusion, the current data demonstrate that supplementing gestation diets with betaine during summer can increase litter size, particularly of older parity sows.

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Supported in part by the Pork CRC Ltd.

The Effect of Diet Density and Lactational Demand During the First Lactation on Subsequent Reproductive Performance

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The premature culling of breeding sows as a result of reproductive failure, poor reproductive performance and/or locomotor problems has resulted in the reduced productivity of the modern genetically lean sow. Many hypotheses exist as to why this has occurred. Increasing gilt fat stores through protein restriction or increased feeding doesn't result in consistent improvements in lifetime performance (Hughes and Varley, 2003) whilst restricting the loss of protein mass during lactation has shown some positive correlation with subsequent litter size (Tritton *et al.*, 1996). It was hypothesised that reducing demand, through litter size manipulation, and increasing lysine supply will conserve body reserves, resulting in improved reproductive performance.

Hybrid gilts (n=988) were offered a standard diet (S, 14.3 MJ digestible energy (DE)/kg, 0.56 g available lysine (AvL)/MJ DE) or a high-lysine diet (H, 14.5 MJ DE/kg, 0.90 g AvL/MJ DE) during first lactation and assigned to one of two suckling regimes, seven or twelve pigs per litter, maintained throughout lactation, in a 2x2 factorial design. Gilts were maintained in the herd under commercial conditions and subsequent reproductive data obtained from the herd-recording system. Data were subjected to analysis of variance, diet and litter size as treatment factors and gilt weight at entry as a covariate. Chi-square analyses were undertaken to determine differences in retention rate. There were no significant differences between treatments in entry weight (215.2±0.68 kg, P=0.584), P2 backfat (17.0±0.11 mm, P=0.323), lactation length (21.2±0.07 d, P=0.679) or total energy consumed per day (81.4±0.43 MJ DE/d, P=0.604). Diet treatments differed significantly in daily lysine intake (S, 45.5±0.34 g AvL; H, 73.0±0.55 g AvL; P<0.001), whilst litter treatments significantly differed in total litter gain (7, 31.4±0.33 kg; 12, 44.3±0.40 kg; P<0.001).

Table 1. *Subsequent reproductive performance of gilts offered either a standard (S) or a high-lysine (H) diet and maintained with a litter size of seven (7) or twelve (12) pigs.*

	Treatment					P value[2]		
	S12	S7	H12	H7	SED	Diet (D)	Litter (L)	DxL
Parity 2								
Total born	10.8[a]	11.3[ab]	10.9[a]	11.5[b]	0.32	0.623	0.011	0.791
Pigs born alive	10.0[a]	10.5[b]	10.1[a]	10.6[b]	0.31	0.696	0.022	0.927
Retention rate[1] (%)	92.3	94.4	90.9	92.9		0.400	0.219	0.524
Parity 3								
Total born	12.2	12.1	12.6	12.3	0.33	0.148	0.414	0.819
Pigs born alive	10.9	10.9	11.5	11.1	0.30	0.058	0.270	0.427
Retention rate[1] (%)	71.8	72.6	73.4	72.9		0.727	0.959	0.981

[ab]Means in a row with different superscripts differ significantly (P<0.05). [1]Retention rate is the percentage of gilts that entered the experiment that farrowed at the second or third parity. [2]P-values from analysis of variance for total born and pigs born alive are from Chi-square analysis for retention rate; SED, standard error of difference.

Significantly higher performance was seen in the second parity when the demand on gilts was reduced in the first (Table 1), with dietary treatment having little effect. The response was not maintained in the third parity where diet appeared to influence (P=0.058) pigs born alive rather than litter size. Quesnel *et al.* (2007) associated this response to lactational demand with reduced ovarian development whilst the lack of response in the subsequent parity to dietary lysine levels was also reported by Tritton *et al.* (1996). The retention of gilts to second and third parities was high but was not influenced by either dietary or litter size treatments. Increasing dietary lysine did not significantly influence subsequent performance, however, reducing the lactational demand on the gilt, via reduced litter size, resulted in an increase of 0.5 pigs/litter in the second parity.

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Supported in part by the Pork CRC Ltd.

Effects Of Dietary Fatty Acids On the Secretion of Metabolic Hormones and Ovarian Properties in Prepubertal Pigs

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The concentration and ratio of n-3 and n-6 polyunsaturated fatty acids (PUFA) in the diet alters the pattern of prostaglandin (PG) synthesis, as the 1- and 2-series of PGs are derived from n-6 PUFA, and the 3-series of PGs are derived from n-3 PUFA. The effects of PUFA supplementation on fertility are unclear, as PGs mediate diverse reproductive processes. Studies show that feeding cows supplemental PUFA increases the total number and size of ovarian follicles (Wathes *et al*., 2007). The effect of dietary PUFA on follicle development in pigs has not been reported. There is increasing evidence that leptin provides the link between metabolic status, the neuroendocrine axis and subsequent fertility in pigs (Barb *et al*., 2008). We hypothesised that the type of fatty acid available in the diet from the time of conception influences body fat distribution and ovarian development in female progeny. The aim of this study was to determine the effects of dietary fatty acids on the secretion of leptin and insulin, carcase characteristics and ovarian properties in female progeny.

Pubertal gilts were fed diets supplemented with either 3% tallow (saturated fatty acid; control), 3% Salmate® (n-3; 1.4% docosahexaenoic acid and 1.5% eicosapentaenoic acid; Feedworks Pty Ltd, Romsey, VIC) or 3% safflower oil (n-6) from three weeks prior to mating and throughout gestation and lactation (n=10/group). After weaning on d 23, female progeny were maintained on a grower diet supplemented with the same fatty acid as their dam was given. On d 137, blood samples were collected hourly over a 12 h period to assess plasma concentrations of leptin and insulin (n=8/group). On d 158, the female progeny were slaughtered. Carcase dressed weight and P2 backfat depth were recorded and ovaries were collected for assessment (n=4, 6 and 5). Data were subjected to analysis of variance and a post hoc test when significant differences were detected (P<0.05; Table 1).

Table 1. *Effects of dietary fatty acids on metabolic hormones, carcase characteristics and ovarian properties (mean±SEM).*

	Tallow (control)	Salmate® (n-3)	Safflower oil (n-6)
Leptin (ng/ml)	3.03 ± 0.07	3.21 ± 0.07	3.58 ± 0.08
Insulin (μM/ml)	24.2 ± 1.33[a]	22.4 ± 1.14[a]	17.7 ± 0.73[b]
Dressed weight (kg)	89.2 ± 5.81[ab]	93.1 ± 4.72[a]	85.2 ± 1.51[b]
P2 backfat depth (mm)	15.0 ± 1.64	15.3 ± 1.23	17.7 ± 1.65
Ovarian weight (g)	7.17 ± 1.30	8.71 ± 0.95	9.84 ± 1.76
No. of 3-5 mm follicles	20.5 ± 5.17	20.8 ± 4.56	21.0 ± 6.69
No. of >5 mm follicles	5.75 ± 2.50	8.17 ± 2.50	5.20 ± 2.80

[ab]Means in a row with different superscripts differ significantly (P<0.05). SEM, standard error of mean.

Gilts of the n-6 group had a lower level of circulating insulin compared with the other groups and a lower dressed weight compared with the n-3 group. Although leptin concentration and P2 backfat depth appeared elevated in n-6 gilts compared with the other groups, the differences were not significant (P>0.05). Assessment of ovarian structures indicated the majority of n-6 gilts had ovulated in at least one cycle, whereas most of the n-3 and control gilts were yet to cycle. Despite the small sample size, the results suggest that PUFA supplemented feeds alter the distribution of body fat in female progeny compared with feeds high in saturated fatty acids. Whether manipulation of fat deposition by using dietary PUFAs can induce earlier onset of ovarian cyclicity requires further investigation.

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Supported in part by the Pork CRC Ltd.

Progeny Reared by Their Birth Dam Do Not Outperform Progeny Cross-Fostered to a Similar Parity Dam

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The growth and health performance of gilt progeny is widely regarded as being inferior to those born and reared by multiparous sows. Miller *et al*. (2007) reported that birth weight, lactation performance and possibly immunity development explains the differences observed between gilt and sow progeny performance through to slaughter. Cross-fostering piglets within 24 h from gilts to older sows may be a strategy to overcome parity differences in lactation and immunity. This experiment tested the hypothesis that gilt progeny nursed by older sows are healthier and grow faster than cross-fostered progeny.

Two-hundred and forty gilts (parity 1) and sows (parity 3-7) (PrimeGro™ Genetics, Corowa, NSW) were selected over summer and allocated to one of six treatments in a randomized block design: Gilts with birth progeny (GB); gilts with fostered gilt progeny (GG); gilts with fostered sow progeny (GS); sows with birth progeny (SB); sows with fostered gilt progeny (SG); and sows with fostered sow progeny (SS). All piglets were allowed to suckle on their birth dam before fostering 18 h post-farrowing. Litter sizes nursed after fostering were 10.1±0.1 and 10.8±0.1 ($P<0.05$) on nulliparous and multiparous sows, respectively. Data were analysed using a one-way analysis of variance with post-hoc comparisons.

Table 1. *Lactation performance of cross-fostered and dam-reared progeny weaned at 26.4 d of age.*

Treatment (sow/progeny)	Average daily gain (g/d)	Litter gain (kg/d)	Average piglet weight[1] (kg)	Total piglet removals[2]
Gilts/birth (GB)	202±0.6^{a}	1.63±0.08^{a}	6.7±0.18^{ab}	49/362 (0.135)^{ab}
Gilts/Gilts (GG)	194±0.9^{a}	1.65±0.10^{a}	6.5±0.23^{a}	42/359 (0.117)^{a}
Gilts/Sows (GS)	209±0.6^{ab}	1.94±0.08^{b}	7.0±0.17^{bc}	37/382 (0.097)^{a}
Sows/birth (SB)	230±0.6^{c}	2.08±0.08^{bc}	7.6±0.18^{d}	53/405 (0.131)^{ab}
Sows/Gilts (SG)	223±0.6^{bc}	1.84±0.10^{ab}	7.2±0.16^{cd}	69/390 (0.177)^{b}
Sows/Sows (SS)	235±0.6^{c}	2.20±0.08^{c}	7.7±0.15^{d}	45/415 (0.108)^{a}
P-value	<0.001	<0.001	<0.001	<0.001

^{abcd}Mean values in a column with different superscripts differ significantly ($P<0.05$); [1]Day 26; [2]Day 1-26.

Gilt progeny reared by sows grew faster than gilt progeny reared by their birth dam or foster gilts and were weaned heavier (Table 1). We showed that lactating gilts are capable of rearing heavier sow piglets to achieve litter gains greater than the GG or GB treatments. However, sow progeny reared by multiparous sows (SB and SS) attained heavier weaning weights than sow progeny reared by gilts (GS). Leaving progeny on their birth dam did not significantly reduce pre-weaning removals (mortality+illthrift) or increase weaning weight (GB v GG; and SB v SS). Post-weaning growth performance to slaughter was greater in GG compared to GB (725 and 695 g/d; $P<0.001$) and similar between the SB and SS progeny (743 and 754 g/d; NS).

The results showed that whole litters of gilt progeny reared by sows outperform gilt progeny reared by gilts from d 1 post-fostering until slaughter. The performance of sow progeny reared by gilts limited the effectiveness of a litter for litter swap. The results reject the hypothesis that progeny reared by their birth dam will outperform cross-fostered progeny when reared by a similar parity foster sow. Creating new litters with cross-fostered piglets within 24 h post-farrowing may be a better practice than partially fostering litters.

MILLER, Y.M., COLLINS, A.M., SMITS, R.J. and HOLYOAKE, P.K. (2007). In "Manipulating Pig Production XI", p. 62, eds J.E. Paterson and J.A. Barker. (Australasian Pig Science Association: Werribee).

Supported in part by the Pork CRC Ltd.

Induction of Oestrus During Lactation Results in Normal Mating and Farrowing Performance

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Previous research has demonstrated that oestrus can be induced during lactation using an injection of gonadotrophin at 19-24 d after parturition, combined with boar exposure and piglet separation until mating (Downing *et al*., 2007). The objectives of this experiment were twofold: to trial the concept under commercial practice and to test the hypothesis that induction of oestrus during lactation has no effect on subsequent mating and farrowing performance when compared with a cohort of weaned sows.

Forty-six F1 multiparous sows (PrimeGro™ Genetics, Corowa, NSW) were allocated at random to two treatments on the basis of parity at 20±1.8 (mean±SD) days after parturition. There were 23 sows per treatment. The first treatment was an intramuscular injection with 400 IU of pregnant mare serum gonadotropin plus 200 IU of human chorionic gonadotrophin (PG 600; Intervet/Schering-Plough Animal Health, Boxmeer, The Netherlands) combined with boar exposure and piglet separation from 1600 to 0800 h each day until mating by artificial insemination (AI). Sows in the second treatment were weaned into dry sow crates with boar exposure each day until mating by AI. The sows were housed in conventional farrowing crates in the same room at Rivalea Australia Pty Ltd, Corowa, NSW. Litter size was 11.4±0.54 piglets per sow. Each sow had unlimited access to a commercial, lactating sow diet estimated to contain 14.9 MJ Digestible Energy (DE)/kg and 0.50 g Available Lysine/MJ DE. Water was provided *ad libitum* via a nipple drinker. Piglets were provided with supplementary heating and a nipple drinker in each pen. After the start of each treatment, piglets were provided with unlimited access to a commercial, creep diet. Piglets on an induced sow were separated to the adjacent farrowing pen vacated by a weaned sow and piglets. Piglet separation ceased after AI and the piglets remained on each induced sow until weaning at 35 d after parturition. All sows were then housed as one group in straw-based accommodation. Pregnancy was confirmed at 40 d after mating by ultrasound. Pregnant sows were farrowed subsequently as one group in the same room. Induction to mating interval and piglets born alive were analysed by Student's t-test using the sow as the statistical unit. Proportional measures for sows pregnant and sows farrowed were analysed using a Chi-square test (Table 1).

Table 1. *Mean (±SE) mating and subsequent farrowing performance of 46 multiparous sows either induced1 during lactation or weaned at 20 d after parturition and mated by artificial insemination.*

Measurement	Induced	Weaned	P
Sows mated within 7 days after induction or weaning	20	20	-
Induction (or weaning) to mating interval (days)	4.4±0.1	4.2±0.1	0.176
Sows confirmed pregnant at 40 days after mating	19	16	0.267; χ^2 1.23
Sows farrowed	16	14	0.465; χ^2 0.53
Piglets born alive per sow	11.9±0.7	10.6±0.7	0.194

[1]Injection PG 600 combined with boar exposure and piglet separation (1600-0800 h) each day until mating; SE, standard error.

There was no difference in either mating or farrowing performance between sows induced during lactation or weaned at 20 d after parturition. The experiment confirmed the previous findings of Downing *et al.* (2007) and demonstrated that weaning can be uncoupled from reproduction in the sow under commercial practice. This new sow strategy has the potential to reduce non-productive days in the breeding herd.

DOWNING, J.A., TORIBO, N. and GILES, L.R. (2007). In "Manipulating Pig Production XI", p. 137, eds J.E. Paterson and J.A. Barker. (Australasian Pig Science Association: Werribee).

Supported in part by the Pork CRC Ltd.

Ovulation Synchronisation for Fixed-Time Single Artificial Insemination in Weaned Sows

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Artificial insemination (AI) strategies in pig farms aim to reduce the number of inseminations without reducing reproductive performance. Timing of the insemination is an important factor for successful AI ensuring that viable sperm are present in the reproductive tract in a 24 h period before ovulation for optimal conception rates (Kemp and Soede, 1997). However, the time of ovulation in weaned sows varies and is difficult to predict even after the onset of standing oestrus is determined (Nissen *et al.*, 1997). Gonadotrophin releasing hormone (GnRH) plays a key role in the regulation of the female reproductive cycle and induces the synthesis and release of follicle stimulating hormone (FSH) and lutenizing hormone (LH) from the anterior pituitary necessary for ovulation. The aim of this experiment was to investigate the effectiveness of using single, fixed-time AI using Pregnant Mare's Serum Gonadotrophin (PMSG) and Gonavet Veyx® Depherelin (Veyx-Pharma, Germany) to synchronise ovulation in weaned sows. Gonavet is an analogue of GnRH, commercially available in Europe and is approximately ten times as potent as native GnRH.

In this experiment, 48 parity 1 and 2 weaned Large White x Landrace sows were randomly allocated into 3 groups; Control, Single AI and Double AI. Control sows were inseminated as per piggery standard protocol including the use of boar nose-to-nose contact for oestrus detection and boar contact during two standard inseminations after standing oestrus was observed. Sows in the Single AI and Double AI groups were given 1000 IU of PMSG 24 h after weaning followed by 50µg of Gonavet 72 h later. Fixed-time, single AI was administered at approximately 1200 hours and double AIs approximately 0800 hours and 1500 hours on the day after Gonavet treatment to ensure that inseminations fell within the 24 h period before ovulation.

Table 1. *The effect of using Pregnant Mare's Serum Gonadotropin (PMSG) and Gonavet in post-weaned sows to synchronise ovulation on subsequent litter size data after one or two fixed-time artificial inseminations (AI).*

Group	n	Number farrowed (%)	Born alive (±SD)	Total born (±SD)
Control[a]	23	15 (65)	11.2 ± 3.5	12.0 ± 4.1
Single AI[b]	21	15 (72)	10.0 ± 2.7	11.1 ± 3.4
Double AI	21	18 (86)	11.4 ± 2.3	12.2 ± 2.9

[a]Control group data was from post weaned sows that were mated according to standard piggery protocols which included boar heat detection and at least 2 AIs; [b]Two sows within this group were culled, one for unknown reasons and one after late abortion; data are presented as mean ± SD (SPSS; t-test, no significant difference found); n, number of sows mated.

In this preliminary experiment, synchronising the time of ovulation in weaned sows with PMSG and Gonavet allowed for single fixed-time AI with non significant difference in farrowing rates or the number of piglets born compared with double AI or control sows (Table 1). Control of reproduction for single fixed-time AI offers many advantages to the pig industry including keeping less boars for heat detection, labour savings in the mating shed and less AI doses required per mating period.

KEMP, B. and SOEDE, N.M. (1997). *Journal of Reproduction and Fertility Supplement.* **52**:79-89.

NISSEN, A.K., SOEDE, N.M, HYTTEL, P., SCHMIDT, M. and D'HOORE, L. (1997). *Theriogenology.* **47**:1571-1582.

Supported in part by the Pork CRC Ltd.

The Effect of Season on Sow Ovarian Morphology

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Reduced farrowing rate caused by embryonic mortality is a manifestation of seasonal infertility (SI) in pigs (Tast *et al*., 2002). The ability of the oocyte to mature, be fertilised and sustain early embryonic development is acquired gradually by the oocyte throughout folliculogenesis. Oocytes recovered from large follicles are more developmentally competent *in vitro* than those from small follicles (Bagg *et al*,. 2007). This experiment was undertaken to determine if there are seasonal differences in ovarian morphology in terms of follicle development.

Ovaries were collected from slaughtered adult Large White x Landrace sows at 4 d post-weaning during winter (June-July; n = 272 sows) and late summer/early autumn (February-March; n = 317 sows). All sows were culled for non-reproductive reasons such as lameness. The average parity for winter and summer was 6.09 and 6.00 respectively. Surface antral follicles were classified according to their diameter (Small: 3 to 4 mm; Large: 5 to 8mm; Pre-ovulatory: 8 to 12 mm) and the number in each size group was recorded. Size classes were selected based on differences in developmental competence of oocytes derived from small, large and pre-ovulatory follicles. If present, the number of corpora lutea (CL) was also recorded. Data were analysed using analysis of variance and Chi-square goodness of fit models (GenStat Release 10.2, Numerical Algorithms Group®, Ltd. Oxford, UK).

Table 1: *The effect of season on follicle distribution per sow at four days post-weaning.*

	Number of follicles and CL per sow (mean ± SEM)			
Season	Small[1]	Large[2]	Pre-ovulatory[3]	CL
Winter	4.12±0.60[a]	13.7±0.59[a]	2.62±0.33[a]	27.4±4.16[a]
Summer	8.07±0.56[b]	16.93±0.55[b]	2.74±0.31[a]	27.3±5.28[a]

[ab]Means in a column with different superscripts differ significantly (P<0.05). SEM, Standard error of mean; C, Corpora lutea; [1]Small follicles (3-4mm); [2]Large follicles (5-8mm); [3]Pre-ovulatory follicles (8-12mm).

The mean numbers of small and large follicles per sow were greater in the summer group compared with the winter group (P<0.05; Table 1). The mean total number of follicles per sow was also greater in the summer group compared with the winter group (P<0.01). A greater proportion of the sows in the winter group had ovulation points and CLs present on their ovaries compared with the summer group (18% vs 6%; P<0.001). However, there were no differences (P>0.05) in the mean number of CLs between seasons.

The results suggest that at four days post-weaning, a higher proportion of sows during the winter are at a more advanced stage of the oestrous cycle than those during the summer. The greater number of sows with ovulation points and CL would explain the lower number of antral follicles seen on the ovaries of sows during winter. Weaning is a random event in regard to folliculogenesis; the lower number of small and large follicles during the winter could also be explained by weaning taking place early during a follicular wave. Due to the presence of numerous large and pre-ovulatory follicles on the ovaries of the summer group, a similar ovulation rate would be expected in summer unless the size of the luteinising hormone (LH) -surge and/or the response to LH were reduced (Gerritsen *et al*., 2008). This is consistent with the observation that reduced litter size is not a manifestation of SI. Further research is underway to determine whether oocyte quality plays a role in reducing farrowing rates during the SI period.

BAGG, M.A., NOTTLE, M.B., ARMSTRONG, D.T. and GRUPEN, C G. (2007). *Reproduction, Fertility and Development.* **19**:797-803.

GERRITSEN, S.J., SOEDE, N. M., LANGENDIJK, P., DIELEMAN, S.J., HAZELEGER, W. and KEMP, B. (2008). *Reproduction in Domestic Animals.* **43**:1-8.

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Supported in part by the Pork CRC Ltd.

CHAPTER 8

Reproduction and Genetics

Symposium: Exploiting Genetic Gains in Litter Size

Symposium Introduction

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The genetic improvement of reproductive efficiency in pigs has been based primarily on improving litter size at birth. Significant genetic and phenotypic gains have been observed in most pig producing countries, including Australia. In Denmark, genetic gains in the order of four pigs have been reported over the last 15 years. Concurrent with the increase in litter size has been significant genetic improvement in the lean growth rate of the sow. As a consequence producers are now faced with managing a significantly different female than that of 10 years ago.

Potential negative impacts of the above breeding goals include lower piglet survival during farrowing and pre-weaning, lighter average weights at weaning and increased weaning to re-mating intervals. The three papers in the symposium will discuss different methods to ameliorate these side effects.

Managing Consequences of Increasing Litter Size: A Genetic Perspective

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Selection for efficient lean growth and litter size can have detrimental consequences for piglet survival. However, survival traits themselves are lowly heritable, making it possible to select for improved survival directly in breeding programs. The generally low magnitudes of unfavourable genetic correlations between traits indicate it is possible to achieve genetic gains in production, litter size and survival traits concurrently. To select for piglet survival successfully requires the implementation of extensive data recording for individual mortality, combined with best-linear unbiased prediction (BLUP) genetic evaluation methodology. Accurate genetic evaluation of piglet mortality is complicated by the categorical nature of some trait definitions, low heritability, the large scale of recording required, population specific management and cross-fostering effects, and potentially the presence of both piglet and sow related genetic and environmental components affecting outcomes. In addition, while prenatal, postnatal and late lactation phases of piglet survival are not strictly independent events, the best approach to selection might differ depending on the relative contributions of each phase to piglet deaths. It is unlikely that there is a generic approach which is universally optimal for all breeding operations. The combination of high performance computing and inexpensive data storage has increased capabilities to apply more complex genetic evaluation procedures, which continue to alter possibilities for selection in this area. However, the efficacy of the chosen strategy should be validated in commercial populations. All breeding companies agree that a balanced breeding goal will include strategies to reduce piglet losses.

Introduction

The implementation of structured breeding programs incorporating well-defined breeding objectives and BLUP genetic evaluation procedures has generated high rates of genetic progress for a wide range of traits within modern pig breeding programs. Historically, the greatest gains were made in the improvement of lean growth potential. Since the 1990s, breeding companies have also successfully increased emphasis on and selection response for reproductive efficiency within maternal lines, largely through selecting directly for increases in litter size. These changes bring with them potential gains in overall productivity, but also several challenges to producers, who are faced with managing a very different sow herd today compared to the sows of yesteryear. Consequently, emerging issues include a decline in sow longevity, along with increased still births and pre-weaning piglet mortality, which are significant production and welfare issues. Increased levels of piglet losses can limit gains in the breeding goal for number weaned despite successful selection for litter size. The economic utility of directly including traits such as sow longevity and piglet mortality in breeding goals was demonstrated by Knap (2008).

This paper focuses on the complexities of evaluating piglet survival from a genetic perspective. It is important to note at the outset that individual piglet survival is the outcome of an extremely dynamic biological process and management environment, starting 115 days earlier at conception when litter size potential was initially determined. The implications of non-genetic issues are covered in other papers within this symposium, and indeed fixing problems in these areas can yield the quickest results (Alonso-Spilsbury *et al.*, 2007). Nevertheless, selection for improved piglet survival is worthwhile, if possible, given the cumulative nature of genetic progress and the desire that sows and their piglets should be able to survive with minimal human intervention. Breeding companies have only seriously commenced addressing the issue of increasing piglet mortality since around 2000, so there is considerable recent work in this topic area.

The indirect effects of historical selection on sow and piglet characteristics

Historical selection for other traits in the breeding goal has had unforeseen consequences for piglet survival. It is generally accepted that selection for lean growth potential and efficiency in finishers is associated with increased mature sow size and altered sow body composition, along with heavier (Hermesch *et al.*, 2001a) but potentially less physiologically mature piglets (Herpin *et al.*, 1993; Canario *et al.*, 2007) with lower energy reserves at birth. Changes at the sow level have implications for their appropriate feeding during gestation, to ensure adequate piglet birth weight and development *in utero*, which is one important factor for piglet survival (Siwek *et al.*, 2005). Larger mature sow size and lean mass are also accompanied by increased sow maintenance requirements, with implications for achieving appropriate sow condition and development pre-parturition (Bunter *et al.*, 2008). It is plausible, but not yet researched, that these changes to the sow phenotype also have implications for mammary development and lactation potential, along with immune competence, which are required for adequate milk production and the

initial transmission of maternal antibodies to piglets via colostrum. Unfavourable genetic associations of growth and leanness with piglet mortality during farrowing (Arango *et al.*, 2005) or for ham production and piglet survival (Cecchinato *et al.*, 2008) have been reported. Alternatively, selection for increased number born alive (NBA) or prenatal survival has produced a correlated response of increased growth and fatness for finishers in some (Holl *et al.*, 2003) but not all populations. Maternal lines have typically had some history of selection towards improved lean growth potential, so are not immune from unfavourable associations between components of body composition and piglet survival. As was previously suggested by Rydhmer (2000), selection for lean growth should be accompanied by selection for piglet survival, suggesting that selection for increased litter size is not the only issue to consider when examining options for selection against piglet mortality.

