Agri-Food and Biosciences Institute

Research to drive sustainable pig production

Proceedings of a Conference held at AFBI Hillsborough on 10th November 2015

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Finally the authors are grateful to all who have been involved at the coal-face of data collection and animal care across the studies reported here.

Their diligence, patience, technical ability and care of the animals is much appreciated.

The Communications team in AFBI are also sincerely thanked for all their efforts in association with this seminar and booklet.

For more information on any of the papers presented or the pig research programme at AFBI Hillsborough, please contact:

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Introduction

Welcome to the AFBI 2015 Pig Conference

The Northern Ireland Pig Sector is an important part of the local agri-food industry, accounting for around 7% of gross industry turnover for the food and drinks sector in 2014. In recent years, the Sector has gone through a period of rapid contraction and restructuring, resulting in a significant reduction in the number of pig farms, but also a major increase in average business size.

One of the key drivers of profitability in the pig industry is technical efficiency, and in particular, feed use efficiency. In this context, it is essential that Northern Ireland retains a strong integrated research programme to ensure that the local industry has access to the latest advances within the areas of production, nutrition, welfare and meat quality. The integrated approach within the AFBI pig research programme ensures that the effects of the introduction of new technologies and innovations are evaluated on the productivity and welfare of the pig, through to the quality of the carcass, the profitability of production and the eating quality of the pork we eat.

Today's conference has been specifically designed