Selection for litter size commenced in several countries in the early 1980s (eg. the French hyperprolific scheme) and with the routine implementation of BLUP genetic evaluation procedures. Breeding companies tended to favour selection for total born (TB), which is more heritable and variable than NBA, thereby providing better prospects for improvement. Unfortunately, as TB improved with selection it was generally accompanied by observed unfavourable trends in stillbirths and early neonatal deaths. Perhaps the trend for stillbirths could have been expected, simply from a numerical viewpoint, since in larger litters more piglets must safely traverse the birth canal over a longer duration of farrowing. An increase in early neonatal deaths may have also been predictable, since there generally is a negative linear relationship between TB and piglet birth weight; piglets from larger litters will be lighter on average. In addition, piglets born later in the farrowing order within larger litters are less likely to obtain adequate colostrum, which is important for their immune competence (Siwek *et al.*, 2005). These trends were not just phenotypic, as can occur when the environment or management becomes inadequate. Negative genetic correlations between TB and piglet survival have subsequently been estimated (Robinson *et al.*, 2002; Su *et al.*, 2007) confirming a genetic antagonism between these traits.

Selection opportunities for breeding programs

Direct selection for survival

Exact levels and patterns of piglet mortality differ between studies, and even different herds supplied with the same breeding stock will exhibit variation in levels, causes and temporal patterns of mortality. This is potentially because in addition to environmental differences between herds, there are both sow and piglet factors that impact piglet survival. Maternal factors include farrowing outcomes, sow behaviour and maternal ability, while piglet factors include newborn vigour and teat seeking, along with developing conditions such as acidosis, hypothermia and hypoglycemia (Alonso-Spilsbury *et al.*, 2007). Many of these factors are not recorded directly, but contribute to the mortality outcome.

To better define an optimal approach to selection, there are a few key time periods which can logically be considered to represent different phases of mortality. In phase I (farrowing losses), total born is reduced to number born alive during the farrowing process through stillbirth (SB) of fully formed piglets. However, there will always be some error associated with differentiating stillbirths from very early deaths unless farrowing is monitored constantly, or post-mortems are conducted. The number of mummified piglets is generally not considered a heritable characteristic, and therefore provides no effective information for selection. Phase II covers the immediate post-farrowing period, when both sows and piglets adapt to their new physiological states and to the environment. The highest rate of post-farrowing piglet loss occurs in this phase, with more than 50 percent of all pre-weaning deaths occurring within the first five days, predominantly from crushing and starvation (Grandinson *et al.*, 2002; Arango *et al.*, 2006). In phase III, after lactation is generally established, causes of piglet losses become more variable. Phase III losses could also include piglets that survive to weaning, but which do not survive the weaning process, and/or which will never attain a saleable live weight (ie. poor quality pigs). However, the latter is generally not considered in analyses because it is not adequately recorded. It is important that data recording procedures allow some discrimination between these phases, since causes of mortality, and sources of genetic and environmental contributions to outcomes, change between phases. In phase I only the genes and phenotypes of the biological dam and her piglet are potentially important, whereas in phases II and III the genes and phenotype of the nursing sow are an additional source of variation for piglet mortality. The relative impact of these different sources of effects on piglet survival can be difficult to separate without very large, well-structured and well-recorded data sets.

The second factor that must be considered for breeding program opportunities is the level at which information on mortality is recorded. Prior to 2000, farrowing and pre-weaning mortality were generally considered solely as traits of the sow. Consequently, the sow trait was number weaned, regardless of whether the sow was weaning her own or another sows piglets. Unfortunately, while recording at this level may be directly related to parameters commonly used to evaluate herd performance, these data provided no opportunity to identify or discriminate amongst the different

phases of piglet loss, were generally not accompanied by the necessary information to correct for cross-fostering effects, had lower variation relative to TB or NBA (due to systematic litter size standardisation) and generally assumed that piglet genotype had no significant impact on piglet survival. The net result was a sow trait (number weaned) that was often not very heritable or variable, and therefore not a good candidate for direct selection; hence the selection focus on litter size traits recorded at farrowing. These problems can be resolved by recording important traits or factors for survival, such as birth weight, cross-fostering activities and dates of death, at the level of the individual piglet. This data can then be used to construct and examine potential traits for genetic evaluation expressed at both the sow and piglet levels. Several breeding companies have relatively recently implemented recording at the individual piglet level. However, since this level of data collection and storage is very labour intensive and computationally demanding, it may not be complete in all details.

From an analytical point of view, when data are recorded only at the sow level, the proportion of variation due to piglet genes versus sow genes can only be estimated using sow and service sire models. However, when data are recorded at the individual piglet level, these effects can be estimated directly from a piglet-sow model. In addition, when all cross-fostering details are recorded, estimation of effects can theoretically proceed at the piglet, biological dam and nurse sow level (while also accommodating the permanent environmental effect of the sow across parities). In reality, these sow level effects are generally confounded for many sows and this creates problems with obtaining robust estimates of genetic parameters, particularly when the piglet mortality trait represents the sum of mortality across all three phases outlined above (Knol *et al.*, 2002a). For pre-weaning mortality in particular, some researchers overcome this particular problem by only using data from non-fostered piglets to evaluate the biological sows performance as a dam and nurse sow (Su *et al.*, 2008), or attribute records of biological rather than foster offspring only to a sow (Su *et al.*, 2007). Other breeding companies or research herds eliminate cross-fostering from the management process for data clarity (Damgaard *et al.*, 2003; Wolf *et al.*, 2008), but this strategy then excludes data leveraged from commercial sows, which will typically be affected by cross-fostering. Still others allocate piglet records only to a nurse sow, since the bulk of piglets are reared by their own dams in any case (ie. nurse=dam), and models fitting nurse sow generally describe pre-weaning mortality better than models fitting biological sows only (Knol *et al.*, 2002a). Obviously, this outcome depends on how much cross-fostering is practiced. Despite these difficulties, separating piglet and sow level effects is important as it will facilitate more accurate genetic evaluation at both levels, even if selection criteria involve only traits expressed by sows. This is particularly important if there is an antagonistic genetic correlation between sow and piglet effects.

A final complication in comparing studies and approaches lies with the huge range of possible trait definitions, influencing how traits should be analysed. Using pre-weaning piglet mortality as an example, the trait can be defined as binary (0/1) at the piglet level, or a categorical count or percentage (of TB or NBA) at the sow level. Each of these trait definitions requires different statistical approaches and appropriate models, particularly when sows have multiple litters in the data. Typically, not all of these issues are well addressed in published literature, which can create some inconsistencies with interpretation. In addition, some researchers look at mortality, whereas for others the trait(s) analysed relate to survival, so the sign of correlations between traits will be reversed. A summary of results from several recent large scale studies (post-2000) is presented in Table 1 to demonstrate the relative magnitude of piglet versus sow genetic components for different phases of piglet survival. These parameters indicate whether selection is possible and which source of genetic effects (piglet or sow) is relatively more important. The sign of published correlations is reversed where necessary, so that all published results are framed in terms of piglet mortality. Further, parameters are averaged across the range of comparable trait definitions and types of methodology (eg. linear versus threshold) used for analyses. Please note, non-genetic factors known to affect values for reproduction and mortality traits (such as seasonal and parity effects) are already accounted for in the process of parameter estimation, so remaining variability amongst sows, for example, is independent of these factors.

It quickly becomes apparent that information on correlations between traits and piglet survival is very limited at the piglet level, but marginally better at the sow level (Table 1). Of note, the magnitude of the sow component for pre-weaning mortality is higher in recent studies compared to previous reviews: 0.11 here compared to 0.05 (Rothschild *et al.*, 1998; Knol *et al.*, 2002b). In addition, the magnitude of antagonistic correlations between TB and pre-weaning mortality is much higher in recent studies (0.44, Table 1) compared to the average from a review by Rothschild and Bidanel (1998), which was (sign adjusted) 0.11. This could indicate that as selection has progressed to increase litter size over recent years, the heritability of the sow contribution to piglet survival has increased, and the correlations between litter size and piglet survival have become more antagonistic. However, this trend could also be an artefact of changes in estimation methodology, which has not been investigated by any researchers.

Table 1. *Averages of genetic parameter estimates (×100) for traits associated with farrowing and pre-weaning mortality of piglets, separated into piglet and sow components (number of studies in brackets)*[a].

	Heritability		Correlation with farrowing mortality		Correlation with pre-weaning mortality	
	Piglet	Sow	Piglet	Sow	Piglet	Sow
Gestation length (GL)	$19_{(2)}$	$30_{(2)}$	$34_{(2)}$	$-7_{(3)}$	$-27_{(1)}$	$-57_{(2)}$
Total born (TB)	$4_{(4)}$	$10_{(12)}$	$-33_{(1)}$	$34_{(6)}$	$26_{(1)}$	$44_{(9)}$
Farrowing mortality (FM)	$4_{(15)}$	$10_{(22)}$	-	-	$21_{(4)}$	$6_{(7)}$
Number born alive (NBA)	$4_{(3)}$	$10_{(10)}$	-	$12_{(5)}$	-	$30_{(6)}$
Piglet weight (PWT)	$5_{(10)}$	$29_{(13)}$	$-18_{(3)}$	$6_{(7)}$	$-13_{(3)}$	$-30_{(9)}$
Pre-weaning mortality (PM)	$5_{(10)}$	$11_{(19)}$	$21_{(4)}$	$6_{(7)}$	-	-

[a]References on which these averages are based are included in the reference list.

Parameters in Table 1 also illustrate that TB and NBA are predominantly traits of the sow, which is why selection based on sow records only, ignoring the piglet component, has been successful in increasing litter size. Total born is highly correlated with NBA at the genetic level (~0.92), since both traits rely on ovulation rate and embryo survival as their primary determinants. As with previous reviews (Rothschild *et al.*, 1998; Rydhmer, 2000) more recent studies also confirm detrimental genetic correlations between TB and farrowing or weaning mortality, which are not as strong between NBA and the same traits. Selecting for NBA instead of TB remains a practical way of improving litter size without escalating still births (Canario *et al.*, 2006) or other farrowing complications, and is a more simplified approach compared to a more complex set of selection criteria (eg. the combination of TB and FM are replaced by NBA).

When data from piglets only are used to generate records for their biological dam, the genetic correlations between TB or NBA and number weaned differ markedly (0.41 versus 0.79, Su *et al.*, 2007), supporting the concept of the importance of NBA compared to TB. Further, when the trait of interest is number of biological piglets alive at d 5, regardless of fostering, this trait is more highly correlated with number of piglets at weaning (>0.95) as one would expect. This strategy focuses selection pressure on the genes of the biological sow for characteristics of piglet survival evaluated early in lactation. However, with this strategy it could also be argued that there is no direct focus on characteristics of the nurse sow that improve piglet survival, and this could be an issue if late lactation issues impinge on piglet mortality.

Average parameters indicate that farrowing mortality is also mostly a sow trait, so selection against stillbirths is most efficient for stillbirths expressed as a sow trait. Leenhouwers *et al.*, (2003) demonstrated that the maternal genetic component of farrowing survival was associated with reductions in all categories of stillbirths but not litter size. However, the variability amongst different studies for piglet versus sow contributions to stillbirths suggests that the source of farrowing losses might differ between populations. For example, Knol *et. al.*, (2002a) demonstrated that in a dam line (higher litter size, lighter piglets) the best model describing farrowing survival only contained piglet effects, whereas for the sire line (smaller litter size, heavier piglets), maternal effects were the primary source of genetic variation for farrowing survival. It could also be argued that the necessity of selecting for farrowing survival is eliminated if the starting point for selection is NBA rather than TB. Farrowing mortality is not highly correlated with pre-weaning mortality at the sow level, supporting the concept that mortalities in these phases are controlled by different genes.

Pre-weaning mortality can also be selected against directly, although heritability is low and once again both sow and piglet components are evident (Table 1). Further, some studies demonstrate a change in the relative importance of piglet versus sow components according to whether mortality occurs during early or late lactation, and this might have implications for the success of selection. Arango *et al.*, (2006) showed consistent relativities between the magnitude of sow and piglet components across different time periods within a lactation, while correlations between mortality recorded in different phases of lactation were less than unity, implying different genes affected outcomes for piglet mortality in different phases. Su *et al.*, (2007) showed the relative sow contribution towards the number surviving increased as lactation progressed. Each of these outcomes illustrate that the pattern of mortality will potentially affect which approach to selection will be more efficient.

Overall, research studies exhibit varying degrees of heritability for piglet mortality and related traits. This suggests it is feasible to select directly against piglet mortality, and this should occur because of antagonistic correlations between litter size and piglet survival. However, it is possible that without adequate understanding of the patterns and basis of piglet mortality, within both nucleus and commercial populations, that response to selection will not be as predicted.

This is because underlying parameters for mortality might differ from expectation in a given population under a particular management system and environment, or change as selection progresses. It is important that recording and selection strategies are validated for the population(s) of interest, and that it can be demonstrated that derived mortality estimated breeding values (EBVs) have some predictive capacity. Where appropriate parameters for a given population are used, and selection is efficient, favourable trends in both litter size and mortality traits can generally be exhibited (see Knap, 2008).

Selection for specific maternal characteristics of the sow

In addition to the generic approach of selecting directly against piglet mortality outlined above, which strictly speaking does not rely on any knowledge of the underlying causes of piglet death in that population, it is also possible to select for specific characteristics of sows and piglets that are known to be associated with piglet survival. The question of whether this is a beneficial approach then depends on the ease and expense with which the necessary data can be recorded, how heritable the recorded traits are, how correlated they are with piglet survival, whether the correlations or relationships change over time, and whether there are any synergistic or antagonistic effects that might exist. Specific traits that have been investigated from a genetic perspective are outlined in more detail below.

Traits of the biological dam

Gestation length. The first step toward maximising number weaned is to ensure that the maximum numbers of fully formed piglets gestated are born alive and healthy. Gestation length is determined by genes of both the piglets and sow (Table 1) because piglets initiate the hormonal sequence leading to farrowing, but it is the sow's physiological response to this that ultimately results in parturition. Gestation length (GL) considered as a trait of the sow is moderately heritable (h^2=0.30, Table 1), and generally has a negative correlation with TB, positive genetic correlations with piglet birth weight, survival and growth (Hermesch, 2001; Rydhmer *et al.*, 2008), but variable association with still births (Rydhmer *et al.*, 2008). The strong correlation between gestation length and piglet survival at the sow level in particular make GL data highly informative when estimating sow genetic merit for piglet survival, and GL data are routinely available. However, the opposing correlations at the piglet level (Table 1) hints at the possibility of more stillbirths with longer GL, potentially counteracting gains in later piglet survival. Hermesch (2001) demonstrated a net gain in number weaned from using gestation length as a selection criterion, under the assumed parameters, particularly when used in combination with average birth weight. However, not all studies report the same correlation structure between traits, so predicted outcomes will differ. Due to its low variability GL is not really a direct candidate for selection *per se*. Further, farrowing induction negates the use of gestation length data for this application.

Piglet birth weight and uniformity of birth weight. Heavier piglets have higher energy reserves and lower surface area to body mass, so are less subject to effects such as hypothermia (Alonso-Spilsbury *et al.*, 2007). Unfortunately, heavy piglets may also contribute to farrowing difficulties, and compete more effectively than lighter siblings for teat access, so within litter variability in birth weight could be important for piglet survival. However, with increasing litter size, we generally expect a decrease in average piglet birth weight, an increase of within-litter variability, and an increase in the percentage of piglets of very low birth weight, with compromised pre-natal development (Morise *et al.*, 2008) and therefore an increased probability of death. Birth weight and its within-litter variability are generally considered as different traits of the sow (h^2=0.29, Table 1, and ~0.08 from six studies in this review), but there is also a small contribution from the piglet genotype on individual piglet weight (0.05, Table 1). Selection against low individual birth weight was proposed (Roehe *et al.*, 2000) as an alternative to selecting for piglet survival directly, primarily because of the strong phenotypic association between birth weight and piglet survival. They demonstrated that individual piglet mortality was predicted less accurately when average birth weight or the standard deviation of birth weight (sow traits) replaced individual birth weight in analyses. Recent studies (Table 1) and unpublished data from Australian populations (Bunter, 2005) confirm that genetically heavier piglets are more likely to survive and are less likely to be overlaid until weaning, when birth weight is expressed as a trait of the sow.

In contrast, some studies show no genetic association and limited predictive value between individual piglet birth weight and survival (Knol, 2001) and argue that selection for increased birth weight might not be effective for increasing piglet survival in all populations. This phenomenon might be because the impact of birth weight on mortality depends on the prevailing environmental conditions (English *et al.*, 1996) and the within nurse litter dynamics, which can be altered by cross-fostering management. Rydhmer (2000) had also previously noted that the relationship between birth weight and survival did not appear to hold when high birth weight was a reflection of lean growth potential. This is possibly because birth weight is not a good indicator of physiological maturity or energy stores at birth (Leenhouwers *et al.*, 2002) in this instance. Alternatively, the average birth weight of high lean growth potential piglets may be already sufficiently high that further increases in birth weight yield no benefits in piglet survival. The low heritabilities reported

for some trait definitions describing within litter variability of birth weight (Hogburg *et al.*, 2000; Hermesch *et al.*, 2001c; Damgaard *et al.*, 2003; Wolf *et al.*, 2008) indicate that the variation between sows in litter homogeneity is mainly environmental in origin. However, genetic correlations indicate that lower within litter variability is associated with reduced piglet mortality (Wolf *et al.*, 2008).

Farrowing kinetics. An efficient farrowing process could be expected to reduce the detrimental sequence of events associated with piglet asphyxia that occurs during farrowing, responsible for some still births and early post-partum deaths (Alonso-Spilsbury *et al.*, 2007). Farrowing duration and birth interval traits are both lowly heritable (h2=0.10 and 0.08, Canario *et al.*, 2006) but difficult to record routinely for selection purposes. Canario *et al.* (2006) reported a strong favourable genetic correlation between NBA and birth interval (-0.49) along with an unfavourable correlation between farrowing duration and still births (0.42), indicating that data on NBA (in contrast to TB) captures a reasonable proportion of the variation between sows in their farrowing characteristics.

Traits of the nurse sow

Sow behavioural traits are important for piglet survival in some production systems, but in intensive systems the use of farrowing crates to reduce piglet mortality has probably weakened selection for a range of maternal behavioural characteristics. For example, in the farrowing crate environment, sow parturition behaviours associated with selection of the farrowing site, nest building and litter defence are no longer required. This appears to reduce behavioural aspects of the nursing sow to acceptance of the litter, encouragement of suckling events and avoidance of piglet crushing. Grandinson (2003) reported that sow behavioural responses to piglet screams and human contact were lowly heritable (0.06 and 0.08). Sows more responsive to screams or that were less afraid of human contact crushed fewer piglets and had better piglet survival. However, in the light of low heritabilities and correlations, an investment in animal handling to reduce fear responses in sows might yield quicker results.

Colostrum quality, milk yield and litter weight. Genetic variation in colostrum output and quality (from both energetic and immunological perspectives) is essentially unknown in pigs. However, it has been observed that Meishan content sows generally have a higher milk fat percentage than traditional white breeds (Farmer *et al.*, 2001). In addition, milk yield is generally not measured directly, but inferred instead from piglet growth rates. Unfortunately, piglet growth rates are a complex interaction between a sow's effects on her piglet's birth weight and her lactation potential, sow and piglet genes for growth, sow and piglet health, the prevailing environmental resources and limitations, along with cross-fostering practices and suckling litter size. Moreover, the expression of a sow's lactation potential is also affected by the same factors (Bunter *et al.*, 2008). Nevertheless, selection programs that utilise total litter weight at weaning indirectly favour both piglet survival and individual piglet weight gain.

Persistence of yield. Lactation characteristics of nursing sows are obviously important for piglet survival to avoid deaths by starvation. Rydhmer *et al.* (2001) studied the aetiology and inheritance of disturbed lactation leading to drying up in the third week of lactation. In their population, the heritability of milk disturbance on the underlying scale was 0.70±0.15. However, the heritability for early lactation failure of primiparous sows in an Australian herd was only 0.14±0.09 (Bunter *et al.*, 2009). Patterns of milk yield, and the genes controlling persistence of lactation, are known to vary in dairy cattle. Although inadequately researched in pigs, persistence of lactation becomes more important with older weaning age, and where sows are housed individually. Where sows are managed in groups and piglets have access to other feed, both cross-suckling and early weaning of piglets are observed (Baxter *et al.*, 2009), making lactation persistence less important.

Piglet quality. By the targeted weaning age, the goal is to have heavy piglets that will survive the weaning process and grow well post weaning. However, while the genetic correlation between litter size and litter weaning weight is strongly positive (averaging 0.53 in the review by Rothschild *et al.*, 1998), this is mostly driven by the number of pigs weighed. The genetic correlation between litter size and individual piglet weight at birth actually tends to be negative in most populations. Therefore, selection for piglet weight or weight gain must be considered separately to selection for litter size. Genetic correlations are very high between individual or average piglet birth and mid-lactation piglet weights (average 0.67: Hermesch *et al.*, 2001b; Bunter *et al.*, 2008), indicating that piglet quality evaluated by weighing early in lactation is mostly a function of birth weight from the genetic perspective. Correlations between birth weight and weaning weight averaged from three other studies were only slightly lower at 0.60. The generally positive genetic and phenotypic associations between birth, weaning and later weights provide a counter-argument promoting selection for birth weight.

Selection for piglet characteristics

The potential efficiency in terms of response to selection of selecting for traits recorded on individual piglets has not been well investigated, since most traits recorded prior to weaning are dominated by sow components. However, the estimation of negative correlations between direct effects for piglets and the maternal effect of sows (Knol *et al.*, 2002a; Mesa *et al.*, 2006; Su *et al.*, 2008; Ibanez-Escriche *et al.*, 2009), particularly for pre-weaning survival, could indicate that both sow and piglet level effects will need to be accommodated in analyses, even if selection subsequently occurs based on traits expressed by sows. However, negative direct-maternal correlations are frequently estimated due to poor data structure and/or inappropriate models which do not partition co-variances properly. The results of Roehe *et al.* (2009), where there was no difference in piglet survival following sire selection based on the maternal component for piglet survival, implies that piglet (direct genetic) and maternal effects are neutral. Since this area remains unresolved on a widespread basis, and it is possible to remove the undesired piglet component as a nuisance factor from the genetic evaluation of a trait expressed by the sow, this section focuses instead on physiologically significant measures of the piglet.

Individual weight or dimensions. As previously noted, the piglets' own genes directly contribute relatively little to piglet birth weight, so perhaps counter-intuitively, recording individual birth weights is not intended to improve response in piglet birth weight through selection because this is more efficiently achieved through selecting for average birth weight as a trait of the sow. However, individual birth weight data can be used as a covariate for piglet survival traits, improving the accuracy of assessing genetic merit for piglet survival given a background of variable litter sizes and birth weights (Roehe *et al.*, 2009). Ponderal index, a function of piglet weight and length, is also related to piglet survival during farrowing (Baxter *et al.*, 2009), but this type of measurement has not yet been investigated at the genetic level.

Placental efficiency. The ratio of piglet to placental weight, or placental efficiency, was first proposed as a selection criterion to target increased litter size without reductions in piglet weight (Wilson *et al.*, 1999). Placental efficiency is incredibly labour intensive to record. Subsequent work indicates that placental efficiency provides negligible additional information on piglet survival when birth weight is already known (van Rens *et al.*, 2005; Mesa *et al.*, 2006), so this trait has little practical value from the perspective of piglet survival.

Cortisol levels and other physiological parameters. Collection of physiological measures associated with individual piglet mortality, such as cortisol, is invasive, costly and not routinely applied. However, physiological measures have been used to confirm that estimated genetic differences in piglet survival were associated with differences in foetal development and physiological maturity (Leenhouwers *et al.*, 2002).

Conclusions

1. There is good evidence that lean growth potential and litter size have unfavourable genetic correlations with piglet survival under prevailing production environments. Unless breeding goals include piglet survival, piglet mortality will likely increase as selection for other traits progresses.

2. Parameters suggest that selecting for NBA is a better option than selecting for TB, as the lower genetic variation for NBA is likely offset by the increased survival of piglets during parturition. There are also favourable correlations between NBA, farrowing kinetics and pre-weaning survival. In Australia, we have only promoted selection for NBA, so detrimental trends in SB associated with increasing litter size should have been at least partially avoided.

3. Recording outcomes for individual piglets improves our ability to separate piglet from sow related factors affecting piglet mortality, and can improve the accuracy of genetic evaluation for piglet mortality at both levels. This will allow strategies such as selection against stillbirths at the sow level, or selection against pre-weaning mortality at both the sow and piglet levels. However, it requires extensive investment in data recording, and the chosen approach should be validated in the commercial population(s) of interest.

4. Accurate genetic evaluation of piglet mortality traits is not straightforward. The best trait definitions are not clear, and the distributions of records for piglet survival or mortality traits are generally not normal, requiring more sophisticated statistical techniques which are computationally more demanding. Cross-fostering introduces further complexity by generating biological and nurse sow effects, in addition to piglet effects. Cross-fostering strategies need to be co-ordinated with the trait definition used for genetic evaluation, or vice-versa. Appropriate genetic evaluation software is still to be developed for national breeding programs in all countries, while some private breeding companies have already made progress in this area.

5. Birth weight is predominantly a trait of the sow and, because of favourable genetic correlations with piglet survival, was proposed as a proxy for piglet survival (particularly in the absence of recording individual mortalities). However, there is some contradictory evidence that direct genetic aspects of piglet survival are not related to birth weight, and there are clearly additional sow related effects associated with farrowing outcomes and maternal characteristics that are also likely to be unrelated to birth weight. Moreover, where heavy piglets are the consequence of selecting for lean growth potential, or where the environment provided to piglet and sow is of good quality, the relationship between birth weight and piglet survival appears to be weaker. In this scenario, a breeding goal combining weight and mortality data might yield the best response in piglet survival under selection. Birth weight is highly correlated with weights up until weaning, which also has implications for post-weaning piglet quality.
6. The best selection strategy is likely to vary according to the history of selection in the population, and therefore the most limiting factor(s) in that population for piglet survival. Therefore, not all breeding companies choose to take the same approach on this issue, and not all companies evaluate the same trait complexes. Some companies will focus on mortality traits directly, whereas other companies might focus on specific sow attributes. Providing genetic gains in piglet survival or number weaned (and not just litter size) can be demonstrated, the actual approach used probably should not concern producers. Ideally, breeding companies can demonstrate both a balanced approach to their breeding goals and good performance in combination with high piglet survival rates, and this is certainly what they promote in their literature.

Acknowledgements

The author would like to acknowledge helpful comments made by Susanne Hermesch, Craig Lewis, Ron Crump, Brian Luxford, Pieter Knap, Scott Newman, Egbert Knol and Hans Graser.

Nutritional Strategies for the Sow to Cope with an Increase in Litter Size

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Introduction

Increasing the number of pigs sold per sow per year is a key component of profitability in commercial pig production. Assuming that we can make significant increases in the number of piglets born alive through genetic selection and improved reproductive technologies, the real challenge is to then rear all of these without any detrimental effect on the sow. We also can't afford to be just interested in piglet survival, because we know that what happens pre-weaning has a large influence on performance thereafter, which in turn can have a big impact on cost of production and hence profitability. The weight of the piglet at birth and the quality of the piglet at weaning are thus important considerations, and strategies involved in maximising survival may not be the same as those required to also optimise piglet quality or long-term performance.

If the sow has the same number of functional teats as there are piglets born alive, then it is theoretically possible for the sow to rear all of those piglets through to weaning. However, some form of artificial rearing of piglets will be necessary as part of any overall strategy because of the likelihood of there not being sufficient lactation capacity available at all times.

It is also difficult to consider nutritional strategies in isolation from other husbandry and management issues. For example, only small gains can be made in increasing nutrient intake during lactation by changing the nutrient content of the diet if there is a limitation on feed intake related to environmental factors. Therefore attention to detail in all areas is required if we are to fully capitalise on the genetic gains that are possible, and many of these come under the banner of management. The aim of this paper is to consider those factors, from a nutritional perspective, that are important if we are to benefit from the increased number of piglets to be born through improvements in genetic and reproductive technologies.

The quality piglet - setting our goal

The weight of the pig at weaning, and indeed at birth, bears a strong positive relationship to subsequent growth and the weight at some time in the future (King, 2003). Hence weaning weight has to be a key performance target in pork production because of the overall influence that it has on growth in the growing and finishing stages. In addition, processes occurring before and after weaning may influence carcase quality of pigs at slaughter (105 kg live weight; Pluske *et al.*, 2005). In the case of large litters, are we prepared to sacrifice some of the benefits of weight at weaning in return for increased numbers?

If we accept that we are not just interested in the number of piglets that survive through to weaning but also on how well these pigs grow thereafter, then we need to define what we mean by a quality piglet. One definition might be an animal that has the capability to withstand the stress of weaning without the need for routine medication and specialist care, and that it grows to its potential from weaning through to slaughter. In simple terms, it is an 'easy to care for' animal. It is relatively easy to set a target weight at weaning, adjusted according to the age at weaning, but a useful target should also take into account a measure of variability. Even though we may be happy if we reach our target average weaning weight, we haven't been successful if the lightest 25 percent of pigs that are weaned subsequently negate the gains that we have made in increased numbers by requiring extra resources (eg. feed, housing, management) through to sale. Payne *et al.* (1999) discussed the impact of variation on long term performance and profitability, and it is already a major problem faced by the pork industry. Having to deal with an increase in variation is a real risk if we increase litter size substantially.

How can we monitor how successful we have been at producing quality piglets? At present it is primarily based on live weight at weaning, but perhaps we need to start taking a more novel approach. For example, it might include the percentage of pigs requiring treatment during a set period or, more likely, the proportion of pigs reaching a target live weight at a set age (eg. 10 weeks). With the likely introduction of technologies that will allow us to individually identify pigs, perhaps automatically monitor their body temperature and obtain regular estimates of their weight and possibly feed intake, it may become relatively easy to monitor performance of individual pigs in a group situation. This in turn will allow us to better measure how successful our management has been and to thus make changes to deal with

the consequences of larger litters. With an increasing proportion of pigs now being grown out on contract, those with responsibility for the rearing of weaner pigs will also want to know more about what has happened to that piglet pre-weaning since it has such a big effect on how that animal performs thereafter.

The sow

How and what we feed the sow from the time of selection as a breeder throughout the breeding cycle will have an important bearing on our capacity to rear as many piglets as possible from large litters. This starts with maximising piglet birth weight, but then must include aspects of quality and quantity of colostrum and milk through to subsequent effects on reproductive performance of the sow.

Birth weight

Much of the published work on the response of birth weight to maternal feed intake was conducted with older genotypes between the mid 1960s and the mid 1980s. Pluske *et al.* (1995) reviewed this work and concluded that the relationship between maternal energy intake and birth weight was linear for sows but curvilinear for first-litter sows. In other words, with young sows there is an increase in birth weight as energy intake of the sow increases to a point at which the sow directs a greater proportion of that additional energy into building up her own body reserves rather than continue to increase birth weight. Data presented by Foxcroft *et al.* (2006) demonstrates the impact of increased litter size on both average birth weight and the proportion of piglets born in the various weight categories (Table 1). This group argue that the introduction of hyperprolific females into the breeding herd needs careful consideration in the context of the overall efficiency of pork production. In other words, it is not just the number of piglets produced that is important, but also the quality.

While the sow is very good at buffering the developing foetus against nutritional inadequacies during pregnancy, it is generally recommended that feeding level is increased during the last three to four weeks of gestation to coincide with the increased demand for nutrients. With the introduction of group housing systems it is going to become more difficult in many situations to guarantee that the nutrient requirements of the sow, and hence birth weight of piglets, is optimised. Of course if we could identify those gilts and sows that we knew were going to have a large litter and feed them accordingly then that would greatly improve the efficiency with which we use feed in the breeding herd. There have been efforts in the past to relate litter size to blood parameters such as oestrone sulphate at about four weeks into gestation (Moenter *et al.*, 1992). While these measures may not be able to accurately quantify subsequent litter size, they may be used to discriminate between low, medium and high litter sizes and may offer the opportunity to manage differently those sows that are likely to have much larger litter sizes.

Table 1. *Effect of litter size at birth on the average birth weight of pigs born to hyperprolific sows in commercial production in France (Foxcroft* et al.*, 2006).*

		Percentage of pigs within specific weight ranges			
Total pigs born	Average birth weight (kg)	<1.0 kg	1.0 to 1.5 kg	1.5 to 2.0 kg	> 2.0 kg
12.6	1.49	7	37	43	13
17.4	1.27	15	57	26	2

Colostrum

Colostrum is the first secretion of the mammary gland. The two major roles of colostrum are to provide the piglet with energy for heat production and metabolism, and with passive immunity to prevent infections (Le Dividich, 2006). Ensuring piglets receive sufficient colostrum is essential regardless of litter size, but obviously as litter size increases the likelihood of some piglets not receiving sufficient colostrum also increases. Le Dividich *et al.* (2005) have extensively reviewed the role of colostrum and its production by the sow. The most important constituents of colostrum are the immunoglobulins (Ig), which are initially high but drop rapidly during the first 24 h of secretion. The concentration of IgG is halved within six hours after the first piglet is born, and so with an increase in litter size it therefore becomes more important to use management techniques to ensure all piglets have equal access to colostrum.

There is a large variation in colostrum yield among sows, but litter size, which is known to have a strong influence on milk production, does not affect colostrum yield (Devillers *et al.*, 2007). While weight of the sow, parity, duration of gestation and induction of farrowing were all characteristics of sows that contributed to variation in colostrum yield, no single factor had a clear effect. It is therefore difficult to see how feeding strategies of sows in gestation could be used

to have a significant impact on colostrum production. Production of colostrum by the sow and its consumption by the piglet result from a close interaction between the sow and her litter because both are dependent on the sow's ability to produce colostrum, and on that of the piglets to reach and extract colostrum from the udder (Le Dividich, 2006).

An increase in litter size makes it all the more important to find ways to stimulate the production of components of colostrum, such as the immunoglobulins, through what we feed the sow pre-farrowing. For example, Funderburke (2002) fed sows mannan oligosaccharides for the three weeks pre-farrowing, and some of the improvement in piglet weight at weaning and reduction in pre-weaning mortality was attributed to a significant improvement in the immunoglobulin concentration in colostrum. Given the importance of colostrum to piglet health and subsequent performance, identifying ways to manipulate its production and composition is clearly an important area of research. Some sows have characteristics of colostrum production that are better suited to rearing a large litter than others, but of course, unless we have a simple marker to identify these animals then we can't use this in a practical sense. To what extent the ability of the sow to produce colostrum has increased in the more prolific genotypes is unknown (Le Dividich., 2006).

Milk yield and composition

Piglet growth can be increased either by increasing the quantity of sow's milk produced or by increasing its concentration of protein (Williams, 1995). Several studies have been conducted to attempt to change the protein and amino acid content of sow's milk. For example, King *et al.* (1993) compared diets containing between six and 24 percent crude protein, and found a small, non significant increase in milk protein (from 53 to 59 g/kg). Other studies (see review by Williams, 1995) have been extended to the level of amino acids, and even then the amino acid profile of the sows' milk was relatively constant with minimal variation between the various estimates.

Even when the body protein content of gilts was manipulated such that amino acids for milk production were supplied by either endogenous or exogenous sources at high or low levels, the proportion of protein in milk was hardly changed (Revell *et al.*, 1998). The sow is thus well able to buffer milk production during lactation by mobilisation of body reserves to cover any shortfall. Although the composition of milk, particularly its protein content, remains fairly constant the total output of milk can vary substantially depending on a number of factors; the protein and energy supply in the diet and the endogenous supply of precursors or the body reserves of animals (Williams, 1995).

Milk production in the sow is largely a factor of stage of lactation and litter size, reaching a maximum during the third to fourth week of lactation and increasing linearly with litter size (Auldist and King, 1995). Estimates of milk yield as measured by dilution techniques by King *et al.* (1989) and Auldist *et al.* (1994) suggested that a sow with a litter of 10 would be producing approximately 10 kg/d, somewhat more than was estimated in an earlier study by Elsley (1971; Figure 1). Furthermore, sows suckling 14 piglets were capable of producing in excess of 15 litres of milk/d in early lactation (Auldist *et al.*, 1994). Thus it seems that the lactating sow can provide more milk if there are greater numbers and heavier pigs, particularly in early lactation, and only in later lactation, milk yield of sows may be limiting in larger litters. A more recent study by Miller (unpublished) recorded milk yields of 13.7 kg/d for primiparous sows and 19.6 kg/d for multiparous sows on d 21 of lactation in an Australian commercial piggery, suggesting that perhaps milk yield has increased substantially during the last 10 to 20 years. However, since there hasn't been a dramatic shift in either litter size or weaning weights during this same period then it seems unlikely that there has been such a big change in milk production of sows. Perhaps it is appropriate to repeat studies like that of Auldist *et al.* (1994) to look at the relationship between litter size and milk production of current genotypes and with litter sizes beyond the 14 used in that study. This would then enable calculations to be done to more accurately predict the nutrient requirements for sows nursing large litters, although reasonable estimates may be made from average litter growth rates between birth and weaning, assuming a relatively stable conversion of nutrients from milk into tissue gain.

A number of cross-fostering experiments have clearly demonstrated that piglet weight is an important controlling factor in determining milk intake and consequently sows' milk production (Auldist and King, 1995). The results support the general hypothesis that sows' milk yield is primarily affected by the demand for milk by piglets during early lactation. As lactation proceeds the supply of substrates, governed by nutrient intake of the sow and the availability of body reserves, becomes increasingly important in determining milk production. This suggests therefore that maximising nutrient intake of the sow during lactation, certainly after the first week, is of high priority.

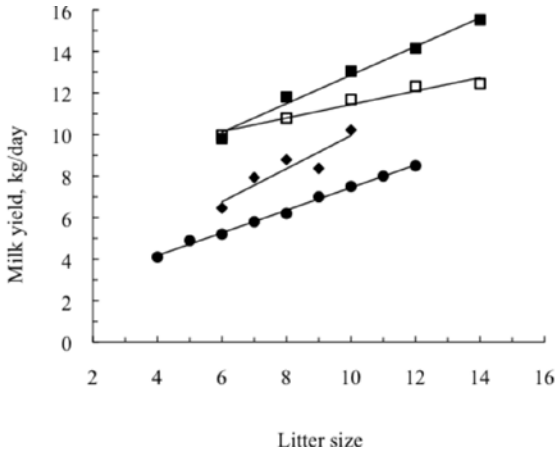

Figure 1. *Comparison of the relationship between milk yield and litter size. (■, Auldist* et al.*, 1998), early lactation; (□, Auldist* et al.*, 1998), late lactation (●, Elsley, 1971; ◆, King* et al.*, 1989).*

Nutrient intake of the sow

Feed intake

Many sows fail to eat sufficient amounts of feed to meet the demands of lactation. The most recent measure of feed intake by sows during lactation was by Jones and Hermesch (2007) who studied the effect of both season and parity on the feed intake of sows during a 21 d lactation in a commercial piggery in south eastern Queensland. Mean feed intake was 5.11 kg/d and the difference in intake between summer and winter months was approximately 1.0 kg/d (5 versus 6 kg/d), and there was a similar magnitude of difference between primiparous and multiparous sows. This result is similar to an earlier study on five commercial farms by Handley *et al.* (1995) in which average intake of first litter sows was 5.46 kg/d and for older sows 6.19 kg/d. Despite estimates that 20 percent of first and 30 percent of second parity sows having reduced lifetime performance due to low feed intake in lactation (Hermesch and Jones, 2007), feed intake is rarely measured and in most cases the amount of feed consumed is over estimated during this critical phase of production.

In a study involving over 19,000 litters, Koketsu *et al.* (1996) examined the relationship between litter size and feed intake of sows during lactation (Figure 2). As litter size increased from 3 to 13 piglets, average feed intake of the sow increased from 4.4 to 5.0 kg/d, but as litter size increased further there was no further increase in feed intake. A similar response is clear from the results of O'Grady *et al.* (1985) and Auldist *et al.* (1998), suggesting that voluntary feed intake of lactating sows nursing relatively small litters increases with increasing litter size, but that at higher litter sizes other factors begin to limit intake.

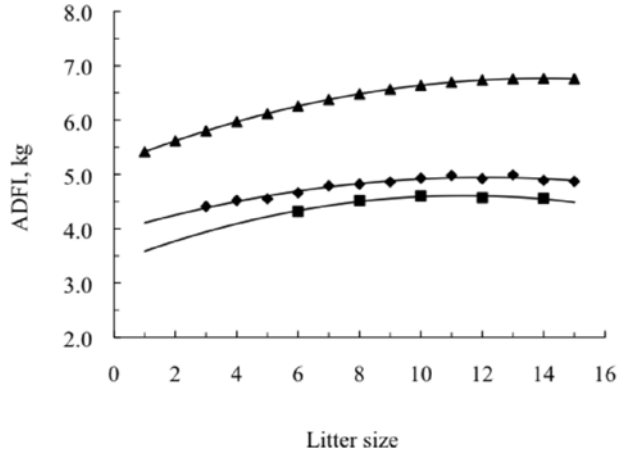

Figure 2. *Effect of litter size on voluntary feed intake of lactating sows. (■, Auldist* et al.*, 1998; ◆, KoKetsu* et al.*, 1996; ▲, O'Grady* et al.*, 1985).*

Fortunately, the sow is able to mobilise her own body reserves to supply the nutrients required for milk production, rather than conserving these reserves to ensure a prompt start to the next reproductive cycle (Mullan and Williams, 1989). This means that a hidden cost of increasing litter size could be a reduction in subsequent reproductive performance (eg. weaning to oestrus interval, subsequent litter size). If this happens, then while we have sows with the genetic potential for large litter size, their lifetime productivity may not be substantially better than what it is at present.

There are numerous factors that influence feed intake of the lactating sow and these have been well documented (Eissen *et al.*, 2000; King, 2003; Bunter *et al.*, 2007). Feed management factors such as *ad libitum* versus frequent feeding, wet versus dry feeding etc., may affect voluntary feed intake but will not be discussed in detail in this paper. One of the major factors, however, that does warrant some discussion is ambient temperature because it is probably the factor having greatest impact in Australian pork production, yet is one which is relatively easy, even though perhaps expensive, to correct.

The ideal temperature for lactating sows is approximately 20°C, whereas that for piglets is closer to 30°C. Numerous studies have been conducted to examine the response of the sow to high ambient temperatures, and the primary response is a decline in feed intake during lactation, an increase in the loss of body reserves as the sow attempts to maintain milk production, and eventually a reduction in piglet growth rates (eg. Black *et al.*, 1993). When multiparous sows were exposed to a high ambient temperature (27-30°C), daily feed intake was decreased by 28 percent compared to sows within the zone of thermal comfort (18-20 °C; Prunier *et al.*, 1997). More importantly was the observation that primiparous sows exposed to high ambient temperature could not effectively mobilise body reserves for milk production as compared to those housed in their thermal comfort zone. High temperatures reduce milk yield indirectly by reducing feed intake, but also have an adverse direct effect on milk yield. Mullan *et al.* (1992) found that sows housed at higher temperatures produced less milk than those kept under thermoneutral conditions, despite receiving the same amount of feed during lactation. Black *et al.* (1993) suggested that exposure to high ambient temperatures may redirect blood flow to the skin and away from other tissues such as mammary glands and hence reduce milk production. This notion was supported by the study of Renaudeau *et al.* (2003) who demonstrated that the amount of blood (measured at the pudic mammary artery) required to produce 1 kg of milk by the mammary gland was higher at 28°C than at 20°C (482 versus 452 L/kg, respectively). This finding indicates that under heat stress sows use a greater proportion of blood flow to irrigate capillaries in the skin.

Options to minimise the effect of heat stress on reproductive performance and weaner performance include early weaning (Spencer *et al.*, 2003), providing creep feed (Renaudeau and Noblet, 2001) and supplying milk replacer during lactation (Spencer *et al.*, 2003). Of these, supplying milk replacer has the greatest potential for meeting the demands of a larger litter provided systems are in place to allow it to be done with minimal human intervention. Cooling systems may also have a role in maintaining the lactation performance of sows. A recent study applied a floor cooling system to sows exposed to ambient temperatures of 21.5 to 29.5°C and found that floor cooling decreased sow body weight loss during lactation, increased feed intake and milk production, and decreased weaning-to-oestrous interval (Silva *et al.*, 2009). While not a nutritional strategy *per se*, control of ambient temperature does have a large bearing on the capacity to optimise nutrient intake of the sow during lactation and it would seem that in most cases an investment of capital into appropriate farrowing accommodation is required if we are to meet the needs of large litters. Ensuring the dietary electrolyte balance was above 300 mEq/kg rather than at either 120 or 200 mEq/kg was also found to be beneficial to piglet growth rates and sow performance during summer months (Lizardo *et al.*, 2009), but like most studies this research was done with a relatively modest litter size as compared to what we are considering might be the norm.

Composition of sow diets

Dietary energy

Allowing for maintenance and milk production, the requirement for digestible energy (DE) can be calculated. For example, a sow with a body weight of 200 kg and rearing 12 piglets would require an average intake of 100 MJ DE/ during a 28 d lactation (Close and Cole, 2000). As suggested already in this paper, records of voluntary feed intake by sows in commercial piggeries indicates an average intake close to 6 kg/d, in which case the diet fed during lactation would need to contain 16.7 MJ DE/kg to meet the energy requirements of the lactating sow. Lactation diets in commercial piggeries would commonly contain between 14.0 and 14.5 MJ DE/kg, and given that the calculated requirement by Close and Cole (2000) was for a litter of 12 then it is hardly surprising that there is concern about the sow's capacity to consume sufficient energy to meet the requirements of milk production with a large litter without losing considerable body reserves.

Meeting the nutrients required for milk production is a combination of that supplied in the diet and that available from the sows' own body reserves. A good example of how the sow mobilises her own body reserves to meet the demands of lactation is in the study of Mullan and Williams (1989). When the energy intake of lactating sows was restricted to around 24 MJ/d, piglets nursed from sows with low body reserves at farrowing grew less than piglets suckling from sows with higher levels of body reserves at farrowing (167 versus 200 g/d, respectively). Modern genotypes would have a far greater proportion of body protein and less body fat than those animals used in this experiment, but there is no reason to believe why the same principles of using body reserves would not apply.

A number of studies (see review by Williams, 1995) have been conducted to examine the relationship between maternal energy intake and litter growth rate, although few of these included any measure of milk yield. These results show that the response of milk output to energy intake is variable reflecting indirect measures of milk output (measured by piglet growth) and factors such as weight of sows, their parity and body reserves, and the protein content of the diets fed during lactation. Williams (1995) makes the point that *ad libitum* intake in these studies, at least for gilts, was generally below 70 MJ of metabolisable energy (ME)/d. To override the normal mechanisms that limit food intake, Pluske *et al.* (1995) fed gilts through a stomach cannula and was able to achieve intakes of 42, 75 or 104 MJ ME/d. A limit to milk production was demonstrated since there was no response in piglet growth beyond an intake of 75 MJ ME/d. The extra energy that the super-alimented gilts received went not into milk but into body reserves. A similar study, this time with sows, by Matzat *et al.* (1990) showed a linear response between milk output and maternal energy intake. Thus it seems that daily energy intakes above about 70 MJ DE may not result in increased milk yield in first litter sows, but older sows may respond to increased feed intake and energy supply above these levels during lactation. Williams (1995) concluded that these results might mean that gilts and sows partition energy differently during lactation as a way of protecting the maternal growth processes in gilts, but the other conclusion was that the ceiling in milk output reflects nothing more complex than a shortage of secretory cells in the mammary tissue of gilts.

The effects of changes in the energy concentration of lactating sows diets has received some attention in recent years in attempts to improve voluntary energy intake and lactation performance. In a recent study Smits *et al.* (2007) tested the hypothesis that litter weight gain would be increased with dietary energy levels of lactation diets offered to genetically lean first-litter sows during summer. Despite a large difference in the DE content of lactation diets (13.0 to 15.3 MJ DE/kg), there was no significant effect on feed intake of the sow or piglet growth rates during a 27 d lactation with litters of 10.5 (Table 2). Maximum energy intake was still around 70 MJ DE/d, and while the higher energy diets did reduce weight loss during lactation there was no effect on piglet growth rates. There may have been a difference in piglet growth rates if litter size was greater, but this result also supports the general philosophy that the sow, particularly the first litter sow, is not as interested in maximising milk production as we might be, but is more concerned about conservation of her own body reserves during the lactation period when they are still capable of depositing appreciable amounts of lean tissue. Therefore, especially with primiparous sows, an increase in litter size may be offset by a decline in weaning weights, because of an intrinsic limit to milk production.

Table 2. *The effect of dietary digestible energy (DE) level on the performance of first-litter sows (Smits* et al.*, 2007).*

Dietary energy level (MJ DE/kg)	13.0	13.6	14.2	14.7	15.3	P value
Sow intake (kg/d)	4.7	4.7	4.6	4.7	4.7	NS
Energy intake (MJ DE/d)	61	64	65	69	71	
Litter growth rate (kg/d)	1.79	1.64	1.84	1.78	1.79	NS
Piglet growth rate (g/d)	201	192	209	205	209	NS
Piglet weaning weight (kg)	6.9	6.7	7.1	7.0	7.1	NS
Sow weight loss (kg)	18.6	12.5	15.4	12.4	10.2	P<0.01
Sow P2 loss (mm)	3.5	3.3	3.4	2.7	2.8	NS

NS, not significant.

Dietary protein

A number of studies have been conducted to examine the relationship between protein intake of the sow during lactation and litter growth rate and/or milk production (King *et al.*, 1993; Tritton *et al.*, 1996; Jones and Stahly, 1999; Yang *et al.*, 2008). For example, King *et al.* (1993) fed first-litter sows diets that ranged in protein content between 6.3 and 23.8 percent during a 24 d lactation with a litter size of nine (Table 3). There was a significant linear response in growth rate of piglets and in milk yield, with the effect on yield being greater in late lactation than in early lactation. The conclusion from this study was that primiparous sows required a diet containing 200 g crude protein/kg or 12.8

g lysine/kg to maximise nitrogen balance during lactation, whereas only 130 g crude protein or 8.5 g lysine/kg seemed to be required to maximise milk yield and litter growth rate (Table 3).

Table 3. *The effects of dietary protein concentration on the performance of first-litter sows during lactation (King* et al.*, 1993).*

Dietary protein (g/kg)...	63	98	133	168	203	238	Significance[a]
Feed intake (kg/d)	3.79	3.71	3.81	3.80	3.76	3.63	NS
Protein intake (g/d)	239	364	507	638	763	864	
Weight loss of sows (kg)	27.4	23.3	25.3	22.3	23.8	24.5	NS
Preweaning growth rate (g/d)	179	193	215	228	213	216	***
Milk yield, early lactation (kg/d)	7.79	8.02	9.12	8.89	8.39	9.19	*
Milk yield, late lactation (kg/d)	7.02	7.40	8.42	8.40	7.76	8.90	**

[a]Linear response; *, P<0.05; **, P<0.01; ***, P<0.001; NS, not significant.

The results of the study by Mahan and Mangan (1975) also showed that if a sufficient amount of exogenous protein is not available during lactation, body protein reserves will have an effect on milk production and lactation feed intake. Clowes *et al.* (2003) analysed 16 experiments and demonstrated that when sows mobilise more than 16 percent of their body protein during lactation, wean-to-oestrous interval starts to increase.

In a more recent study, Hewitt *et al.* (2009) fed primiparous sows a diet that contained either 0.58 or 0.90 g available lysine/MJ DE (14.3 and 14.5 MJ DE/kg, respectively) during a 21 d lactation. Litter size was set at either 7 or 12 piglets. With a litter of 12 piglets, there was no significant difference in litter weight gain nor in weight loss of the sow despite a large difference in lysine intake, a result which is somewhat surprising given the results from previous studies (Table 4). However, there may have been differences in the composition of that weight loss between the two protein treatments. The study did demonstrate, however, that a consequence of having a larger litter was a reduction in weight gain of piglets and a possible reduction in subsequent litter size. As with energy intake it would seem that we may have to accept some reduction in performance as a consequence of increased litter size, especially with first-litter sows.

Table 4. *Response of sows and progeny to amino acid content of the lactation diet and litter size (Hewitt* et al.*, 2009).*

Litter size...	12	7	12	7
Available lysine/MJ DE...	0.90	0.90	0.58	0.58
Feed intake (kg/d)	5.63	5.57	5.70	5.70
DE intake (MJ/d)	82	81	82	81
Lysine intake (g/d)	86	86	56	56
Sow weight loss (kg)	29	23	31	23
Average piglet gain (kg)	3.71[a]	4.36[b]	3.67[a]	4.55[c]
Total born, parity 2	10.9	11.5	10.8	11.3

[abc]Means in a row with different superscripts differ significant (P<0.05).

Dietary fat

In an early review by Pettigrew (1981), it was concluded that supplementation of diets with fat during late gestation and lactation could increase milk production and the concentration of fat in milk. A more recent study by van den Brand *et al.* (2000) has examined the interaction between feeding level and dietary energy source. In this study sows were fed a diet high in either fat or starch at either a high (44 MJ/d) or low (33 MJ/d) level of energy intake. At the low feeding level, energy source had no effect on milk production, milk composition or litter growth rate. However, at the high feeding level, sows fed the fat-rich diet (81g/kg tallow) produced higher milk fat (84 versus 69 g/kg), higher milk energy concentrations (5.38 versus 4.77 kJ/g), and higher piglet body fat concentration (152 versus 135 g/kg) than sows fed the starch-rich diet. The results suggest that even at what was a relatively low level of energy intake, dietary fat was preferably used for milk fat synthesis and increased body fat gain in piglets while decreasing the loss of sow fat reserves. It is obviously important to look at more realistic levels of energy intake with litters of at least 12 to see if dietary fat has a similar effect.

Often the effects of fat on lactation performance are observed when different levels and sources of fat are imposed during gestation. For example, Lauridsen and Danielsen (2004) showed that at 80 g/kg inclusion, supplementation of animal fat, coconut oil, palm oil or sunflower oil increased litter weight gain whilst supplementation of fish oil and

rapeseed oil did not affect progeny performance. In this study it was also evident that the milk fatty acid composition was affected by dietary fatty acid composition. Laws *et al.* (2009b) fed multiparous sows with either a control diet (13.1 MJ ME, 127 g/kg crude protein, 45 g/kg fat) or a diet similar to the control diet but with 10 percent extra energy (3.93 MJ/d) in the form of palm oil, olive oil, sunflower oil or fish oil. The diets were fed during either the first half (0-60 d) or second half (61-115 d) of gestation. Results showed that supplementation of sunflower oil during the first half of gestation increased the proportion of low birth weight piglets (20%) while supplementation of olive oil during the same period decreased the proportion of low birth weight piglets (5%) compared with control, palm oil and fish oil supplemented sows (9%, 11% and 12%, respectively). Another study by the same research group (Laws *et al.* 2009a) observed that sows fed sunflower oil during the first half of gestation had greater gestational gain in P2 backfat than sows supplemented with olive oil. This possibly indicates that extra energy supplemented in the form of sunflower oil might be partitioned to maternal gain rather than placental development. This research highlights that energy supply in the form of polyunsaturated fatty acids may increase the proportion of low birth weight pigs while energy supply in the form of monounsaturated fatty acids may reduce the incidence of low birth weight piglets. This could have important ramifications with an increase in litter size likely to decrease average piglet birth weights and is worthy of further consideration.

Dietary fibre

Again the effects of fibre on lactation performance often arise from changes in the levels and sources of fibre that are offered during the preceding lactation. Increasing the fibre content in diets for gestating sows is one way that we may be able to increase nutrient intake of the sow during lactation. Van der Peet-Schwering *et al.* (2003) demonstrated that feeding high fermentable non-starch polysaccharides (NSP, soybean hull and sugar beet pulp, NSP 123 versus 300g/kg) decreased body weight and backfat gain during gestation but increased lactation feed intake by 9 percent. Therefore high levels of fermentable non-starch polysaccharides during gestation and high levels of starch during lactation could be the most effective feeding strategy to maximise lactation feed intake and milk production. However, to be really effective we would need to get an increase in intake during the second and third week of lactation when nutrient demand is at its peak, rather than during the first week of lactation.

The type of fibre is another consideration. Vestergaard and Danielsen (1998) have demonstrated that feeding fermentable fibre (sugar beet pulp) decreased gestation feed intake (2.5 versus 3.2 kg due to energy density of 8.7 versus 7.0 MJ of net energy (NE)/kg) and increased lactation feed intake (5.5 versus 5.1 kg/d) compared with feeding the same amounts of mixture of insoluble fibre (grass meal, wheat bran, oat hulls). Feeding mixed insoluble fibre did not increase lactation feed intake compared with sows fed a standard diet. This result implicates that insoluble fibre may have minimal effect on the development of gastrointestinal tract whilst soluble fibres supplies energy such as butyrates upon fermentation which is pivotal for mucosal development of the gastrointestinal tract.

In a recent study, Quesnel *et al.* (2009) fed sows either a low fibre (172 g/kg neutral detergent fibre (NDF), 33 g/kg acid detergent fibre (ADF)) or a high fibre diet (307 g/kg NDF, 110 g/kg ADF from sunflower meal, wheat bran, sugar beet pulp and soybean hull) during gestation. Energy intake during gestation was standardised at 33 MJ/d, and all sows were fed a standard diet during lactation. During lactation, sows that had been fed the high fibre diet during gestation ate 940 g/d more feed than sows fed the standard fibre diet. Piglets nursed from the sow fed a high fibre diet grew faster (244 versus 217 g/d, for 28 d lactation) than piglets nursed from the sow fed a standard fibre gestation diet. The benefit of feeding a high fibre diet during gestation on piglet performance predominantly occurred in the first week of lactation (220 versus 194 g/d). Such a study would be worth conducting with large and small litter sizes.

Dietary additives

It is not within the scope of this paper to review all of the possible additives that could be used to stimulate milk production either directly or indirectly. Much of the research has probably been done with relatively low litter sizes and with genotypes not representative of commercial production, which makes having confidence to implement the results difficult. Some additives are reported to stimulate feed intake of the sow and possibly milk production under some circumstances, whereas products such as betaine can help alter the maintenance requirements of the sow and potentially direct a greater proportion of nutrients into milk production. Other additives, such as organic minerals, may not have a direct effect on milk production but may still improve the survival of piglets and/or the subsequent reproductive performance of the sow and so should be considered as part of any feeding strategy.

Alternative manipulation with metabolic modifiers

Tremendous improvements in the efficiency of production in growing pigs has been achieved in the past 20 years through research and subsequent adoption of metabolic modifiers, in particular the use of somatotropin and β-agonists (Dunshea and Walton, 1995). The vast majority of this research has been conducted with the grower-finisher pigs where, undisputedly, the greatest gains for the pork industry can be made. In more recent years the possibility of using these same technologies to help improve performance of the lactating sow has been investigated.

Somatotropin

Harkins *et al.* (1989) administered porcine somatotropin (pST) between d 12 and 29 of lactation and showed an increase in milk production of 22 percent on d 28 of lactation (11.0 versus 9.0 kg/d), with a similar response in piglet weaning weight (6.52 versus 6.17 kg). However, sows treated with pST consumed less feed during the treatment period (4.8 versus 5.4 kg/d) and lost more weight (-13.6 versus -7.0 kg) and backfat (-3.7 versus -1.2 mm). However, in other studies sows treated with pST showed no response in either milk yield or piglet growth rates, but still consumed less feed and lost more weight (Cromwell *et al.*, 1992; Toner *et al.*, 1996). King (2000) suggested that sows' milk production may respond to pST only when sows have heavier litters and larger litter size which place sufficient nursing demand on the sow to exceed the intrinsic limit to milk yield. It would also be important that nutrient intake of sows was not a limitation, so it might be a strategy that could be used with particular multiparous sows that fit certain criteria. Research currently underway in Australia will hopefully determine the suitability of this technology as a way to counter the demands of large litters.

Ractopamine

Pain *et al.* (2007) supplemented 10 ppm of ractopamine from d 1 to 13 of lactation and 20 ppm from d 13 until weaning and found that ractopamine supplementation during lactation did not alter lactation weight loss but increased milk fat on d 3 and decreased milk protein on d 13 and 20. Ractopamine supplementation to the lactating sow also decreased piglet weight gain between weeks 3 to 4 of lactation (260 versus 310 g/d), so on that basis it would not seem to be a strategy for increasing milk production. However, it may have a role in gestation diets if it can be used to manipulate the body composition of sows pre-farrowing. For example, Head and Williams (1995) demonstrated that piglets suckling the lean sows grew 50 percent faster than piglets suckling fat sows, and one possibility was that increasing lean gain in gestation could increase the secretory capacity of mammary glands and therefore potential milk production post-partum. As with pST, the use of ractopamine may present opportunities for how we use nutrition to rear larger litters and the results of research currently in progress will be of great interest.

Feeding strategies over parities

When we consider how sows might be able to rear significantly more piglets, then we need to consider the different capabilities of primiparous as compared to multiparous sows. As stated previously, this might reflect differences in the way gilts and sows partition energy during lactation as a way of protecting the maternal growth processes in gilts, but alternatively may be simply a difference in secretory capacity of mammary tissue (Williams, 1995). There is certainly greater attention given to how gilts are selected and introduced into the breeding herd now than previously, although in many commercial piggeries more progress has still to be done. The main objective is to allow the gilt sufficient time to build up her body fat and protein reserves before breeding, and they should also be fed a higher quality diet during the first lactation to minimise the mobilisation of body reserves.

When we develop feeding programs for gilts and sows, it is common to consider the stage of gestation and lactation as two quite discrete phases. This is primarily done as a matter of convenience since it also coincides with the way sows are accommodated. However, Mahan (2007) has analysed the total mineral content of foetal tissue throughout gestation and reported that approximately 50 percent of minerals were deposited within the last 14 d of gestation. At best the feeding level of sows might be increased in late gestation, but the supply of nutrients is probably still not sufficient to meet this sudden increase in demand. In future, there may be greater attention to different feeding levels during different stages of gestation and even different diets to maximise sow performance.

It is normal to consider the period of lactation as one phase and to thus feed the same diet throughout lactation, yet the nutrient requirements of the sow during the first week are relatively low compared to that during the subsequent weeks. Perhaps there is merit in having a three-diet program for sows, with a gestation diet fed for the first 3 months of gestation, a transition diet fed for the last part of gestation and first week of lactation, and then a super diet for the remaining period of lactation. This is certainly a concept that could be modelled and is worthy of testing with gilts and sows that are known to have large litters.

The Piglet

There are a multitude of management strategies that can be employed that will have an indirect effect on nutritional requirements of the sow and, more importantly, the capacity to rear large litters. It is not appropriate to dedicate discussion in this paper to those techniques, suffice to say that they include practices such as cross fostering, age at weaning and split weaning. Those techniques with a more direct relationship with nutrition include providing piglets with creep feed and/or liquid diets pre-weaning.

Creep feeding

There is a plethora of studies in which the effects of creep feeding during lactation on weaning weight and subsequent performance have been investigated (see reviews by Pluske *et al.*, 1995; King and Pluske, 2003). The major argument for providing creep feed to piglets is that it attempts to bridge the gap between the piglet's energy requirement and nutrients obtained from the milk (Pluske *et al.*, 2005). Creep feed consumption varies significantly within and between litters. For example, Fraser *et al.* (1994) estimated that creep feed intake accounted for only 1-4 percent of the variation in bodyweight gain in piglets during the first 14 d after weaning at 28 d of age, but the majority of these studies would have been done with much smaller litter sizes than what we are now contending with.

If piglets really do use creep feed as a supplementary source of nutrients then one would expect consumption to increase with litter size, assuming that the sow has reached peak milk production. Techniques to get a qualitative measure of creep feed intake have been developed (Pluske *et al.*, 2007) and this together with the advent of new products designed to enhance piglet intake and performance might mean that it is worth doing more research in this area, particularly at larger litter sizes. The criteria upon which we base the success of a creep feeding strategy should also be taken into account, because if we can enhance gut health and prepare the piglet to cope with the stress of weaning then this might be classed as a more satisfactory long-term result as compared to weight of the piglet at weaning.

Liquid feeding

Supplementing piglets with liquid diets has been shown to give benefits to the growth of piglets pre- and post-weaning. For example, Dunshea *et al.* (1997) fed piglets liquid milk replacer both prior to weaning and in the first week after weaning. Piglets that received milk before and after weaning were 10 percent heavier at 120 d of age compared to those that suckled the sow and were weaned onto dry starter feed. Even when supplementary milk is available *ad libitum* to the piglet pre-weaning, piglets still remove a similar amount of milk from the sow (King et al,.1998). Williams (1995) suggested that the cues that arise from sow-piglet interaction still override the potential nutritional response. While providing piglets with supplementary liquid diets will increase weight at weaning and possibly lead to improved performance thereafter, it is a difficult practice to implement on a commercial scale and so is rarely done. However, it may well become a more standard practice if the economic benefits of producing large litters are large enough to warrant the investment in equipment and labour.

Total artificial rearing

It has been known for decades that young, artificially-reared (ie. weaned at 1-2 d of age) piglets given *ad libitum* access to liquid milk diets can grow at rates in excess of 500 g/d (Pluske *et al.*, 2005). Williams (2003) suggested that if studies such as these were repeated with modern genotypes, young pigs might grow even faster. Is it still beyond us to do this on a commercial scale, at least with the extra piglets in a litter that will not cope if left to compete with their littermates? If we can make big gains in litter size, then some form of artificial rearing from birth or even at 7-10 d of lactation when milk demand by piglets may outstrip the amount of milk the sow can produce, might have to be considered, especially on larger farms where the investment in infrastructure could be cost effective. An alternative would be to have a group of nurse sows that continue to lactate for as long as possible and are hence used as a home for extra piglets.

Sow research

To a large extent our knowledge of how to feed the sow to enable her to rear large litters is very poor. The vast majority of sow research was done many years ago with genotypes and litter sizes that are quite different to what we have today, let alone what we might have in the future. We therefore need to take some care in how we interpret the results of that research for future needs. It is fair to say that we don't have an accurate direct measure of how much milk modern sows can produce, especially not when rearing litters of 12 or more. Unfortunately, some of our lack of progress stems from not being able to measure milk production easily, unlike parameters such as number born alive. However, piglet growth rate should be an acceptable indirect measure of milk yield as the efficiency of conversion of milk into piglet growth is relatively constant at about 4 ml milk:1 g growth (depending upon piglet age) where piglet growth is

not compromised by disease or environmental conditions. We may need to place a greater emphasis on selecting sows for their rearing ability, even if measures of milk production are indirect measures.

Whatever research is done must take into account possible long-term effects, since we know that a drain on the sows body reserves has a direct impact on her subsequent reproductive performance. High levels of culling in many countries is something that we can ill afford to continue. Unfortunately it is expensive to conduct good sow experiments, especially over several parities, but gains could be significant. We could make more use of modelling, but then this still needs validation with research. It is certainly important to take a multi-disciplinary approach to the problem, but in research and practice it still relies on getting the basics right.

Summary

In theory it shouldn't be difficult to rear 13 to 14 pigs per litter, making use of a range of management and nutritional strategies that are available. It is going to be far more difficult to then take that number beyond 14 as might be possible through genetic selection. There is no simple fix, but instead a need to address the basics of good management and not expecting something for nothing. The modern sow quite possibly has the potential to produce enough milk to rear the larger litters that genetic and reproductive technologies might deliver. However, it seems, at least with the primiparous sow, that attempts to alter diet composition and increase feed intake fails to give us the increases in piglet growth rates that we have been hoping for. Part of the reason might be that there are other limitations in place that are masking the real effects. Finally, and probably most importantly, our capacity to achieve target levels of production relies on good management and staff implementing work practices and new technologies.

Piglet Survival in Large Litters

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Danish Pig Production, Axeltorv 3, 1609 Copenhagen, Denmark.

High litter size

During the last 20 years, average litter size in pigs has increased by approximately 0.1 piglets/litter/year (Figure 1). This development has been achieved in most pig producing countries. This increase in litter size was primarily due to a steady improvement in general management procedures. It was no problem for skilled pig producers to respond to this slow increase of 0.1 piglets/litter/year, with a concurrent slow improvement in farrowing house procedures. As a matter of fact, weaning weights and piglet survival have both improved during this period.

New breeding strategies now increase litter size by 0.3 extra piglets/litter/year. A focussed improvement in management strategies is now needed to maintain high piglet survival rates and to prevent a decreasing weaning weight.

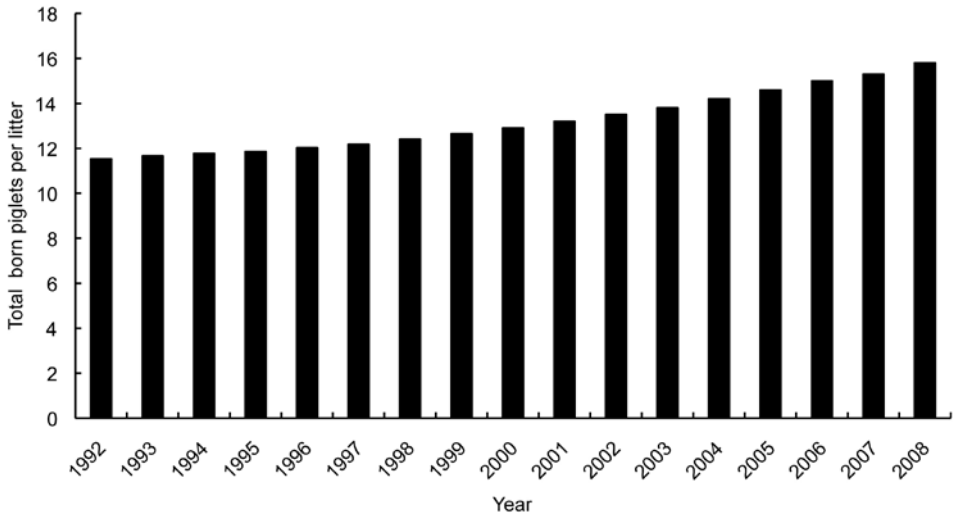

Figure 1. *Development in average litter size (stillborn + liveborn) in Danish production herds since 1992 when litter size was included as a breeding goal. From 1992 to 1996, the slow increase in litter size of 0.1 piglets/year was maintained. After 1996, the effect achieved in the nucleus herds was transferred to the production herds, thus increasing litter size with 0.3 piglets/litter/year.*

High litter size improves the productivity of each sow, if the producer can handle the following challenges:

1. The number of piglets exceeds the number of productive milk glands;
2. The farrowing pen is too small for the large litters;
3. Average piglet birth weight decreases;
4. Sows use more energy to produce more piglets;
5. Sows give more milk, when all glands are in use. This leads to a negative energy balance.

This leads to the question that if large litters cause problems, why not go for smaller litters?

Despite the problems related to large litters, Figure 2 indicates that even going from 19 to 20 piglets born/litter, more piglets will be weaned. Every extra piglet weaned represents a value for the producer. This extra value should at least cover the cost of maintaining this extra piglet. The cost consists of the negative effect of the extra piglet on the sow and on the littermates, but also the cost of extra care (time, space) needed for the extra piglet. The first producers to achieve a high litter size will pay the cost of developing methods to assure piglet survival in the larger litters. When the average producer reaches the same high litter size (and the best producers have gone even further), the problems for the average producer will already be solved.

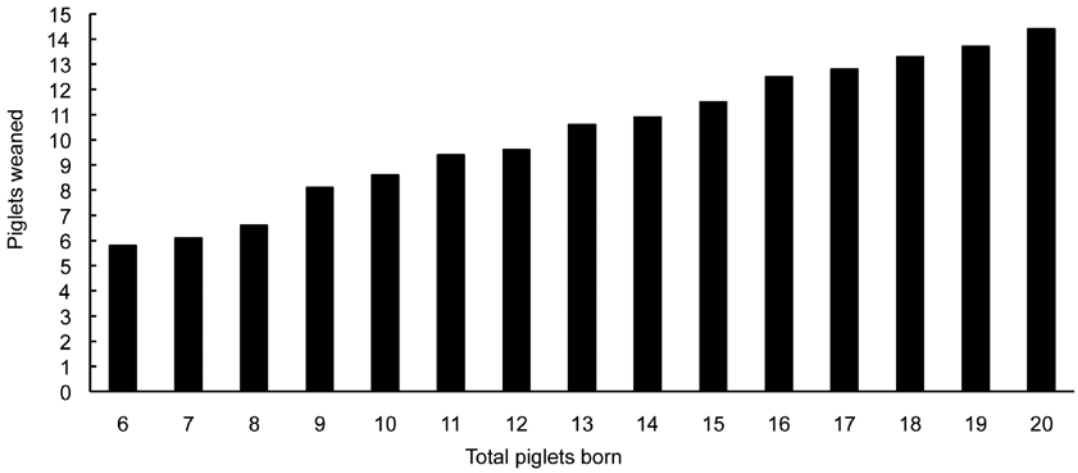

Figure 2. *Average number of weaned piglets, when number of total born piglets increases. Even when litter size increased from 19 to 20 piglets, the number of weaned piglets increases (Nurse sows were used during this study).*

Important factors for piglet survival in large litters

A range of factors are important for piglet survival in large litters including:

- Access to colostrum
- Handling underweight piglets
- Adjusting litter size
- Introducing nurse sows
- Control of infections.

Colostrum

Colostrum is essential for piglets as they are born without maternal immunoglobulins (Ig). Piglets need more than 10 g of Ig/L of serum to survive (Thorup *et al.*, 2004a). We investigated colostrum intake in 221 piglets. Birth order was observed, and the piglets stayed with the sow for at least 24 hours after birth. All piglets were bled 12 hours after birth (Figure 3). The 14th to 18th piglets born in the litter had low levels of colostrum intake compared to the first to 13th piglets born. However, none of the piglets born late in the process had less than 10 g of Ig/L. Thus, piglets born in litters of up to 18 piglets will rarely need an extra supply of Ig.

Piglet birth weights in large litters

There is a negative linear correlation between litter size and average piglet birth weight (Figure 4). Piglet birth weights will also deviate more in large litters. Thus, a higher percentage of the piglets will be underweight and need extra care in large litters. Nevertheless, as shown in Figure 2, productivity will still increase, if improvement in management handles the additional challenge. Large litters and birth weights are genetically positively correlated. Thus breeding for high litter size has been less detrimental to birth weights than expected.

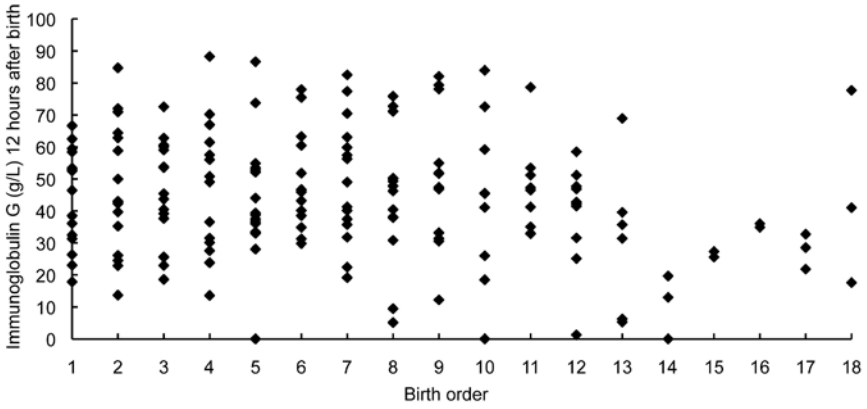

Figure 3. *Level of immunoglobulin G when birth order is increased. Each piglet was tested 12 hours after birth (Thorup* et al.*, 2004).*

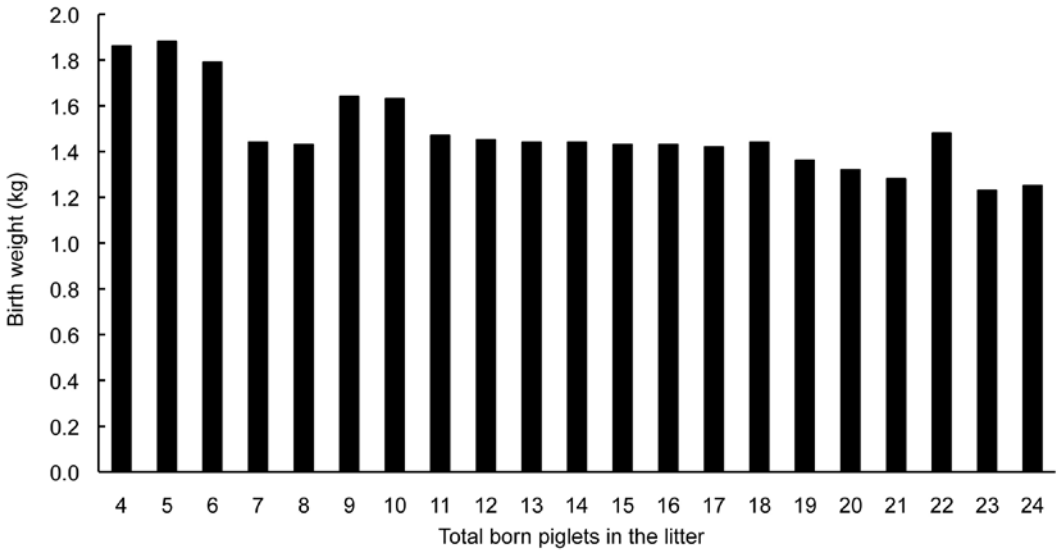

Figure 4. *Average birth weight per piglet when litter size increases.*

Underweight piglets can also survive

When small piglets grow up in small litters, piglet survival rates can be high (Figure 5). In an investigation, we weighed and mixed 39 newborn piglets. These piglets were randomised to 3 sows given 11, 13 or 15 piglets to nurse. The investigation comprised 44 replicates (Figure 6). In litters where the sows only nursed 11 piglets, mortality among the smallest piglets was as low as 12 percent. This was still higher than the mortality among the larger piglets. Having 15 piglets in the litter, mortality of the underweight and the small piglets tripled, while the same low frequency of large piglets died. This indicates that under good conditions even small piglets stand a good chance of surviving. If conditions in the litter become harsh, the smallest piglets are the first to lose. Small piglets should not be a problem, if conditions for all piglets in the litter are sufficient for piglet survival (Thorup, 2009a).

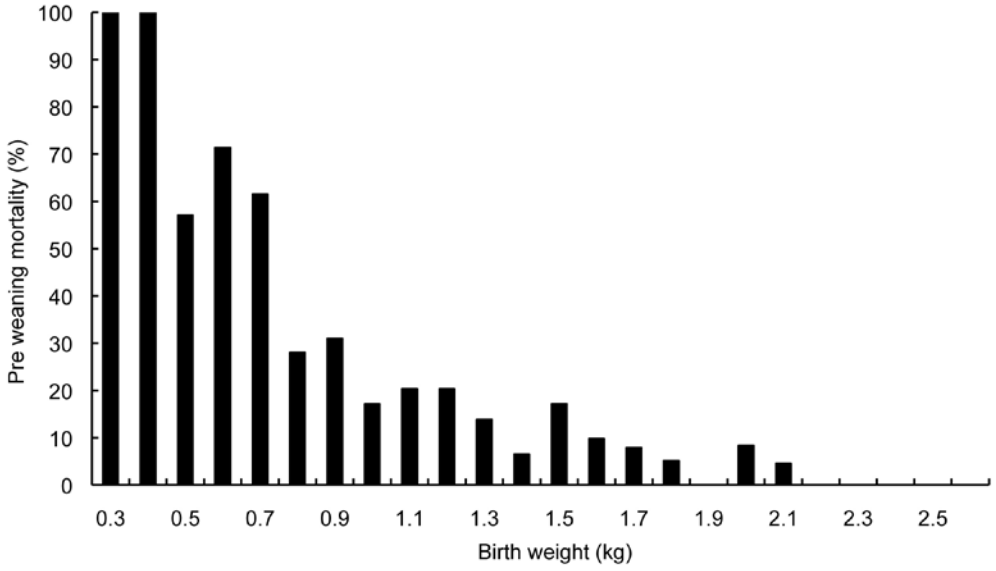

Figure 5. *Mortality among live born piglets when birth weight increases.*

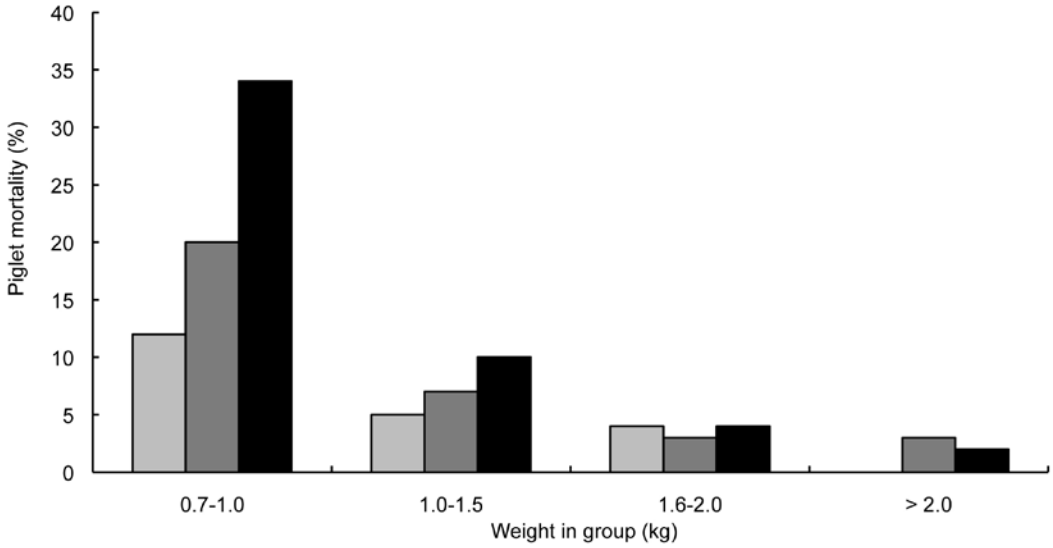

Figure 6. *Percent mortality among underweight, small, medium and large piglets in litters adjusted to 11 (■), 13 (■) or 15 (■) piglets (Thorup, 2009a).*

Litter size

The more piglets the sow handles without increasing mortality, the better the outcome. Sows of commercial breeds will have 12 to 16 productive glands. As the sow has very short milk bursts, there should be at least one gland per piglet. Even when the sow has more productive glands than the number of piglets, sows nursing many piglets may have a higher mortality and more runt piglets. This was also found by Thorup (2009a; Figure 7).

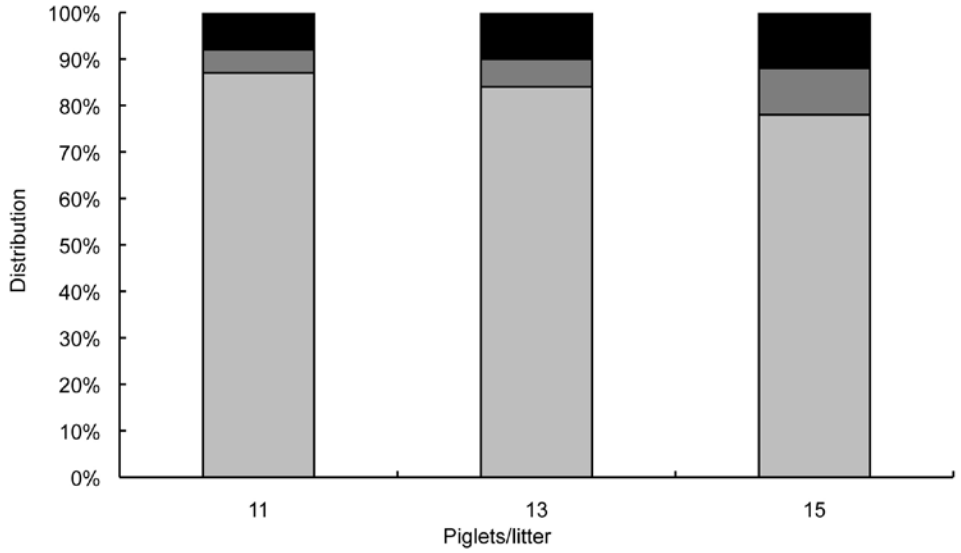

Figure 7. *Effect of litter size on percent mortality (■), percent runt piglets (■) transferred to nurse sows and ultimate number weaned (■).*

Adjustment of litter size

Under normal conditions, piglets from sows with excessive live born piglets can be transferred to sows having fewer newborn piglets. Investigations indicate that if a piglet is transferred to a new litter within 48 hours after birth of both the transferred piglet and birth of the recipient litter, then growth and survival will be normal for both the transferred pig and the recipient litter (Straw, 1997). If the transferred piglet is older than 48 hours, the transferred piglet will survive if the sow has enough productive glands, but weaning weight of the transferred piglet will be reduced by 0.9 kg, when compared to a piglet that was not transferred.

Nurse sows

If a group of sows farrow more piglets than can be adjusted between the new born litters, nurse sows are a useful solution. As seen from Figure 3, piglets are well supplied with Ig when they are more than 12 hours old. They can then safely be transferred to a lactating sow that no longer supplies the piglets with colostrum. Our investigations indicate that a good nurse sow for 12 to 24 hour old piglets is a first or second litter sow (Thorup *et al.*, 2004b) that has nursed her own piglets for four to seven days (Thorup and Sørensen, 2006). As four to seven day old piglets cannot be weaned, these piglets must be transferred to another nurse sow that has weaned her own older piglets. If the nurse sow has been lactating for more than two days, the number of nurse piglets should be equal to or lower than the number of piglets taken away from the nurse sow. Under Danish conditions, a nurse sow in a traditional farrowing pen will readily accept the new piglets. Though the new piglets are accepted to come to the udder soon after transfer to the nurse sow, the nurse sow rarely gives the new piglets a milk burst until the nurse piglets have been with the nurse sow for 6 to 8 hours. This process can be sped up by letting a few of the nurse sow's own piglets stay. However, this will result in unwanted mixing of piglets of different ages.

Handling runt piglets

Some piglets do not thrive in the litter. These piglets may have been the smallest in the litter, and the ones to lose fights for a good nipple. If these piglets are collected in time and transferred to a nurse sow, that just has weaned her own piglets, then good survival rates can be achieved. In the study above, involving 11, 13 or 15 piglets in the litter, runt piglets were transferred to nurse sows, and among these, only 1.7 percent did not make it until weaning. It is important to have a system where runt piglets are identified in the litter, and for every 12 to 14 runt piglets a nurse sow should be made available. Any sow weaning her own piglets will normally do as a nurse sow for runt piglets.

Infections

Different specific infections in nursing piglets will be present in all pig producing countries. The relevance of each disease will vary between countries. Thus, the handling of specific infections will not be included in this presentation. Under good management and sanitary conditions, infections are rarely the primary cause of death. Most piglets die from the effects of starvation or being crushed or savaged by excited sows. Gilts and sows must be vaccinated against the specific diseases that threaten piglets in your country to protect the new born piglets via the colostrum. To control non-specific diseases, good hygiene and strict separation of piglets of different ages are important management strategies. Controlling climate conditions, feed quality and water supply to sow and piglets will support piglet immunity.

Conclusions

1. When litter size increases, new management strategies must be introduced.
2. Initially, batch farrowing and adjustment of litter size will solve the problems.
3. When litter size exceeds the number of productive milk glands, nurse sows must be introduced. Be sure that the piglets ingest enough colostrum before they are transferred. Use the right nurse sow for the right nurse piglets. Handle sows and piglets gently. Excited sows make bad nurses.
4. Feeding the sow becomes very important to keep body condition when milk production increases.
5. Special attention should be given to underweight piglets as they have problems surviving when conditions become suboptimal.

Symposium Conclusions

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In the first paper, Bunter (2009) showed that continual selection for improving lean tissue growth and litter size, would result in decreased piglet quality and survival from a genetic perspective. While simultaneous genetic gains for all the above traits are feasible, both piglet quality and survival were complex traits. Optimum improvement in both traits required measurements at an individual piglet level, with respect to birth weight and the age of any deaths, as well as identification of the biological and nurse sow. This allows for adequate accounting of both piglet and sow contributions to both traits.

Mullan *et al.* (2009) highlighted in the second paper that while the sow was able to mobilize body reserves, increased demands from higher litter sizes would lead to reduced weights at weaning and potentially lower subsequent sow reproductive performance. A number of strategies were discussed to enhance nutrient intake of the sow during lactation. The areas that were prioritized for research included use of dietary fibre and fat and the use of multiple diets during late gestation and lactation. Finally, the use of supplementary feeding of piglets was noted as worth further investigation.

Finally, Thorup (2009b) in his paper noted that focused management strategies were necessary to prevent reduced pre-weaning survival and piglet weights with increased litter size. The critical factors included the use and management of additional nurse sows and the provision of optimal environmental conditions to maximise feed intake and prevent disease.

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CHAPTER 9

Nutrition and Carcase Quality

TINSPIRATION.

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Blend Feeding or Feeding a Single Diet Reduces Feed Costs With No Impact on Growth Performance or Carcase Value

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Conventional practice in the pig industry is for pigs to be fed three or four diets during the grower-finisher period. However, since the requirements of pigs are constantly changing the diet is frequently supplying excess nutrients. Blend feeding, in which two diets are mixed together in varying ratios, allows the diet to be changed at least weekly. This has the potential to reduce feed costs as the diet more accurately matches the requirements of the growing pig (Mullan *et al.*, 1997). The opportunity to blend feed is now more commercially viable with the development of dry and liquid feeding systems, which have the ability to deliver any number of blends of feed in different pens. On the opposite spectrum is feeding the same diet through the grower-finisher period. The hypothesis for this experiment was that blend feeding or feeding a single diet would reduce the cost of production compared to the conventional system, by minimising the over-supply of nutrients without adversely affecting pig growth performance or carcase quality.

Two hundred and sixteen female pigs (Large White x Landrace) were allocated to the following treatments: 1) Conventional: diets changed when the average liveweight (LW) of pigs in the pen reached 20 (14.5 MJ digestible energy (DE)/kg and 0.7 g available lysine (AvL)/MJ DE), 50 (14.0 MJ DE/kg and 0.6 g AvL/MJ DE) or 80 kg (13.7 MJ DE/kg and 0.5 g AvL/MJ DE); 2) Blend: diets changed weekly to meet the requirements of the average LW of pigs in the pen and, 3) Single: the same diet fed throughout (formulated to meet the requirements of the pig at 60 kg LW; 13.72 MJ DE/kg and 0.56 g AvL/MJ DE). The experimental diets were fed from 22 to 102 kgs LW and nutrient requirements were determined using AUSPIG (Black *et al.*, 1986) based on performance from previous experiments at Medina Research Station. The pigs were housed in groups of 6. All data were analysed by analysis of variance and the pigs were blocked on their initial weight.

Table 1. *Growth performance, carcase quality and feed costs for female pigs using three different feeding strategies (n=12).*

Parameter	Conventional	Blend	Single	SED	P value
Daily gain (g/d)	954	961	951	12	0.701
Voluntary feed intake (kg/d)	2.14	2.12	2.11	0.040	0.817
FCR (MJ DE/kg LW gain)	31.5[a]	30.3[b]	30.3[b]	0.342	0.006
Carcase weight (kg)[1]	68.9	69.6	69.2	0.430	0.228
Dressing percentage (%)	68.1	68.1	68.1	0.279	0.957
Backfat (P2, mm)	10.7	11.0	11.1	0.359	0.534
Feed costs per pig/kg LW gain ($)	0.882[a]	0.849[b]	0.851[b]	0.009	0.002

[ab]Means in a row with different superscripts differ significantly (P<0.05); [1]Hot carcase weight: AUSMEAT trim 13-head off, flare off, fore trotters off, hind trotters on; FCR, feed conversion ratio; LW, liveweight; DE, digestible energy.

There was no significant effect of feeding strategy on growth performance and carcase quality (P>0.05; Table 1). However, it was 3.3 and 3.1 cents/kg of LW gain cheaper to use the blend and single diet feeding strategies, respectively, compared to a conventional feeding program (P=0.002). This experiment has shown on a relatively large scale that blend feeding can be used to reduce the cost of production. Feeding a single diet appears to have merit and may have appeal for certain circumstances, however, it would need to be investigated further before being implemented, particularly when variation at the start of the grower phase is large. The successful implementation of these feeding strategies also relies on having a good knowledge of the nutrient requirements of particular genotypes and the conditions in which those animals are reared.

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Supported in part by the Pork CRC Ltd.

Effects of Dietary Lysine on Growth Responses of Pigs to Increasing Doses of Ractopamine

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Commercial recommendations for dietary lysine specifications in diets for pigs supplemented with ractopamine (RAC) is 0.56 g available lysine/MJ digestible energy (DE; King *et al*., 2000). A recent study confirmed that when RAC supplemented diets are formulated to 0.56 g available lysine/MJ DE, growth rate and feed efficiency are improved (Dunshea *et al*., 2005), together with an increase in lean tissue deposition in both sexes, although fat deposition was reduced in boars and remained constant in gilts. The aim of this experiment was to determine whether the current dietary lysine recommendations are sufficient to optimize the response in feed efficiency (FCR), growth rate (ADG) and tissue deposition in boars and gilts offered high and low doses of RAC in diets.

The study involved 108 individually penned pigs (17 weeks of age, start weight 65 kg) in a 2x2x3 factorial design with 2 sexes (gilts, boars), 2 levels of dietary lysine (low and high, 0.56 and 0.65 g available lysine/MJDE respectively) and 3 RAC doses (0ppm, 5ppm and 20ppm Paylean®, Elanco Animal Health, Macquarie Park, NSW) for 28 d. Pigs were weighed at -7, 0, 7, 14, 21 and 28 d and voluntary feed intake (VFI) determined at d 7, 14, 21 and 28 d. Body composition was determined using dual energy X-ray absorptiometry (DXA) at d -1, 15 and 29 of treatment. Data were analysed by analysis of variance.

Table 1. *Effect of ractopamine dose and dietary lysine on average daily gain (ADG), feed conversion ratio (FCR), lean and fat tissue deposition and carcase traits in finisher gilts and boars.*

	Sex (S)		RAC (ppm)			Lysine[1] (L)			Significance			
										RAC		
Treatment (T)	Gilt	Boar	0	5	20	Low	High	SED	Sex	Dose	Linear	L
ADG (kg/d)	1.20	1.34	1.22	1.31	1.28	1.26	1.28	0.06	<0.001	0.026	0.072	0.268
FCR	2.47	2.30	2.45	2.36	2.35	2.43	2.34	0.09	<0.001	0.080	0.045	0.027
HSCW (kg)	76.8	78.8	76.5	79.0	77.9	77.4	78.2	1.92	0.016	0.045	0.153	0.315
P2 (mm)	14.0	12.2	13.9	13.9	11.6	13.4	12.8	1.31	0.002	<0.001	<0.001	0.302
Lean Tissue (kg/d)	0.98	1.11	1.00	1.03	1.10	1.03	1.06	0.91	0.001	0.111	0.044	0.451
Fat Tissue (kg/d)	0.34	0.35	0.34	0.38	0.32	0.37	0.32	0.06	0.776	0.161	0.509	0.072

[1]Dietary Lysine formulated to 0.56 (Low) and 0.65 (High) g available lysine/MJ digestible energy; HSCW, hot standard carcase weight.

Dietary RAC improved ADG, hot standard carcase weight and P2 back fat. FCR improved linearly (p=0.045) with increasing RAC dose and was reduced by dietary lysine (p=0.027; Table 1). Lean tissue growth increased linearly (p=0.044) as dietary RAC increased whereas fat tissue deposition tended to be reduced in high lysine and high RAC diets. In the first 7 days (data not shown) there were interactions between the effects of RAC and lysine for FCR (p=0.013) and ADG (p=0.023) with both traits only responding positively to RAC dose on the higher lysine diet. The results suggest that in the early stages of a dietary RAC regimen, the high lysine diet enhances a response, while over the study duration both diets contained sufficient dietary lysine to elicit a similar response to RAC. These data verify that the current recommended lysine level is sufficient to elicit a similar response in ADG, FCR and lean tissue growth for low and high levels of RAC inclusion over 28 days.

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Supported in part by the Pork CRC Ltd.

Nano- and Micro-Size Chromium Picolinate Increase Carcase Weight and Muscle and Decreases Fat in Finisher Gilts

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Chromium (Cr) is an essential mineral element. Over the past two decades, various forms of Cr^{3+} have been used in pig diets in order to improve growth performance, insulin sensitivity, immune response, carcase traits, pork quality, and to reduce stress responsiveness. However, Cr^{3+} is normally poorly absorbed and utilised even when supplemented in an organic form (Matthews *et al.*, 2005), perhaps in part because of the tendency to form large aggregates. The efficiency of uptake of 100 nm size particles by intestinal tissue was 15 to 250 fold higher compared to 1 µm size particles (Desai *et al.*,1996). It is possible that micro- or nano-sized chromium may be a means of improving the poor absorption of chromium and ensuring more consistent responses to dietary supplementation. The aim of this experiment was to investigate the effect of normal size, micro- and nano- chromium picolinate on growth and carcase characteristics of gilts.

A total of 96 finishing gilts (initial weight 51.9±1.20 kg) were stratified on weight into 4 blocks of 8 pens of 3 pigs and then within each block each pen was randomly allocated to 8 treatment groups in a 2×4 factorial design. The respective factors were dietary fat (25 or 100g/kg) and dietary Cr (0, 400 ppb normal size Cr picolinate (CrP), 400 ppb 1µm Cr picolinate (µCr), or 400ppb 100 nm Cr picolinate (nCr)). The µCr and nCr particles were made through grinding CrP through appropriate sized sieve end plates. Feed intake and weight gain were recorded weekly and blood samples were obtained on d 0, 21 and 42. At the end of the experiment, pigs were slaughtered at a commercial abattoir and underwent an ultrasound scan to determine eye muscle depth and P2 back fat. Data were analysed by analysis of variance. Initial weight was used as a covariate for final weight and carcase weight was used as a covariate for P2 backfat and muscle depth.

Table 1. *Effect of dietary fat and size of chromium picolinate on carcase characteristics in gilts.*

	Low fat				High fat					
	Con	CrP	µCr	nCr	Con	CrP	µCr	nCr	SED	Significance[A,B]
Carcase weight (kg)	65.5	65.0	70.4	68.5	65.2	68.3	67.6	69.6	1.52	C*, CxD^{NS}, T**, FxT^{NS}, FxCxD*,
P2 back fat (mm)	8.1	7.6	7.4	7.9	8.4	7.7	7.5	6.7	0.42	C**, T*, FxT*, FxCxD*
Muscle depth (mm)	51.4	52.3	50.8	52.5	47.1	52.9	50.3	53.9	1.96	C*, FxC*, T*

Con, Control; CrP, normal chromium picolinate; µCr, micro-chromium picolinate; nCr, nano-chromium picolinate; [A] C; Con vs all Cr diets: D; Con vs CrP vs µCr vs. nCr: F; low fat vs high fat; T; CrP vs µCr vs nCr. [B] NS, P>0.05; *, P<0.05; **, P<0.01; SED, standard error of the difference for FxCxD.

Over the first 21 days of the experiment there was a significant effect of Cr on average daily gain (ADG) (944 vs 1011 g/d, respectively, P=0.021) but not of Cr size (P=0.17). Pigs offered the higher fat diet grew faster than those offered the low fat diet during the first 21 days of the experiment (963 vs 1026 g/d, P=0.013). These effects, however, diminished over time and neither Cr (P=0.35) or dietary fat (P=0.93) significantly affected ADG over the 42 day experimental period. However, dietary Cr increased carcase weight and muscle depth with responses being greatest for nCr (Table 1). Also, dietary Cr decreased P2 back fat with the greatest response seen in pigs fed nCr and a high fat diet. Furthermore, dietary Cr tended to decrease plasma insulin (6.9 vs 5.1 µU/mL, P=0.055) without changing plasma glucose (3.55 vs 3.47, P=0.62) indicating an improvement in insulin sensitivity. In conclusion, dietary Cr can increase ADG and improve carcase traits in a lean genotype with responses being most pronounced in pigs fed a high fat diet and µCr and nCr.

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Supported in part by the Pork CRC Ltd.

Altering The Timing Of An Immunocastration Vaccine to Optimise Pig Performance

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Entire male pigs are more efficient and leaner than surgical castrates, but 'boar taint' can compromise eating quality. Vaccination of boars with a gonadotropin releasing hormone (GnRH) vaccine (Improvac®, Pfizer Ltd, Parkville, VIC) can eliminate boar taint, and allows pigs to retain all of the performance attributes of entire males up until the time they receive the second vaccination, normally four to five weeks pre-slaughter (Dunshea *et al*., 2001). However increases in backfat depth (P2) and feed conversion ratio (FCR) compared to entire males has limited the uptake of this technology. If giving the second vaccination closer to the time of slaughter could eliminate boar taint, there would be less of a cost in lost production to producers. An experiment was conducted to test the hypothesis that reducing the time between administration of the second vaccination with the GnRH vaccine and their slaughter will reduce the impact on P2 and FCR while still reducing boar taint.

The experiment involved a total of 175 Large White x Landrace entire male pigs randomly allocated into one of five treatments at approximately 16 weeks of age (58.7± 0.43 kg). Each treatment had five replicates with the pigs housed seven per pen (35 pigs/treatment) The pigs were vaccinated with the GnRH vaccine at 6, 4, 3 or 2 weeks pre-slaughter and compared against a control group that were not vaccinated (0 weeks). All pigs, apart from those on the control treatment, received the initial vaccination at approximately 10 weeks of age. All pigs were fed *ad libitum* on a diet with 13.2 MJ digestible energy (DE)/kg and 0.55 g available lysine/MJ DE. Pigs were slaughtered in a commercial abattoir at the end of the study. Data were analysed by GLM.

Table 1. *Effect of time between second GnRH vaccination and slaughter on performance and carcase characteristics in finisher pigs*[1,2]

Time (weeks)	0	2	3	4	6	SEM	P value
Final liveweight (kg)	105.2	105.3	104.4	107.6	108.7	1.00	0.158
VFI (kg/d)	2.43^{a}	2.56^{a}	2.75^{a}	2.78^{a}	2.91^{b}	0.099	0.026
Average daily gain (g)	1113	1109	1102	1159	1181	26.4	0.157
FCR (kg/kg)	2.18	2.32	2.50	2.40	2.46	0.084	0.083
Carcase weight (kg)	69.0^{ab}	68.6^{ab}	67.7^{a}	70.7^{ab}	71.5^{b}	0.69	0.036
P2 (mm)	11.6	11.4	12.7	12.6	13.8	0.56	0.057
Testicle weight (g)	209^{a}	162^{b}	134^{bc}	98^{cd}	64^{d}	9.7	<0.001
Androstenone (µg/g)	0.91^{a}	0.11^{b}	0.11^{b}	0.10^{b}	0.13^{b}	0.053	<0.001
Skatole (µg/g)	0.05	0.04	0.03	0.04	0.04	0.00	0.420

[1] Liveweight at start of the experiment used as covariate in statistical analyses (except VFI, FCR, testicle weight, androstenone and skatole); [2] Data calculated on pen basis; [abcd]Means within a row with different superscripts differ significantly (P<0.05); VFI, voluntary feed intake; FCR, feed conversion ratio; SEM, standard error of mean.

Final liveweight, average daily gain and FCR were similar (P>0.05) and there was a tendency (P=0.057) for P2 to increase with increasing time between the second vaccination and slaughter (Table 1). There were differences in voluntary feed intake (P=0.026) and carcase weight (P=0.036) between pigs vaccinated 6 weeks before slaughter and all other treatments. Control pigs had the heaviest testicle weight (P<0.001) with pigs vaccinated 6 weeks before slaughter being the lightest, but this was the same (P>0.05) as pigs vaccinated 4 weeks before slaughter. Control boars had fat androstenone levels nine times greater (P<0.001) than all GnRH vaccine-treated boars regardless of vaccination time before slaughter. These results can be used to determine the optimal time for giving entire males the second vaccination with the GnRH vaccine.

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Supported in part by the Pork CRC Ltd.

Effect of Xylanase on Feed Intake of Piglets Fed Diets Based on Wheat and Wheat Bran

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High fibre raw materials are less useful in young pig diets as the high fibre content are believed to exert a negative effect on feed intake (Eggum, 1995). In a weaner pig study by Schulze *et al*. (1997), voluntary feed intake appeared to be negatively influenced by the dietary fibre content of wheat. The aim of this experiment was to investigate the effect of increasing dietary xylanase inclusion on feed intake of young pigs fed a high fibre, wheat-based diet.

Seventy-two, 28 day old, male Landrace x Duroc piglets, approximately 8kg liveweight, were housed in groups of three in slatted floor pens in environmentally controlled housing. Effects of xylanase (Endo- 1,4-beta-xylanase, EC 3.2.1.8; Porzyme® 9300, Danisco Animal Nutrition, Marlborough, UK) supplementation at 0 U/kg feed, 2200 U/kg feed and 4400 U/kg feed, were studied during a two phase (0-21d and 21-42 d), randomised block experiment with eight replicates per treatment. For phase 1 and 2 respectively, pelleted diets containing 15.5 and 14.5 MJ/kg digestible energy (DE), 13 and 9 g/kg digestible lysine, 39.1 and 39.6 g/kg crude fibre, 146.2 and 148.3 g/kg neutral-detergent fibre, 33 and 37 g/kg acid-detergent fibre were fed. To increase fibre levels, diets contained 63% wheat and 13% wheat bran. Pigs were weighed at the start, then at weekly intervals. Feed and water were provided *ad libitum*. Food consumed was recorded weekly. Data were analysed for the overall period (0 to 42 d) for start and final body weight, daily feed intake (DFI), daily liveweight gain (DLWG) and feed conversion ratio (FCR). Data were analysed using analysis of variance to determine treatment effects. Significance was determined at P<0.05 level.

Table 1. *Performance data of pigs (0-42 d) fed high fibre diets containing 0 U/kg, 2200 U/kg and 4400 U/kg xylanase.*

	Treatment					
	0 U/kg	2200 U/kg	4400 U/kg	SED	P Value	Linear P
Final body weight (kg)	17.9	18.4	19.5	0.8	NS	<0.05
DFI 0-42 d (g/pig)	574[a]	611[a]	695[b]	37.0	<0.05	<0.005
DFI 0-21 d (g/pig)	359[a]	371[a]	458[b]	34.0	<0.05	<0.01
DFI 21-42 d (g/pig)	788[a]	851[ab]	931[b]	49.0	<0.05	<0.01
Daily liveweight gain (g/pig)	242	252	277	19.0	NS	NS
Feed conversion ratio	2.31	2.36	2.52	0.17	NS	NS

[ab]Means within a row with different superscripts differ significantly (P<0.05); NS, non significant; SED, standard error of difference; DFI, daily feed intake

Due to the high fibre diets, performance and efficiency were relatively poor and variation was high. Despite this, a positive effect of the dietary xylanase inclusion on DFI was evident (Table 1). Increasing xylanase concentration linearly increased DFI (P<0.005). The effect of xylanase on DFI was statistically significant in both the 0-21 d and 21-42 d phase. The 2200 U/kg and 4400 U/kg xylanase inclusion did not significantly (P>0.05) alter DLWG or FCR. In conclusion, feeding a wheat and wheat bran-based diet with xylanase supplementation reduced the negative impact of the high dietary fibre on feed intake by piglets. The effect was directly proportional to xylanase dose.

EGGUM, B.O. (1995). *Archives of Animal Nutrition*. **48**:89-95.

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Maximising the Benefits From High Fat and High Fibre Pig Diets During the Finisher Period

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The addition of high concentrations of neutral detergent fibre (NDF) sourced primarily from mill mix (mill run), or the addition of supplemental fat (tallow) in finisher diets have been demonstrated to improve feed efficiency and weight gain (Collins *et al.*, 2009). While both feeding strategies improved production efficiency, the maximum responses were obtained during the initial 2 weeks of feeding and diminished with time. Further investigation is therefore required to determine optimal feeding strategies that will optimise finisher growth performance and economic returns under Australian conditions, with this forming the aim of this experiment.

A total of 1296 pigs (Large White x Landrace, PrimeGro™ Genetics, Corowa, NSW) were selected at 16 weeks of age (average 61.8 kg) and housed in pens of 9 pigs of the same sex. Pens were allocated to a 2x6 factorial experiment with the respective factors being sex (entire male and female) and feeding strategy (A: control finisher diet fed for 6 weeks; B: High fat diet fed for 6 weeks; C: High neutral-detergent fibre (NDF) diet fed for 6 weeks; D: High fat diet fed for 3 weeks followed by high NDF diet for 3 weeks; E: High NDF diet fed for 3 weeks followed by high fat diet for 3 weeks; F: Constant digestible energy (DE) strategy in which the control diet was fed for 3 weeks followed by a diet high in both fat and NDF (50g/kg added tallow and 190g/kg NDF) for the final 3 weeks). All diets contained 0.53 g available lysine/MJ DE. High fat diets contained 50 g/kg added fat (tallow), while high NDF diets contained 190 g/kg total NDF. All diets contained 13.8-14.0 MJ DE. Pigs were offered their respective diets *ad libitum* from 16 to 22 weeks of age. Pen weights were recorded at d 0, 21 and 42 with feed disappearance measured. Differences in average daily gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (FCR) were analyzed using analyses of variance. The experimental unit was the pen. Economic implications were assessed using 2009 feed costs, a carcase price of $3.50/kg and a price penalty of 25c/kg for P2 > 12mm. Net margin was determined by difference to feeding strategy A.

Table 1. *Influence of feeding strategy on performance of finisher pigs (16-22 weeks).*

							SED	Significance		
Feeding strategy[1]	A	B	C	D	E	F		FS	S	FS xS
ADG (g/d)	901.9	950.0	917.3	933.2	933.9	922.8	17.26	0.11	<0.001	0.88
ADFI (kg/d)	2.42	2.46	2.38	2.39	2.42	2.44	0.036	0.29	0.11	0.44
FCR (kg/kg)	2.69	2.59	2.60	2.58	2.61	2.67	0.034	0.006	<0.001	0.74
Carcase weight (kg)	76.7	78.3	76.3	77.3	77.3	76.9	0.65	0.057	0.039	0.89
Carcase P2 (mm)[2]	9.1	9.1	8.6	8.6	8.6	8.9	0.22	0.005	<0.001	0.51
Dressing %	77.0	77.1	76.1	76.6	76.7	76.7	0.34	0.098	<0.001	0.44
Cost/kg gain ($/kg)[3]	0.92	0.89	0.90	0.89	0.90	0.90				
Net margin ($/pig)	5.28	-0.38	3.22	2.61	1.78					

[1]Feeding strategies A to F described in body of text above; [2]Carcase weight used as a covariate; [3]Feed cost per kg live weight gain; SED, Standard error of difference; ADG, average daily gain; ADFI, average daily feed intake; FCR, feed conversion ration; FS, feeding strategy; S, sex

During the initial three weeks, FCR was enhanced when pigs were offered the high fat and high fibre diets (2.50, 2.39, 2.36, 2.35, 2.42, 2.56 for the A to F feeding strategies respectively, P<0.001, SED 0.049). A similar result was obtained for the entire experimental period (Table 1), with the pigs offered feeding strategies B, C, D and E displaying the lowest FCR's. Economic analyses suggest that the use of the high fat feeding strategy for 6 weeks (Strategy B) provides the greatest improvement in net returns. It appears that high fat diets fed for the entire finisher period will optimise production efficiency and economic returns for lean, fast growing genotypes.

COLLINS, C.L., PHILPOTTS, A.C. and HENMAN, D.J. (2009). *Animal Production Science*. **49**:262-267.

Supported in part by the Pork CRC Ltd.

Adding Straw to Diets Did Not Affect Growth Performance and Carcase Measures of Finisher Pigs

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Dietary fibre, when included at levels of up to 100 g/kg in finisher pig diets, can reduce carcase fat without impacting on growth performance (Håkansson *et al.*, 2000). In pigs, the relative proportion of fat deposited during growth increases with age and weight therefore increasing fibre levels during finishing is expected to have the greatest impact on carcase quality. Fibrous ingredients, such as cereal straw, have the potential to be used as a management tool, however, it is important to determine whether the effect of fibre is related to the ingredient itself or to the dilution of dietary energy and nutrients that occurs. It was hypothesised that finisher pigs fed high energy diets containing straw would have similar growth performance but leaner carcases than pigs fed a standard high energy finisher diet. In addition, pigs fed a lower energy diet (+/- straw) were expected to be leaner but slower growing, and therefore less efficient, than pigs fed a standard high energy finisher diet.

The experiment was conducted as a 2x2 factorial to investigate the effect of straw inclusion (0 or 100 g/kg) and two levels of energy density (high or low) on finisher pig performance. At approximately 16 weeks of age (55.9±6.18 kg; liveweight (LW)±SD) 60 Large White x Landrace female pigs were blocked by LW into groups of four. Pigs within each block were allocated to adjacent individual pens within an insulated naturally-ventilated grower-finisher facility. Treatments were randomly allocated within each block and were: 1) high energy, (HE; 13.8 MJ digestible energy (DE)/kg), 2) high energy + 100 g/kg chopped cereal straw (HE+S; 13.5 MJ DE/kg), 3) low energy + 100 g/kg chopped straw (LE+S; 12.7 MJ DE/kg), and 4) low energy (LE; 12.8 MJ DE/kg). All diets were formulated to contain 0.55 g available lysine/MJ DE and were pelleted (9 mm diameter) to incorporate the chopped straw. Pigs were fed the HE diet *ad libitum* for seven days, after which treatment diets were fed *ad libitum* until slaughter at 98±5 kg LW. Feed intake and LW were measured weekly. Pigs were slaughtered at a commercial abattoir and hot carcase weight (AUSMEAT Trim 13; head off, fore trotters off, hind trotters on; AUS-MEAT Ltd, South Brisbane, QLD) and P2 backfat depth were measured. Data were analysed by two-way ANOVA (Genstat v11). Carcase weight was a covariate in the analysis of P2.

Table 1. *Effects of dietary energy density and straw inclusion on finisher pig growth performance.*

	Treatment					P value	
	HE	HE+S	LE+S	LE	SED	Energy	Straw
Average daily gain (kg/d)	1.28	1.26	1.31	1.30	0.051	0.337	0.716
Average food intake (kg/d)	3.20	3.37	3.68	3.45	0.207	0.060	0.180
Feed conversion (kg food/kg gain)	2.52	2.79	2.83	2.64	0.195	0.556	0.092
Carcase weight (kg)	63.6	64.0	63.2	64.6	0.99	0.940	0.497
P2 (mm)	12.0	12.6	12.8	14.2	0.93	0.067	0.554
Dressing %	65.8	67.0	65.3	65.7	1.16	0.256	0.645

HE, high energy; HE+S, high energy + 100 g/kg chopped straw; LE+S, low energy + 100 g/kg chopped straw; LE, low energy; SED, standard error of difference

Straw inclusion, energy density and their interaction did not affect growth performance or carcase measures (P>0.05, Table 1). There was a trend (P=0.060) for pigs fed low energy diets to have higher feed intake, though this did not explain the trend for greater P2 depth (P=0.067) as calculated daily energy intake was similar for LE and HE pigs (44.2 MJ), highest for LE+S pigs (46.7 MJ) and intermediate for HE+S pigs (45.5 MJ). Under commercial conditions pigs fed the low energy diet would be expected to have poorer growth performance as feed intake is lower for group-housed pigs than for individually-housed pigs. It would be pertinent to determine if these growth performance and carcase results are reproducible under commercial pig production conditions.

HÅKANSSAN, J., LUNDHEIM, N. and CIDH, M-A. (2000). *Acta Agriculturae Scandanvica (Section A - Animal Science)*. **50**:83-92.

Supported in part by the Pork CRC Ltd.

Adding Straw to Finisher Pig Diets Does Not Affect Objective Pork Quality

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Pigs housed in deep-litter systems can consume significant amounts of fibrous bedding material (Staals *et al.*, 2007) and bedding materials, such as cereal straw, are of little nutritive value to growing pigs. The daily intake of bedding is variable, however, it is estimated that bedding can contribute to up to 10% of the pig's total daily intake (van Barneveld *et al.*, 2003). The consumption of bedding dilutes the pig's total energy and nutrient intake and may contribute to the differences found in pork quality between pigs raised in conventional and deep-litter systems. This experiment was designed to determine whether straw consumption directly affects pork quality or whether the effect is indirect via the dilution of dietary energy density. It was hypothesised that objective pork quality would differ between pigs fed high and low energy finisher diets but that the addition of straw, in the absence of differences in diet energy density, would not affect objective pork quality.

The experiment was a 2x2 factorial design investigating the effect of two levels of straw inclusion (0 g/kg and 100 g/kg) and two levels of energy density (high and low) in finisher pig diets. At approximately 16 weeks of age (55.9±6.18 kg liveweight (LW) ±standard deviation) 60 Large White x Landrace female pigs were housed individually and allocated to treatments and feeding regimes as described by Trezona *et al.* (2009). The treatments were: 1) high energy, (HE; 13.8 MJ digestible energy (DE)/kg), 2) high energy + 100 g/kg chopped cereal straw (HE+S; 13.5 MJ DE/kg), 3) low energy + 100 g/kg chopped straw (LE+S; 12.7 MJ DE/kg), and 4) low energy (LE; 12.8 MJ DE/kg). Pigs were slaughtered at a commercial abattoir at 98±5 kg LW. Twenty-four hours after slaughter, approximately 1 kg of the *longissimus dorsi* muscle was collected and pH_u (24h), muscle colour (L*, a*, b*), drip loss, cook loss and Warner-Bratzler peak shear force measures were determined. Data were analysed by two-way analysis of variance (Genstat v11).

Table 1. *The effect of energy density and straw inclusion in finisher diets on objective pork quality.*

	Treatment					P value	
	HE	HE+S	LE+S	LE	SED	Energy	Straw
P2[1] (mm)	12.0	12.6	12.8	14.2	0.93	0.067	0.554
Carcase weight[2] (kg)	63.6	64.0	63.2	64.6	0.99	0.940	0.497
pHu	5.57	5.55	5.63	5.62	0.057	0.120	0.943
Shear Force (kg)	5.80	5.72	6.12	5.54	0.558	0.884	0.539
L*	52.1	53.3	52.1	53.4	1.10	0.888	0.939
a*	5.66	6.05	5.35	8.86	2.656	0.481	0.413
b*	2.33	2.83	2.17	2.49	0.336	0.311	0.700
Drip loss (%)	5.22	5.82	4.58	5.19	0.581	0.132	0.987
Cook loss (%)	36.06[a]	35.33[ab]	34.64[b]	34.99[b]	0.507	0.016	0.136

[ab]Means in a row with different superscripts differ significantly (P<0.05); [1]Adjusted for carcase weight; [2]AUSMEAT Trim 13; HE, high energy; HE+S, high energy + 100 g/kg chopped straw; LE+S, low energy + 100 g/kg chopped straw; LE, low energy; SED, standard error of difference .

Most measures of objective pork quality were not affected by diet energy level, straw inclusion or their interaction (P>0.05). However, pork from pigs fed low energy diets had significantly lower cook loss than pork from pigs fed high energy diets (P=0.016). Higher levels of intramuscular fat may explain the difference in cook loss as the trend for higher P2 backfat in low energy fed pigs (P=0.067) suggests differences in body fat content. There was an effect of diet energy level on pork quality, however, the inclusion of straw at 100 g/kg did not directly influence objective pork quality.

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CHAPTER 10

Product Commercialisation

A profitable finish

Poor performance during the finishing phase is a leading cause of variation and failure to achieve full market value. Paylean® 20 premix from Elanco helps to produce more "full value pigs" by directing nutrients towards lean muscle instead of fat, thereby improving growth rates, feed efficiency and lean carcass yield. The end result is more pigs achieving market specifications, on time! For more information about how Paylean can maximise the profitability of your herd, contact your feedmill or Elanco on **1800 226 324** or visit **www.elanco.com.au**

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Symposium: Strategies for Successful Commercialisation of Pig Research

Symposium Introduction

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Since the first proceedings of the Australasian Pig Science Association (Manipulating Pig Production, Volume I) were published in 1987, there have been numerous papers reporting on advancements in the understanding of the biological mechanisms regulating pork production. These findings have covered all areas such as nutrition, health, reproduction, genetics, meat quality, environment and welfare. Similarly, if one looks through the current volume and the previous 11 proceedings, you will find frequent references to products that are now available from profit driven companies that have identified a solution to improve or remove the effects of an underlying barrier which results in improved pork production, better being defined in many and varied ways. What is not so obvious from this review of past papers is why have some solutions been easily developed and adopted by industry, yet other problems for which the scientific explanation is known, are still frustrating producers and have not been practically solved? The answer lies in the process of commercialisation.

Commercialisation is a multi-step process that takes an idea on how to solve a problem through the long and tortuous process of identifying the solution, validation of the solutions' effectiveness, registration or other regulatory processes and manufacturing, marketing and distribution of the solution. The aim at the end of the process is that there are sufficient consumers that will buy the solution in significant quantities (locally or internationally) at an appropriate price to justify the investment and profit objectives of all the parties that were involved along the way. Commercialisation needs to start with research and finishes with acceptance and implementation by the end user. In a series of three papers, this symposium explores the issues that organisations involved in research (either by funding or conducting the research) need to consider at the outset through to the evaluation process that the end user will apply before implementation of the commercial product.

The first paper in the symposium by Wilson (2009), considers the role of commercialisation principally from the view point of publically funded research as provided by the Cooperative Research Centre model in place in Australia. The paper also reviews some of the findings that relate to technology transfer and adoption in the Australian Pork Industry.

The second paper by Boyd and Donovan (2009) gives a comprehensive insight into the methodology employed by a large commercial pork producing organisation to evaluate products that are needed to assist their operation, the return on investment of these products and the appropriate measures that are used to determine the return or investment within their operation.

The final paper in the symposium by Hennessy (2009) is a detailed chronology of the commercialisation of a product that was developed in Australia. This paper successfully highlights, in a commercial scenario, the key elements discussed in the first two papers of the symposium and provides some salient points about the trials and tribulations in the research commercialisation process that are relevant to all involved in the pork supply chain.

Commercialisation and Adoption of Research in the Australian Pork Industry

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Commercialisation not only means the direct transfer of research to commercial companies, with the intent that they make the new technologies or products available to industry, but more importantly to encourage adoption of new technology by industry to value add to their business. The latter is particularly relevant to the Australian pork industry given the nature of the existing national research program and the type of intellectual property developed through these research programs. This paper outlines the basic principles of commercialisation and adoption and practical considerations for the application of these technologies by the Australian pig industry.

Commercialisation

A commercialisation strategy usually follows three integrated stages encompassing discovery, commercialisation and adoption or utilisation. The strategy will recognise different types of processes or products arising from research and will identify appropriate pathways for their commercialisation which could include intellectual property (IP), patent and trade mark protection where necessary. This may involve technology transfer, or the utilisation and/or commercialisation of research outcomes and new knowledge. More specifically the Cooperative Research Centre (CRC) Association (CRCA) outlines in their information guidelines that the commercialisation of research outcomes may include exploitation of IP and involve a number of different channels (CRCA Information Guides) including:

- Transfer of IP by license or assignment;
- Transfer of IP through publication or otherwise without royalty and other fees for the public good;
- Establishment of a spin-off company in which the CRC itself or some or all of the participants and investors may hold equity.

A generic commercialisation strategy for research outputs or products is outlined in Figure 1. Generally as the products or processes from research are developed to a pre-commercialisation stage, a business plan will be produced outlining the value proposed for potential business partners and commercial companies who may need additional funds for further product development, manufacturing and marketing. To be successful in the venture, these plans need to clearly outline the business ownership and structure; IP management, ownership and responsibilities; the market competitive position; and budgets, resources and management of the entity.

Two studies measuring the economic impact and evaluation of the potential benefits from the overall CRC programs in Australia reported three similar conclusions (Allen Consulting Group, 2005; Insight Economics, 2006).

- Most benefits from the CRC programs have come from industrial application of research rather than through narrowly defined commercialisation events such as spin-off company formation and licensing of IP. That is, the benefits delivered through end-user application of research remains the most significant channel of quantified benefit.
- Time lags between the formation of a CRC and the generation of measurable end impacts are significant and are generally between five and 10 years.
- The challenges in assessing the impact of research are to convey how a research groups' inputs have flowed through to delivery of an end impact for the community. This means measuring the 'impact' rather than merely the 'activity'.

These reviews also included case studies of "star" companies from publicly funded research and development (R&D). The case studies highlighted that the largest commercial pay-offs in Australia have been associated with truly break- through science rather than with incremental improvements to existing knowledge. In some cases the break-through involved not only the creation of new products, but the creation of new markets. A National Survey of Research Commercialisation (2007) calculated that the ratio of commercial expenditure to research expenditure in all CRCs amounted to 7.5 percent and 8.2 percent in years 2003/04 and 2004/05, respectively. For Agriculture and Rural Based Manufacturing Sector CRCs specifically, the ratio was 6.8 percent and 7.3 percent for each year, respectively. These ratios, however, would need to be considered with caution as the allocation of expenses to commercialisation activities across CRCs may vary considerably. The survey also reported the license income as a proportion of research

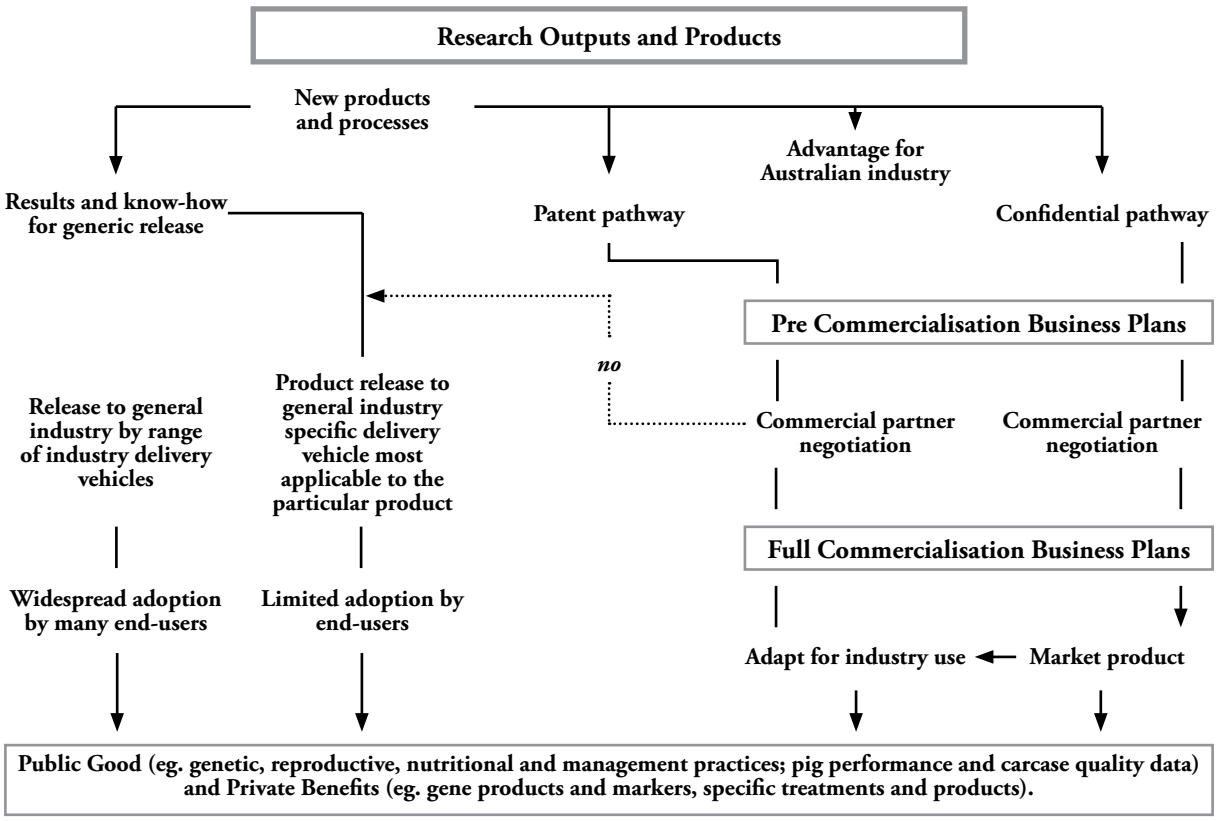

Figure 1. *Schematic representation of a generic commercialisation strategy*

expenditure for this publicly funded sector as a whole was 1.7 percent. The average returns for the top 20 percent of Australian license income earners (by volume) was only 2.5 percent.

The major economic returns are to companies that have successfully commercialised the R&D rather than to the research organisations. The findings above have important ramifications for successful commercialisation involving commercial entities when profit alone is often the driver. A survey of spin-off companies from CRCs (Yencken, 2002) showed that of the 64 CRCs included in the survey, 56 percent reported no spin-off companies and 70 percent of these CRCs relied on participants to achieve their technology transfer and commercialisation objectives. Of the 69 spin-off companies identified, 36 percent were either holding companies or technology transfer companies involved in activities such as consultancies, contract research and education, and 64 percent were direct research spin-off companies where there were ongoing IP links with the CRC. Of the 10 Agriculture and Rural Based Manufacturing Sector CRC's, there were three spin-offs; a holding company, a technology transfer company and a direct research spin-off company. However, it is clear that CRCs and Research and Development Corporations generate significant economic, social and environmental benefits for Australia in key areas that have been determined as priorities by rural industries and the Australian Government.

A recent study of Rural R&D Corporations calculated a return of $AUD10.5 billion in quantified benefits from 36 highly successful projects, with a sample of randomly selected projects found to deliver an average return of $11 for each dollar invested (RIRDC, 2008).

An economic impact assessment from 10 Pork CRC projects was shown to give a benefit to cost ratio higher than 20 for eight of those projects and an overall net present value of $2.149 million (Mousa *et al.*, 2008).

Adoption

Successful farming requires the producer to make decisions on many and varied complex conditions, and although there is a large number of published studies that attempt to understand what drives a producer to adopt new management practices and/or new technology, there is little information that specifically relates to how business and other decisions are made on farm.

The best management practices (BMP) approach is widely used by researchers and extension officers to assist producers make their operation more profitable and sustainable. Decision making at this level is often complex and the BMP approach may well be ineffective.

Rogers (1995) and Moore (1998) indicate that adopters of any innovation or technology can be categorised into five areas (Figure 2), each with its own philosophy, experience and mix of benefits and risk.

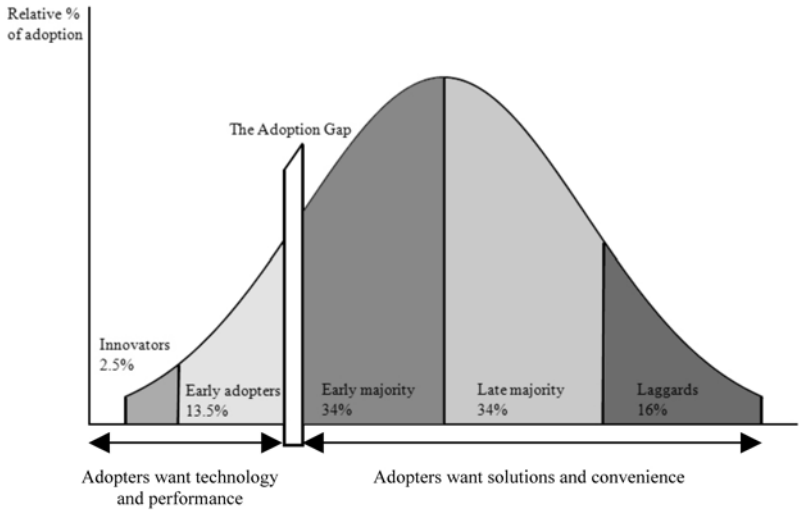

Figure 2. *The 'adoption curve' (from Rogers, 1995).*

The categories are:

- Innovators – small groups on the 'bleeding edge' and first to use a new technology.
- Early adopters – visionaries, the 'leading edge' who look for new technologies to stay ahead of the competition and solve problems.
- Early majority – 'fast followers' who do not buy technology for its own sake or for future advantages, but rather for filling a need today.
- Late majority – risk averse and cautious about implementing new technology, not for innovations sake, but because they have to.
- Laggards – 'die-hards' minority where tradition is more important than continual innovation, being the last to adopt new technology, doing so because they are forced into it.

There are six stages in the adoption process identified by Rogers (1995):

- Awareness – the first time a product or process is heard of, without knowledge of the benefits.
- Interest – search for information about the new product.
- Evaluation – consider whether the product will be useful.
- Trial – the product is evaluated to determine whether it will be useful.
- Adoption – decision made to regularly use the product.
- Confirmation – the decision is either re-affirmed or rejected.

As well as these adoption stages, there are many other factors to be considered which may impact on whether a new technology will be adopted or not, along with the rate at which adoption of a particular technology may occur. These could include:

- The time it takes to implement or use the technology.
- On-farm trials to demonstrate practicality of the technology.
- Ability to readily measure the results of any trials of the technology or in ongoing use.
- Benefit to costs of application and relative to competitive technologies or products.
- The technology should not be too complex to apply to realise the advantages.
- Compatibility with current management practices and other product or technology usage.

A recent adoption survey conducted at Australian Pork Ltd's (APL) Roadshow (InnovatE, 2009) provided some useful information about technology transfer and adoption of research outcomes. Of the 44 respondents, 67 percent on average had heard about the various technologies and 25 percent had adopted them. The most heard about technologies were the economic use of ractopamine (Paylean) and/or pST (Reporcin) (95%), increased energy in first lactation (86%), and immunocastration and high energy diets, both at 84% (Figure 3).

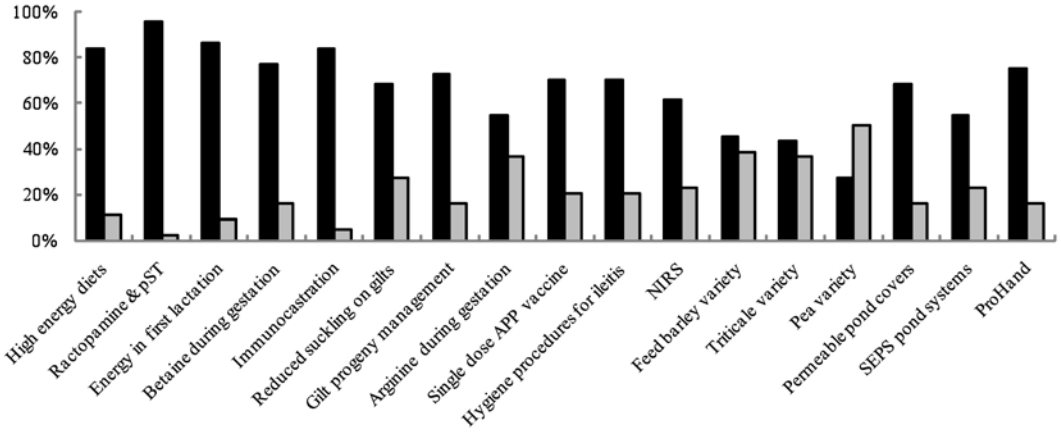

Figure 3. *APL Roadshow technology transfer. Percentage of respondents who had heard about the technology (■) and the percentage of respondents who had not heard about the technology (■).*

Ractopamine and/or pST had the highest adoption rate among respondents at 57 percent, followed closely by hygiene procedures for ileitis (52%) and betaine during gestation (48%; Figure 4). A number of respondents had deemed some technologies unsuitable for their business or were in the process of adoption.

Fisher *et al.*, (2007) described a new approach to measuring and monitoring the quality of commercialisation between research and the wider community, by employing survey methodology based on established marketing processes for monitoring customer satisfaction. These authors concluded that this community value analysis was a promising path to adoption of new science and technology which implied that economic, social and environmental benefits will be delivered sooner with a greater return on the investment. They also claim that this approach may provide researchers with advanced notice of the likely community reactions, particularly to some more contentious technologies such as biotechnology and nanotechnology.

Rather than making rational decisions, humans make decisions by matching the information they are getting with their own experience and expectations (Snowden, 2003). They also do things out of habit, while observing and copying others, and tend to go out of their way without assessing the probabilities and risks (Dawney and Shah, 2005). These management and decision approaches are also of relevance to producers' decision making as they often rely on trusted networks for information and reconcile this with their own experience, values, beliefs and habits.

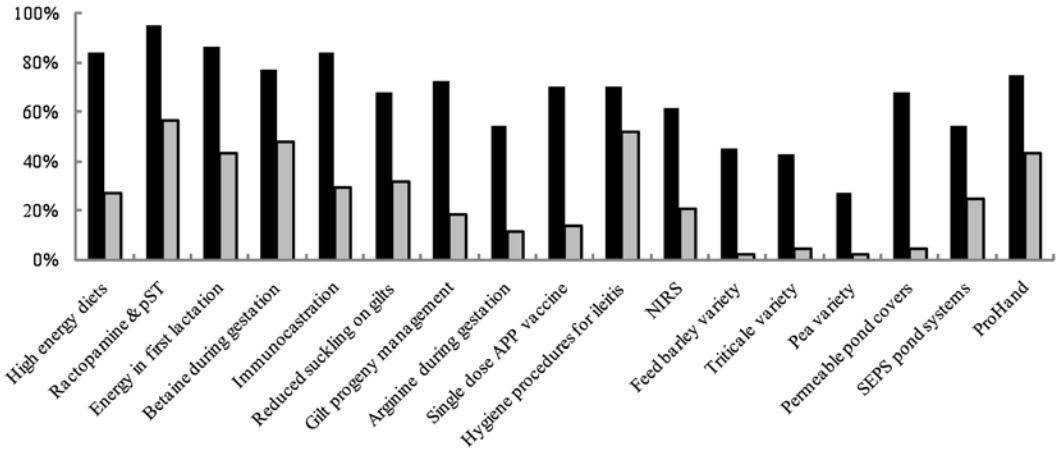

Figure 4. *APL Roadshow adoption rates. Percentage of respondents who had heard about the technology (■) and the percentage of respondents who had adopted the technology (■).*

McGuckian and Rickards (2008) produced a number of discussion papers from the result of social research carried out in the "Grain & Graze" project with the aim to provide informed discussion for those involved in decision making on mixed farms. They developed a 'Tip Sheet' for regional research and extension for this project which aimed to present helpful hints to communicate the findings from research. Though developed for the grazing mixed farming industry, these hints are all relevant for the pork industry and could be easily applied.

Applying technologies in practice

Implementing new technologies in pig production involves both basic and applied studies. Basic studies typically involve small numbers of animals under tightly controlled conditions to demonstrate that the technology being investigated will affect the anticipated biological mechanism. Applied studies are conducted with large number of animals under field or farm conditions which can provide critical information on the range of a response that can be expected. Most applied studies are undertaken by producers who are interested in determining whether a new technology, product or management practice can improve performance.

There are three basic aspects to consider when conducting on-farm studies:

- Treatment periods long enough to allow them to work biologically.
- Contemporary groups that reflect normal untreated management practices.
- Sufficient numbers to successfully determine differences.

The length of treatment period will be determined by the specific physiological aspect that the new technology or product is supposed to influence. Technologies affecting the timing of oestrus and ovulation only need to be administered for days or weeks, while technologies affecting feed intake or growth may need to be applied over many weeks or months. Control groups are necessary to avoid confounding results from a situation whereby two or more factors are altered at the same time and may therefore make identifying the one that caused a response virtually impossible. The size of the number of animals in the experiment will assist to determine with confidence whether any improvement or advantage in performance due to the new technology was real or simply just due to chance.

An approach commonly used in on-farm experiments is to apply the new technology to all animals at a given point in time, collect the data over that time and then compare the performance of the herd before and after the technology was applied. Though this is easy to implement because all the animals in the herd do, or do not, receive the treatment at the same time, the results would only be valid if all the animals and conditions about the production and environment remain constant for the duration of the evaluation period. Unfortunately this would rarely occur as feed, labour, temperature, seasonal and disease variations for example, would not be constant in practice. In studies conducted in his manner, changes over time in the production environment, or the animals themselves, would be unrelated to the treatment and therefore bias or confound the outcome. This confounding means that if two factors were changed or altered at the same time, there would be no way to decide if a response to the result of the change was due to one or both of the changes.

As previously mentioned, to determine whether a new product or technology should be adopted, it is important it be tested on enough animals to have confidence that any improved performance is due to the technology and not to unrelated, normal fluctuations that are present in all herds. There are three questions that producers should ask when determining the number of animals to be included in the experiment, to have confidence that the new technology is working:

- What size of an improvement does the new technology need to produce in order for it to be adopted;
- How much normal variation is present in the herd; and
- How much confidence is required in the results?

The answer to the first question is herd-specific as the current level of performance and the cost of the new technology are important considerations; typically there is a positive relationship between the cost of the technology and the level of improvement that needs to be achieved.

Knowing the normal variation in the herd is important to establish whether, for example, parity structure or seasonal effects on performance are due to the new technology or due to other unrelated changes inherent in the herd. The most common measure of variation is the standard deviation (SD). In theory, the average plus or minus one SD would encompass about two-thirds of the entire herd, while the average plus or minus two SD would encompass over 90 percent of the herd. In general there is an inverse relationship between the normal variation within a herd and the level of management; as management expertise improves the SD for production measures decrease.

The degree of confidence in the results is important in minimising mistakes. That is, confusing the situation where a new technology does improve performance but the results show otherwise, and also the opposite effect. The best way to minimise these mistakes is to test a sufficient number of animals as there is usually a positive relationship between the level of confidence and the number of animals used in the experiments. As an example, the relationships among normal herd variation, numbers of animals per treatment and the relative advantage that a new technology would need to produce in litter size are given in Table 1 (Flower, 2008).

Table 1. *Estimates of the relative advantage in litter size required of new technologies to be significant (based on 90% confidence).*

	Number of animals per treatment			
Herd variation (standard deviation)	50	100	200	500
1.0	0.5 pigs	0.4 pigs	0.3 pigs	0.2 pigs
2.0	1.0 pigs	0.7 pigs	0.5 pigs	0.3 pigs
3.0	1.5 pigs	1.1 pigs	0.8 pigs	0.5 pigs

Conclusions

For many CRCs, technology transfer and research commercialisation has been managed successfully without the use of separate legal entities, while for others it has been convenient to set up holding or technical transfer companies. There has been an increase in the establishment of spin-off companies by CRCs to commercialise and exploit their research outcomes with considerable actual and potential economic benefits to be achieved.

Commercialisation not only means the direct transfer of research to commercial companies, with the intent that they make the new technologies or products available to industry, but more importantly to encourage adoption of new technology by industry to value add to their business, that is, a 'commercial path to adoption'.

Structured Process for Evaluating and Integrating New Technologies into Animal Production Systems

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This paper provides a format for evaluating prospective new products in animal production systems. Commercial production companies, and their science advisors, need a structured process to 1) screen or select worthy products/technologies, 2) evaluate for performance potential and 3) using data from the latter, compute financial value to the system. This process is not complete, however, until one knows the extent to which the new technology performs in practice. Inherent in all of this is the fact that proper experimental design, execution and analysis must be conducted by the service provider as well as by animal production companies to minimise the chance of making incorrect decisions.

This process begins with a screening format because there are far more product and technologies proposed by service/solution providers than are feasible to rigorously consider. The screening process places the burden on the providers to do sufficient product evaluation, after development, to become worthy of consideration. Producers should in most cases perform due diligence to verify efficacy and value in their system. This may involve advisor guided farm tests, but in some cases decisions can be made based on the work of trusted technical advisors or third party companies.

The Hanor Company uses a template to guide key decision-makers through the selection process. This is provided as an example for consideration by others and we acknowledge the contribution of Kendall (2005) in developing these guidelines. A summary of the key steps in a structured process for selecting and implementing new technologies (products) in a production system is as follows:

Prospective product screening process

- Is there a specific need for the product in the production system?
- Is there a plausible biological explanation for the products' efficacy?
- Is there 'proof of concept' or initial data to support the claim?
- Are there specific conditions necessary for product response?

'Me Too' products are not excused from verifying efficacy, independently.

Prospective product testing – 5 axioms of the structured process

- Appropriate experimental design to control random variation (includes experimental unit choice).
- Suitable replication to overcome random variation.
- Reliable data collection process.
- Data must be comprehensive enough to answer the questions posed.
- Competent analytical capability (statistical and financial).

Exceptions to 'discrete' treatments exist and sometimes require a farm level experiment that involves 'Process Charting' that is more typical of a manufacturing process. The objective is to determine whether there is a shift in performance that corresponds to product initiation and withdrawal.

Decision to implement a new product

- Product value to the production system determined with internal data and financial approach.
- Product value is determined by return over investment (preferred to reduced cost).
- Decision to implement product depends on 1) financial value, and 2) ease of implementation.

Track system performance to verify that product value is delivered on

- Implement product in the segment of production that is most able to deliver on the protocol or that which meets specific conditions necessary for the product to perform.
- Capture production data to verify the expected response.
- What if the evaluation does not yield the anticipated response? Review implementation.
- Start with implementation since it is the most distinguishing feature between systems.
- Perhaps other factors need to be understood before the product can be used.

These basic steps will now be considered in more detail.

Prospective products screen

The screening process in our decision-making template is guided by 4 considerations:

1. Is there a specific need for this product in our production system?
2. Is there sufficient 'proof of concept' data?
3. Are there specific conditions necessary for product response?
4. Is there a plausible biological explanation for this product's efficacy?

These 'hurdles' make it clear that commercial companies must do a certain amount of homework, prior to presenting their product to decision-makers (veterinarians, animal scientists with post-graduate qualifications, experienced production leaders) for consideration. It is important to know the approximate cost so that we can determine if further consideration is appropriate. However, it is acceptable if the cost/pig treated is not 'nailed down' in the early phase of product life provided that the potential benefit is attractive. This is especially true under 'dire' circumstances (eg. Porcine Circovirus Associated Disease (PCVAD)), when collaborative efforts are needed to accelerate a prospective product development in order to resolve a pressing problem. We might enter this situation as a willing participant in the 'proof of concept' or initial data phase, but proper experimental design and analysis must be adhered to.

Does the product address a specific need?

The product must address a specific need (problem or opportunity). If that condition is met, a priority ranking is then determined by production leadership. The time available for production technical personnel to test and implement new products is in short-supply. Products with a low priority ranking are normally excluded on this criterion alone. Even candidate products with a moderately high priority ranking are sometimes postponed from immediate consideration, because of time constraints.

Product proof of concept data

Proof of concept or 'initial' data is required by the supplier to demonstrate product efficacy and to establish potential value. This data may come from a variety of acceptable sources such as university experiments (small scale but detailed), if they are conducted by credible researchers. They may also come from experiments that were conducted in commercial research facilities. Methods must be detailed so that the competence of the experiment can be judged. Experimental design and statistical analysis must be shown. A low Type-I error rate of 5 percent is preferred, because it minimises the risk of declaring a difference in performance, when none exists. The secrecy associated by some systems, requiring that the data be cited as a 'large producer' is unacceptable. The report cannot be independently verified and the competence of the system for testing cannot be judged.

Sow studies are the most difficult to do correctly because 1) there are so many variables to control when conducting the test, and 2) the numbers required to overcome variation for variables such as litter-size is large. Some improvements are possible (eg. +1.5 pigs/litter), but not probable, and must be viewed with caution. The nature of the question asked may also require a test format that is almost impossible to deliver on, except in small university experiments (eg. feed product over a series of reproductive cycles). This issue is discussed further under the experimental design section.

Another problem is with European-based studies and growing pigs. Diet differences are normally significant and this can influence the response. For example, nursery pigs that are fed diets without spray dried porcine plasma and (or) gut active antibiotics are more likely to exhibit a growth response to a product such as an 'essential oil'(OEO). These diet omissions make it more likely that pathogens will cause immune stress (enteric), so that OEO is more likely to produce a growth response through improved pathogenic control. Alternatively, in the less challenging environment of universities and some nutrition company facilities, certain products that might have proven valuable to counter health or water quality conditions in the field might have been missed. For this reason, proof of concept studies must be conducted under diverse circumstances by service providers to understand environmental interactions before approaching animal production companies.

Specific conditions necessary for response

A classic consideration in product response is whether it works under conditions of high or low health status or both (but with different responsiveness). This is a moot point for vaccines. In their case, efficacy and then dose related effectiveness must be determined in relation to the disease. Nursery diet complexity (simple, complex) is an example since diets that are less complex can perform well under conditions of high health. Non-traditional feed additives are emerging for treatment of systemic (eg. dried plasma or colostrum for PCVAD) and enteric pathogens (eg. OEO for

ileitis and hemorrhagic bowel); these have important questions beyond efficacy. The 'timing' of treatment application is also vital because effectiveness may be best when administered in advance of the problem. Does the amount to be used in the feed change with season (eg. summer heat stress reduces feed intake) or if it is added to the water, does it react with pharmaceutical's that may be provided?

Plausible biological explanation

Vendors must be able to provide a plausible explanation or basis behind their product's improvement of performance. If the product protects the animal against disease, then how is that accomplished? There must be science-based rationale that is able to withstand 'mild' critique. However, it is acceptable if a thorough understanding of the mechanism or mode of action is not known. An example can be given for an enzyme that is sometimes used in poultry (ß-mannanase) to improve feed conversion efficiency (FCR) and to decrease the wetness of faeces. It is known that ß-galactomannan (component of soybean meal) induces a gut level immune response (Daskiran *et al.*, 2004). If the proposition was that commercial ß-mannanase binds and cleaves this 'mannan' in soy and thereby prevents stimulation of intestinal immunity, then 'proof' for improved FCR would be reinforced. There is data to illustrate that this is true in poultry and some data is now available for young pigs fed soy.

To be clear, demonstrating that a technology provides a repeatable performance response, with sufficient return over investment (ROI) is immediately more important. Mode of action information is helpful to establish credibility. We also understand the significant financial resources and time required to deliver on in-depth mode of action. For this reason, some understanding of mode of action rather than in-depth understanding is sought.

What about the 'Me Too' products

'Me Too' products are an important part of the product landscape, but they are immediately disqualified from consideration if the company has not done their homework. An example is the OEO products that are emerging from a variety of commercial sources. The proposal that each is equally effective in controlling hemorrhagic bowel in growing pigs or coccidiosis in the sow herd, despite having some differences in chemical composition or purity, is unacceptable. Claiming to be the same as product A and assuming the same efficacy as the 'proven' product is not good enough. We cannot assume that product A = product B = product C in terms of efficacy. Examples of products or technologies that do not perform equally include a) distillers grain by-product from different plants (variation in amino acid digestibility), b) vitamin forms (Natural E versus Synthetic E-RRR), and c) vaccine efficacy (eg. against PCVAD). Inferior 'Me Too' products can reflect poorly on genuinely good products and cause confusion about a product class.

Prospective product testing by the production system

Products that pass the 'screening' stage must now be tested within the production system to determine effectiveness. Each system develops their own method of evaluating new products. An increasing number of systems have or consult with trained animal scientists, who understand experimental design and data analysis. For this reason, some groups use their consulting nutritionist as the technical person to construct and guide proper testing protocols, whether the candidate product is nutritional, medical or genetic. Hanor and several other groups have a pyramid style format for research, beginning with a discovery centre (allows for detailed evaluations with 4-8 treatments) at the pinnacle and proceeding immediately to field test barns and then field test sites.

Five axioms lay the foundation for product testing:

1. Proper experimental design.
2. Suitable replication to overcome normal variation.
3. Reliable data collection.
4. Data collected must be comprehensive enough to answer the questions.
5. Analytical capability (statistical, financial).

Experimental design

The research method can be successively applied in a commercial setting but improper experimental design is a big problem. Experiments need to be simple and sources of variation managed. This requires proper experimental design to control factors (that produce variation) that are outside the control of the researcher, and that are not associated with the product being tested. Adequate replication is important because it gives power to the test. There are 'global' sources of variation, whose effects can be minimised by design, but interpretation often has to be made with them in mind. Major sources include: season (time), pig flow (health status) and site (management confounded with pigs derived from different sow farms). If the test is simple and properly designed so that a conclusion, positive or negative, can be reached then the experiment will be successful.

Trials that are conducted at Hanor research facilities typically involve 2-4 treatments for comparison. Number of treatments is dictated by the number of replications required for key criteria. All treatments must be represented in a block (site, barn, sex etc). Research farms (sow, nursery, finish) are part of our production system, but they are equipped for detailed testing. We find the excellent and practical reference by animal scientist, T. R. Morris (1999), to be very useful in designing experiments, computing the number of replicates (barns, pens, sows) needed per treatment and so forth. Sometimes we collaborate with academia or industry who can provide the personnel to collect more detailed information. This approach has been a very important facet because the outcome is always improved.

Some examples of poor experimental design include 1) treatments that are not equally represented across finish sites (eg. three treatments per eight barn site), 2) three treatments randomly placed over two sites (16 barns total) and with each gender housed in separate barns. As previously stated, sow litter-size (LS) research is difficult to do correctly. Sire can have an impact on LS born (sire age, line, variation within line) but can be controlled by using pooled semen. An example of poor experimental design involved the evaluation of four feed additives that were intended to improve lactation feed intake. Four treatments were applied to 16 farrowing rooms, but a treatment was applied to 4 successive rooms before allocating the next treatment (two rooms fed by one feed bin). The main problem was that treatments were separated in time and because of climate changes, summer room temperature varied by 8-12°F. Limiting the total number of treatments to two (alternating treatment in sets of two rooms) would limit the number of questions that could be addressed but the conclusion would have been more reliable. As it turned out, the outcome was in question.

Number of replicates requires an understanding of variation

Prior to conducting an experiment, a statistical power test has to be computed for each criterion to ensure adequate replication. The advantage of conducting research within a production system is the ability to generate a large number of replications, under good but not pristine conditions. Relatively high variation for a trait (eg. LS born) can be 'overwhelmed' by a large number of experimental units (sows, pens, barns, farrowing rooms). A guide for estimating the number of experimental units to use in reproductive and growth performance tests is presented in Table 1.

Table 1. *Difference between treatments needed for statistical difference, P<0.05*[1]

Sow or Litter Traits	Standard Deviation	100 Litters / Treatment	500 Litters / Treatment	1000 Litters / Treatment
Farrowing rate, %	29.40	11.66	5.23	3.70
Number born alive	3.0	1.21	0.54	0.38
Number weaned	1.4	0.55	0.25	0.18
Litter birth weight (kg)	2.7	1.06	0.48	0.34
Litter Wean weight (kg)	10.20	4.03	1.81	1.28
Wean–Oestrus (d)	4.9	1.96	0.88	0.62
Growth-Carcase Traits	**Standard Deviation**	**25 EU / Treatment**	**50 EU / Treatment**	**150 EU / Treatment**
Pen ADG (g/d)	45.4	36.3	27.2	13.6
Individual pig ADG (g/d)	95.3	77.1	54.4	31.8
Lifetime carcase ADG (g/d)	45.4	36.3	27.2	13.6
Pen FCR (kg/kg)	0.09	0.07	0.05	0.03
Individual pig FCR (kg/kg)	0.30	0.24	0.17	0.10
Finish Pig Mortality (%)	12.41	9.87	6.97	4.03
FOM fat depth (mm)	3.80	3.05	2.03	1.27
FOM loin depth (mm)	5.84	4.57	3.30	2.03
Calculated lean (%)	2.72	2.16	1.53	0.88

[1]Graciously provided by geneticist Steve Jungst, Genus PIC North America; EU, experimental unit (eg. pen, pig, sow are EUs); FOM, Fat-o-meter; ADG, average daily gain, FCR, feed conversion ratio.

Comprehensive data – Sufficient to answer important questions

The type of data to collect depends on what questions you want to answer. However, sometimes the questions that are most important are limited by the data that one is willing to collect. If the questions are right but the measures are 'too simple' then the wrong conclusion can be drawn. This is illustrated nicely using nursery nutrition research, since

dietary components (and the feed budget) have an impact on piglet health. Simple measures such as average daily gain (ADG) and FCR are normally collected, but they are not adequate measures of the impact of diet composition on piglet health. Diet does indeed impact health of humans and animals (British Nutrition Foundation Report, 2002). Mortality may be affected by diet, but this criterion is sometimes misleading, unless the number of replications is greater than that which is normally required to assess ADG and FCR effects. Morbidity in practice can be quantitatively determined by collecting data on the number of pigs that had to be medically treated. Guidelines must be clearly defined and adhered to in order to minimise human variation; treatments should be blind to the person taking the measures.

If the question is to address how the feed or water additive affects weaned pig growth and health, then additional variables must be taken. This was illustrated in a study that involved two dietary components, separately or in combination (animal plasma, steamed oats; Musser, 2004). In this experiment, the number of pigs removed and injected with an antibiotic (due to determined illness) was reduced significantly with plasma, oats and especially by the combination. Treatment also affected the number of smaller pigs at the end of the nursery period. If the conclusion were based on ADG, FCR and feed cost of gain, the merit of extra diet cost was negligible. However, when the cost of antibiotic treatment was added to the evaluation, the more expensive diets (plasma, oats) had the best return over investment. The greater proportion of small pigs from diets without plasma, oats (or both) suggest a further penalty in full value pigs, market carcase weight or both. Another excellent illustration of this concept (variation) was published by Pearce *et al*., (2002).

Competent helping hands

One cannot underestimate the time and energy required to undertake a product evaluation or to implement a successful product into the system. Several groups have provided 'additional hands' and highly skilled minds to help us conduct large scale product tests that could not otherwise have been completed (student interns, university or industry personnel). These have either made an experiment possible (moderate priority but insufficient time to consider) or more detailed.

Exceptions to perfectly designed trials

What if the nature of the question requires a test that cannot be conducted 'perfectly', except under the conditions of small, controlled university experiments? Examples include a) a diet treatment that must be fed to sows for two or more reproductive cycles, or b) special situations involving disease transmission. First, the controlled study must be conducted because that is normally the discovery phase of the project. Second, the large field validation should be conducted to the best of one's ability. Some departure from 'perfect' design can still produce a reliable result and be legitimate, perhaps with an increase in error. However, one can also compromise too much in order to make the study 'real world' and produce an incorrect conclusion.

Special situations require a team approach to deliver the best outcome. This is especially true with health and disease. Graduate trained animal scientists are skilled at experimental design and are often used to design the trial and to statistically analyse the data. In studies that involve disease, or an understanding of the impact of disease on production, a veterinarian's understanding of disease epidemiology is essential in defining the constraints that guide the choice of design. For example, there are two complicating factors to consider when managing disease transmission - 1) pathogen, and 2) epidemiology of that pathogen. Take for example, the disease Ileitis which is caused by the organism *Lawsonia intracellularis*. Ileitis management is especially challenging to study in the field because the organism is easily transmitted and survives the cleaning and disinfection process. For this reason, room (or barn) is more appropriate as the experimental unit than pens within barn when studying the effectiveness of a medical control. Room would also be more appropriate when comparing the efficacy of two antibiotics to suppress respiratory disease. The problem of a within room comparison is that the most effective treatment would reduce the density of airborne respiratory pathogens and present the alternative treatment with less of a challenge.

A potential product for sows may require more than one reproductive cycle to understand the implications of that technology. In that instance, a farm level comparison may be required because of the difficulty and labour required to manage control and treated sows through recurring gestations. A trace mineral complex with an amino acid (eg. Manganese proteinate) might be tested by establishing a pre-treatment response (eg. one year), followed by a period of treatment (equal time period, seasons matched) to determine whether there has been a shift in performance that corresponds to product initiation and withdrawal. This format is not complete until a period of post-treatment is completed to determine if performance returns to pre-treatment level (or differs from treatment performance). This type of 'switch-back' protocol has been used in a number of published experiments involving the effect of hormones on nutrient metabolism (Figure 1). Hagen *et al*. (2000) also provided a good example of how a sow farm site can be used as the experimental unit to study how of chromium tripiconilate affects litter size and farrowing rate. Few are in a position to do this correctly but this trial illustrates the type of control that must be imposed across farms.

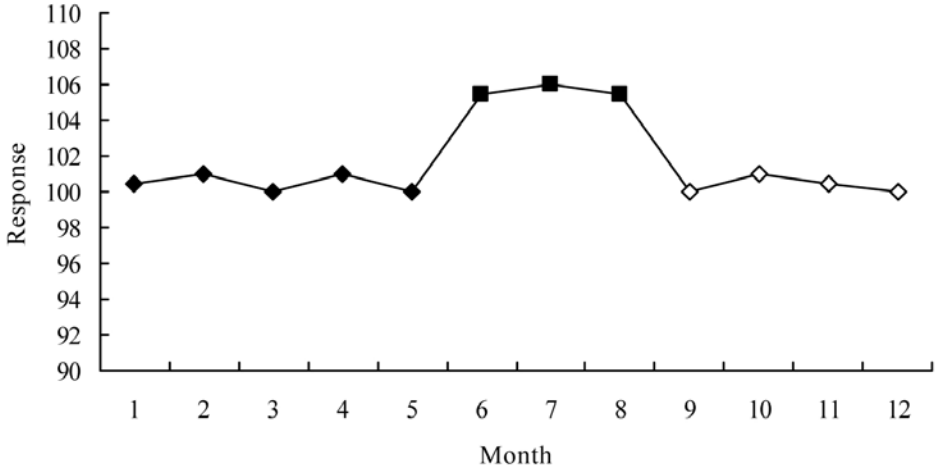

Figure 1. *Example of a 'Switch-back' protocol that could be used on a sow farm where disease transmission may impose a constraint on design. This 'design' involves a period of response prior to test (◆, months to year), in which a stable pattern of response is observed. This is followed by a period of test (■) and a final stage of product withdrawal (◇) to determine if performance returns to pre-test level.*

An example of how the study of a sow farm disease may require an even less conventional approach than presented for Ileitis is with Porcine Reproductive and Respiratory Syndrome (PRRS). PRRS infection, severity and challenge are not controllable. In this case, a switch-back protocol is probably unsatisfactory. A recent example of a 'last resort' approach involved a statistical process control (Campbell *et al.*, 2006). In this trial, the researchers studied the ability of dietary animal plasma to modulate the response of a sow farm to PRRS activity (titres, abortions etc). The probability of drawing an incorrect conclusion is increased but there seemed to be little option for studying a costly problem.

Implementation and subsequent verification of a new technology

Processes to this point, including this section on implementation and performance verification, were summarised in the initial template that guides key decision-makers in Hanor from screening prospective technologies through implementation and performance verification. This guide is also provided to service providers so that they understand what is required before attempting to introduce a technology to our team.

A value is placed on the technology by computing the marginal return over investment (ROI) from internal test data. The decision to implement then depends on its' value in relation to ease of implementation. Technologies that are more difficult to implement correctly require a higher ROI than those that are easy to implement. A decision to implement simply moves us to a large scale test in part of our system. It is introduced into that segment that is best able to deliver on the protocol or that satisfies special conditions for efficacy. We undertake a benchmarking study in which data is collected to verify that the anticipated response is delivered on before the tentatively 'approved' product is incorporated into the production 'tool-kit'. If the evaluation does not yield the anticipated response, implementation is reviewed carefully. Having made necessary adjustments, the data is collected for a financial analysis and decision prior to expanding the use of this technology in our system. Clearly, some technologies are valuable but systems differ in their ability to successfully implement them.

Summary

A structured process is needed to facilitate sound decision-making when considering the plethora of new products that are emerging. The process that has been developed for The Hanor Company has been presented as a template that guides key decision-makers from screening prospective technologies through implementation and performance verification. Each organisation must prioritise needs for the production system and focus on them. Prospective products must align with these priorities or be 'screened' out from further consideration. Products that emerge from the screening process and that are then 'proven' to have value must move past one more obstacle –verification that it works in the field. The axiom that the product must 'always work or it doesn't work at all' is lethal. The differentiating factor for each system is implementation so this is the first place for inspection, when expectations are not met. The major challenge for the vendor is understanding the conditions under which the product is most efficacious.

Persistence - The Secret Ingredient to Any Success

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This is the story of a little Aussie invention that is set to revolutionise the global production of pigs. But it has not been an easy road to success and there are several lessons and insights from this story that are relevant to others considering commercialisation of science.

Successful commercialisation takes much more than just good science and a good idea. Market knowledge, funding, perseverance, vision, excellence in science and above all, a dedicated product team or champion are all pivotal to success. The role of these will be explored as this paper examines the story of Improvac® (Improvac, Pfizer Animal Health, Parkville, Victoria), the world's first vaccine to control boar taint and the first commercially successful immunocastration vaccine for any species. However, like many technological breakthroughs, the development of a vaccine to control boar taint was far from simple.

Introduction

Australia has a proud history of excellence in pig science over many years and has produced many recognised, internationally renowned scientists - Tony Dunkin, Ross Cutler, Roger Campbell, Ray King, Paul Hemsworth, Ted Batterham, Bruce Mullan, Robert van Barneveld, Frank Dunshea and Ian Williams to name just a few who come to mind. This paper will detail another example of Australian pig science leading the way. It is the story of a true team effort and is a great example of Aussie endeavour and an iconic breakthrough that we should all be proud of.

In the telling of this success story the author give praise and recognition where due but also make criticisms where warranted. For this no apology is made.

Just because you have a good idea and some exciting results does not mean that your product or idea will be a commercial success. Take Improvac as a case in point. In 1996, there were some excellent results, proof of concept and proof of value. Boars in Australia were non-castrated and pork quality was poor and inconsistent – the product filled a perceived need. In 1998, the product was first registered in Australia and 10 years later in 2008 less than 10% of the boars killed were vaccinated with this product. This is despite considerable research by Australian Pork Limited (APL) to identify eating quality pathways and to benchmark branded pork against generic pork. For example, in the early 2000's after years of research, APL published a list of the most important items that producers, abattoirs and processors could do to influence eating quality (Taverner, 2004). Sex of the pig was the biggest single on-farm factor that influenced eating quality, and yet until recently little was done to address this issue. In 2003, the group at Agriculture WA submitted a report on experiments to APL demonstrating the superior sensory performance of branded quality improved pork compared to generic pork (Moore, 2003) and yet little action was taken - until recent times. The message here is that just because you see a need and have a product does not mean that others will align or put their hand in their pocket to support your idea or product if it is commercialised. The best products will never be used if the need is not recognised by the whole industry and there is cooperation and goodwill to instigate change.

Unfortunately for the quality of pork in Australia (and New Zealand), and the success of this little Aussie invention, the pig industry has had its head firmly in the sand until recently on the issue of eating quality. But there is hope - several groups have recently moved into branded quality improved pork marketing and as a result the use of Improvac has increased. Penetration rate of total boar production in Australia peaked eight years after launch in 1998 before decreasing during the industry downturn. Finally this year sees an increase in sales as key producer groups finally recognise that eating quality is a serious issue and instigate measures to at least control the sex of the pig.

Developed in Australia in a partnership between Government research scientists and an animal health vaccine provider, Improvac was first registered and released in Australia and New Zealand in 1998 by CSL Animal Health where it has been used with limited success for the past 11 years. Improvac is now being progressively introduced around the world and is currently registered in 53 countries, including the European Union. It is in the process of registration in all other major pig producing nations. This is Improvac's story.

What is Improvac?

Improvac is a vaccine to control boar taint. It is a safe, effective alternative to physical castration to control boar taint. As such the boar is raised as a non-castrate and thus benefits for most of its productive life from the

superior growth performance and carcase quality of boars. The vaccine works just like a conventional vaccine by stimulating the pig's immune system to produce natural antibodies. In the case of Improvac the antibodies are against the pig's endogenous gonadotrophin releasing factor (GnRF), a messenger compound released by the hypothalamus. Neutralization of the pig's GnRF blocks testicular function and hence the production and accumulation of boar taint substances. This temporary immunological castration has a number of benefits for both castrating and non-castrating markets (Table 1).

Table1. *Benefits of castration in different markets*

Benefit	Castrating markets	Non-castrating markets
High eating quality – no taint	No change	Yes
– higher marbling	No change	Yes
Improved feed efficiency	Yes	No change
Increased growth rates	Sometimes	Yes (following the second dose)
Leaner carcase	Yes	No slightly fatter than boars
Improved welfare	Yes	Yes
Decreased pre-weaning mortality	Yes	No change
Less manure and lower greenhouse gases	Yes	No change

While Improvac is indeed a novel and unique product, this in itself presented significant hurdles to registration and adoption in many markets. Anything that is fundamentally new will always pose difficulties in overcoming the status quo. This is where persistence and industry knowledge are vital to success.

Why is an alternative method of taint control needed in the pig industry?

The primary reason for castration of male pigs is to eliminate boar taint. This offensive smell/taste is present in the meat of many sexually maturing male pigs and makes it unacceptable to most consumers. Boar taint can be noticed when the pork is heated, with the smell said to resemble urine, musk, perspiration, faeces or onion (Bonneau, 1982). In most countries controlling boar taint is an absolute necessity for pork producers with studies showing that up to 75 percent of consumers are sensitive to its odour. Throughout the world 95-98 percent of the male pigs born are castrated at an early age, frequently without anaesthesia simply to control boar taint.

Boar taint is caused by the presence of two substances:

- Androstenone, a male sex pheromone produced in the testes;
- Skatole, a metabolite of tryptophan (amino acid) produced in the hindgut by intestinal bacteria.

Both androstenone and skatole are highly fat-soluble and their concentration in the meat from some boars can be extremely high. These are the animals that consumers detect as tainted. As the boar begins puberty, at around 13-14 weeks of age, there is a surge of testosterone and androstenone production, which leads to an increase in androstenone in the fat.

Skatole is more complex, because although androstenone is produced only in boars, skatole is produced in both male (intact and castrated) and female pigs. However, the fat concentration of skatole is higher in boars than in either castrates or gilts. The reasons for this are most likely related to the presence of male sex hormones and their effect upon the liver's ability to clear skatole from the blood stream.

For non-castrating markets like Australia, New Zealand, the United Kingdom, South Africa and parts of Spain and Portugal, the fact that pigs are slaughtered after the commencement of puberty means that there will always be a proportion of pigs that have concentrations of androstenone and skatole above the sensory thresholds (Hennessy *et al.*, 1995; Salvatore *et al.*, 1995; Dunshea *et al.*, 2001; Mullan, 1997). This represents a serious and insidious decrease in the quality and consistency of pork in these countries. Even with pigs of 70-80 kg live weight, or as young as 15-16 weeks, a small proportion will be highly tainted. Indeed, as mentioned above, the APL funded eating quality research program identified that sex was the single biggest factor that was under direct producers' control that could impact on eating quality. It is a pity that major retailers did not take notice of this and act on it. Perhaps if the Top Group from South Australia and their key customers acted on this information we may have seen an increase in demand for pork

in Australia. Thus, it is little surprise that fresh pork consumption in countries like Australia and New Zealand is low and has not really increased significantly in recent year despite strong promotion and a substantial price advantage compared to beef and sheep meats in the retail arena.

However, in Australia at least, it is pleasing to see recent efforts by some producer groups such as Perth Pork Centre (PPC) and Rivalea Australia Pty Ltd, to name just two, making concerted efforts to increase quality and consistency of supply of pork into the retail arena.

Current control of boar taint - Physical castration

As mentioned, physical castration is by far the most common method of controlling boar taint with an estimated more than 95 percent of the world's male pigs currently managed using this procedure. This, in essence, removes the problem before it arises. However, there are major risks involved in the process, with potential complications such as hernias, infection and even death. The procedure is often performed without anaesthetic, raising issues of animal welfare. Castrated pigs have also been found to convert feed less efficiently and produce a carcase with higher fat and less meat (EFSA Report, 2004; Dunshea *et al*., 2001).

Importantly, and contrary to popular opinion, physical castration is not 100 percent effective at controlling boar taint (Nederveldt *et al*., 2006). Although efficacy is very high, there will be a small proportion of cryptorchid and intersex animals in every pig population (usually in the range of 0.1-0.6 percent for intersex and 0.3-0.8 percent for cryptorchids) which will be missed by physical castration. Yet these pigs are known to be potential sources of high levels of boar taint. Significant concentrations of skatole may also be occasionally found in pigs other than intact males.

An alternative solution – vaccination

The search for alternatives to physical castration has been driven by prime three considerations:

1. A desire to capture the natural metabolic efficiency of boars and improve production efficiency (ie. Profits).
2. A desire to find a method of boar taint control that avoids or minimises the animal welfare problems inherent in physical castration.
3. A desire to produce pigs in a more environmentally sustainable manner.

History of vaccination against boar taint

The concept of using vaccination to control gonadal function, and hence in the male pig, boar taint, is not new. Several research groups over the past 20+ years have attempted to develop vaccines against various components of the reproductive axis of both sexes. These attempts have frequently been done with the aim of fertility control which by necessity requires a reasonable duration of immunity – perhaps at least 6 months to be commercially viable for most species. However, many groups have also attempted immunocastration for boar taint control in pigs – this theoretically should be easier since only a short duration of immunity or less than 6 months is required.

While many of these attempts have been experimentally successful (Shenoy *et al*., 1982; Caraty and Bonneau, 1986; Awoniyi *et al*., 1988; Dunshea *et al*., 1993; Bonneau *et al*., 1994; Oonk *et al*., 1995; Zeng *et al*., 2002) and have demonstrated proof of principle, none have been successfully commercialised. In part this was because of inconsistent antibody titres or the necessity to use potent adjuvants, with resultant site reactions, in order to elicit a consistent immune response.

If the concept of immunocontraceptive vaccines is not new, why has this Australian technology been successful where others have failed? What can we learn from the story? Why have these excellent research groups failed while a small Australian outfit has succeeded. In my opinion the reasons are simple – faith and perseverance by a team of dedicated true believers and some good old fashioned hard work and good luck. Some research groups perhaps lacked commercial inputs – they had good science but no or limited commercial backing and certainly not the "true believer" type support that was offered by CSL. Some lacked efficacy when combined with commercially viable adjuvants – the initial research was with oil based adjuvants which present some difficulties in registration (Oonk *et al*., 1995). Some were perhaps the victim of poor timing and did not have the market conditions favourable to commercialisation.

There has been one other reproductive vaccine commercialised, Vaxstrate (Websters Animal Health) for use in free range female cattle in Northern Australia (Hoskinson *et al*., 1990) but for various reasons it was largely unsuccessful. Vaxstrate, comprised a conjugate of ovalbumin and a Luteinising Hormone Releasing Hormone (LHRH) peptide, presented in an oil emulsion adjuvant. It was sold for use as an immunospaying vaccine for extensively grazed female cattle in northern Australia. It was launched in the late 1980s and withdrawn from the market in 1996 due to poor

sales, resulting mainly from being highly reactogenic (about 40 percent of animals with aggressive abscesses) and poor efficacy and duration of immunity in the field. The two doses required with Vaxstrate prevented its wider use, as this did not fit well with the single annual mustering of cattle in northern Australia (Meeusen *et al.*, 2007). Vaxstrate is a good example of the market driving the need for a product but the product not meeting market specifications – a must for commercial success. As a result, beef producers reverted back to surgical spaying, even with the associated welfare implications.

So others have failed while we have succeeded. To fully understand this we need to examine the story from initiation to commercial success. Improvac was first commercialised in 1998, however, that is not the beginning of the story. As with many revolutionary products, there were many set-backs and problems to be ironed out along the way.

History of Improvac

The research program, from which Improvac was derived, began sometime before 1987 with collaboration between the Australian cattle industry's Meat and Livestock Council and the Victorian Department of Agriculture at Werribee. The main focus at that time was to develop a vaccine for use in female cattle that were destined for live export – an alternative to Vaxstrate which did not meet the ideal profile of the industry.

In January 1987, with the Meat and Livestock Council funded research completed, CSL Animal Health and Daratech Pty Ltd (the commercial arm of Agriculture Victoria (AV)) formed a joint venture to further continue the research. CSL Animal Health at that time was still wholly government owned and was one of Australia's leading animal health manufacturers and suppliers. In the joint venture, CSL manufactured candidate vaccines and conducted laboratory animal testing, while AV did the endocrinology research and some of the large animal testing. In mid-1990, Daratech withdrew from directly funding the joint venture but continues to sub-contract the services of AV to CSL.

In mid-1988 the lead scientist from AV suddenly resigned and the author was invited to co-lead the project. At that time I was head of the endocrinology department at AV at the Victorian Institute of Animal Science, Attwood (VIAS).

Because of CSL's commercial strength in companion animals, the focus soon shifted away from cattle to companion animals. CSL continued to manufacture and formulate experimental candidate vaccines with various combinations of antigen and adjuvant looking for the ideal combination of strength and duration of immunity and low injection site reaction. AV did the analytical assays and ran most of the companion animal experiments. One of the issues was the duration of immunity – the ideal profile for a commercially viable vaccine was a combination of a high percentage of responders in the target animal, the desired duration of immunity (generally 6-12 months after the full course of two doses) and low or no injection site reaction to the adjuvant. It was easy to satisfy two of these requirement but difficult for all three.

Because of AV's strength and excellence in pig research, they soon identified an opportunity for a short acting efficacious vaccine in the pig industry. Even from that early time the drivers for AV were an international opportunity to stop castration and increase production efficiency, reduce environmental damage and improve animal welfare. They also saw an opportunity in Australia to control boar taint which at that stage the industry totally denied was as issue. Senior management at VIAS agreed to fund the pig research program and so we approached CSL with the aim of them manufacturing candidate vaccines and for VIAS to conduct the research.

When VIAS approached CSL in the early 1990s about a pig vaccine, it became evident that CSL had also had similar thoughts about a pig opportunity. However, there was a conflict of approach. The VIAS concept was for late vaccination and thus duration of immunity was not an issue. We wanted to leave the animal as a fully functional boar for as long as practical to gain the production and environmental benefits and then use a short term immune response to control boar taint. CSL's approach was more simply as an alternative castration method for welfare benefits and so they were advocating a longer duration of immunity where vaccination was given early in life as a true replacement for castration. Many arguments ensued between CSL's "pure" scientists, their "MBA" qualified scientists and the VIAS staff, who were perhaps more applied and industry focused. Compromise is often the answer to conflict and so a comparative trial was run looking at the efficacy, in terms of immune response and testosterone levels, comparing early and late vaccination. Needless to say the VIAS approach won the day. The lesson here: Do not let your commercial partners totally dictate the terms as if they are the only ones who know best. As a researcher, if you want to be involved in commercialisation and you believe you have an industry perspective stand your ground. Views with an industry perspective are often more focused than research and development groups within commercial companies.

After a successful "design study" to determine the approach – short term vaccination versus longer term vaccination – a full pig research program was run in parallel with the dog and cat research program. In late 1992,

the dog research trials had proved successful and the team had identified a formulation that gave a high percentage of responder animals, good duration of immunity and appeared to have low injection site reactivity. The CSL/VIAS team were poised to begin the "development" phase leading to a registration submission. Then someone in the team gave a dose of the vaccine to their pet dog. The dog displayed a strong pain response at the injection site and became depressed and lethargic for several days. This adverse reaction was then verified in several other pet dogs. Clearly the prospective formulation was not commercially viable. This reaction had not been detected in our experimental dog colony despite regular individual daily observations. The trial dogs were so excited to see the researchers each day that their excitement overcame their depression and pain. Our experimental unit had masked the reaction. The lesson here is to ensure your experimental model is truly representative of real life, otherwise you risk disaster.

Faced with this set back, CSL decided in September 1993 to abandon their involvement and withdrew all funding and support for the immunocastration research program. This was to have included the supply of vaccines to the pig program which VIAS had been running in parallel. But the VIAS team were persistent and refused to give up the dream. They approached AV management to continue the funding for the pig program and then they approached CSL to gain their commitment that they would reinvest in the development of the pig work if VIAS could demonstrate proof of concept. As they were also "true believers", CSL Animal Health agreed and supplied VIAS one last batch of experimental vaccines.

VIAS continued the pig research program alone and by mid-1994 had some exciting and positive results demonstrating high efficacy in suppressing boar taint in late vaccinated animals. To ensure that they were reading the market correctly, VIAS conducted some market research to verify the need for an alternative to castration and to check the product profile. Coupled with the new research findings and the market research, they presented a plan to CSL for moving forward. True to his word Dr Hugh Middleton, General Manager, CSL Animal Health, decided to reinvest and proceeded from the discovery phase to the development phase of the pig vaccine.

The necessary efficacy and safety trials to support a registration application were planned with Bunge Meat Industries (now Rivalea Australia Pty Ltd) and approvals sought from the Australian Pesticides and Veterinary Medicine Authority (APVMA) and appropriate ethics committee. By early 1995 we had the full development program mapped out and were ready to commence. Then at this late stage, CSL decided to check the cost of production only to find that the cost was over $US3.00/dose. Why they did this at such a late stage I do not know. The problem was that the chemistry they were using to prepare the vaccine was very inefficient and the majority of the GnRF analogue and carrier protein were being thrown away. Faced with this news, CSL Animal Health reluctantly decided, for the second time, to withdraw all support and funding from the immunocastration program in March 1995. The lesson here: Don't trust – challenge – commercial companies might know their business but they can be wrong and do make mistakes. If an individual or team really want to commercialise an idea then you will need a true product champion.

And that might have been the end of the story, had it not been for the determination of the VIAS research team who would not give up the dream. At the time that CSL withdrew their full support, VIAS had an organic chemist working in the endocrinology laboratory who had just finished her PhD, Julie Simons and an immunologist who had just completed his research project, Ian McCauley. Both believed that there had to be an alternative, more efficient method of preparing the antigen that could reduce the costs of production to a viable level. VIAS decided to continue funding for one last attempt to identify an efficacious, cheaper alternative formulation provided CSL agreed to proceed with development if they were successful. In addition, VIAS consulted the peptide manufacturer, Auspep, to provide some alternative views on manufacturing options.

So armed with a plan, some funding and eager staff, VIAS again approached CSL to obtain their commitment that if VIAS could find an alternative chemistry and reduce the costs of production to CSL's target that CSL would re-invest in the pig development plan. Targets for costs of production and manufacturing constraints were agreed and in April 1995 Julie and Ian set to work.

By August 1995 the target had been reached. A new test-tube scale formulation had been identified that was efficacious and met the CSL requirements for costs of production and manufacturing requirements. VIAS presented this exciting breakthrough to CSL, and true to their word, CSL decide to reinvest in development and registration of the pig vaccine.

The plans for the necessary efficacy and safety trials to support a registration application were resurrected and new approvals sought. VIAS was contracted to conduct the animal testing, analytical testing and report preparation. But we were still not ready to begin. What VIAS had presented to CSL was a "rough and ready" test tube scale manufacturing chemistry. The method had not been validated, needed scaling up to pilot batch size and needed a range of validated in-process and final product quality control (QC) tests developed. At around that time Dr John Walker had joined CSL

and he was responsible for taking the small unvalidated test tube manufacturing method and transforming it into the current validated manufacturing method used today. As well, he led the development and validation of all the quality control (QC) tests used in production. Improvac would not have been possible without his expert input and guidance. While John Walker was scaling up and validating the manufacturing process at CSL, VIAS, under the guidance of Ian McCauley, began work on obtaining National Association of Testing Authorities (NATA) accreditation for the analytical tests and for the conduct of Good Laboratory Practice (GLP) research trials so that the trial results could be used to support registration in other countries. This was the first time GLP accreditation for analytical assays and GLP compliant trials had been achieved by any AV laboratory.

Once the pilot scale vaccines were available and NATA accreditation achieved, the pig trials began at Bunge, Corowa. We appointed a full time person to work at Corowa for around 10 months to oversee the experiments and the CSL and VIAS team spent many days at the Corowa piggery and abattoir. In approximately 18 months of hectic work the QC tests and validation and the animal trials were completed and the registration dossier was submitted to both the APVMA and New Zealand Ministry of Agriculture and Forestry (MAF) in June 1997.

Submission of the dossier to the APVMA was not the end of the VIAS battles. While the dossier was under review by the APVMA, the head of CSL, Dr Brian McNamee engaged a high profile pig industry figure (who was his neighbour) as a consultant to review the opportunity for Improvac in Australia. The consultant strongly recommended to Dr McNamee not to launch in Australia. He advised that the industry did not see boar taint as an issue and as they already gained the inherent benefits of boar production they would not need Improvac. He advised that we focus on the bigger overseas castrating markets. However, the VIAS and CSL Animal Health "true believers" did not accept the consultant's recommendation and argued that we needed to gain field experience with the technology to strengthen our ability to penetrate international markets – if and when we gained registration. And so CSL's Animal Health division decided to launch in Australia and New Zealand. Had the team accepted the consultant's recommendation, it is probable that Improvac would not be available today. CSL certainly were not able to register the product internationally and without some local success and experience in the Australian market place the technology would have been less attractive to multinational companies, such as Pfizer. The real benefit from launching in Australia, where it is true that Improvac has not been a strong success, was what we learnt about the implementation process and market acceptance that strengthened our technical knowledge and ability to deliver successful vaccination programs under any management conditions.

In November 1998, registration was granted by both regulatory agencies – a true landmark – the world's first vaccine technology for the prevention of boar taint was registered in both Australia and New Zealand. At this time, David Hennessy and VIAS parted company after 25 years and I joined CSL to manage the commercialisation of Improvac in both Australia and New Zealand.

From 1998 until 2004, Improvac remained a little known antipodean curiosity until Pfizer acquired the animal health division of CSL, in May 2004. Having undertaken significant analysis into the safety of the product, Pfizer was satisfied in putting its name behind the revolutionary vaccine. And in realising the international potential of this new technology, Pfizer set about registering the vaccine in swine producing countries around the world. The lesson here is that size can matter depending on needs – locally focused, dedicated companies with limited resources versus well resourced experienced multinational companies. Many large multinational animal health companies, including Pfizer, had tried to develop immunocastration vaccines and had all walked away without success. Their research and development groups are so pushed for new products that when they face hurdles and setbacks, they often drop the project and move on to the next. They lack the dedication and drive that can be found in smaller groups determined to breakthrough. In this case a small focused dedicated team, with a true product champion in the VIAS crew, were able to succeed. However, when it came to resourcing and power to take the local product to the international markets the larger multi-national was able to succeed where the smaller local company would have struggled.

One of the things that Pfizer did very well at an early stage after obtaining the technology was to establish a commercialisation team across multi-functional areas of the company to lead the development, with inputs from regulatory, production, marketing, technical, legal, market research and sales divisions. One common issue with large multinational companies is that their size and bureaucracy can make decisions more difficult and can hamper action. One advantage of CSL was its smaller streamlined size and it was able to react fast and make decisions. It also meant that the core team was more stable and provided they were true believers the project would be kept alive. Thus in choosing a commercial partner to work with, research groups should consider what they are likely to need. For products requiring significant investment in registration and market preparations, the strength and resources of large multinationals is definitely an advantage. Compared to the costs to discover, the costs of development and registration can be very high. Discovery certainly has lower investment and as the product moves into development and registration the investment

costs also increase, especially if the product is used in the food chain – this is where size can be of value. However, for other situations the smaller more nimble local company is desirable. In the case of Improvac, the success is also attributable to having access to both models at strategic times in the development.

Conclusions

Improvac is now being progressively introduced around the world and is currently approved for use in 53 countries, including the European Union, most of Latin America and several countries in Asia. Just over 20 years since the inception of the initial research program, almost 17 years since the pig vaccine program began and just on 11 years since the launch in Australia and New Zealand, Improvac is poised to become a revolutionary product in all major pig producing nations. A true success for Australian pig science that we should all be proud of. The success is firstly due to a team of true believers who saw the vision, and secondly, had the perseverance to make it real. The team had a vision and they never gave up.

Symposium Conclusions

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The three papers comprising this symposium have successfully detailed a number of important considerations that need to be addressed in the commercialisation process, whether that be in the details around embarking on research which may result in a commercial product, when investing in the next stage of development of a product or technology identified from research that may have some commercial value, or when that product or technology is being evaluated for implementation by an end user. This symposium demonstrated that there are many vital steps that all have to be successfully negotiated in order to take a good idea through to a good product that will actually be adopted routinely by an end user and that this process can be a lengthy one. Unless all parties in the discovery through to delivery path are fully prepared for the technical, practical, legal, physical, regional, institutional, financial and sometimes emotional obstacles that may appear, the chances of successfully commercialising a product or technology or service will be limited.

The symposium has provided valuable insights into the decision making process that is undertaken by each of the stakeholders along the path to adoption of an idea. Wilson (2009) identified that in terms of financial gain, it is rarely the public research body that enjoys the lion share of the success of a commercialised product. This outcome is not a disincentive to public funding organisations, but rather the data presented by Wilson (2009) clearly showed that that the return on investment for these organisations has averaged 11:1 and there were measurable economic, social and environmental benefits for the community as a result of the investment. These are very promising signs for the future of Cooperative Research Centres in Australia.

Boyd and Donovan (2009) presented a true and enlightening account of the evaluation process a large pork producer employs to assess whether a technology or service should be implemented. The information in this paper has relevance to all end users as well as the suppliers of products and services. Just because a product meets a need and/or is financially beneficial is no guarantee that the product will gain widespread acceptance by the end user. The paper by Boyd and Donovan (2009) also provided some timely advice for the evaluation of the so called "Me Too" products – those products which are similar to the market leading products but may not have the same technical credibility.

The final paper in the symposium by Hennessy (2009) provided a 'warts and all' insight into the real struggles that occur in trying to commercialise a product. There are many valuable take home messages in this paper for all those that are associated with the Australasian Pig Science Association (APSA), whether they are new graduates embarking on a career or late career scientists. Recognition by more people than just the 'true believers' of the ramifications of the major and minor issues that can occur along the path from observing a problem to getting wide-spread acceptance of the solution is vital for success.

This symposium has maintained the high quality and relevance to current issues that APSA symposia are recognised for. It is hoped that future volumes of Manipulating Pig Production will see many more papers reporting successful science that also results in successful commercialisation outcomes in a timely manner as a result of the contributions to this symposium on 'strategies for successful commercialisation of pig research'.

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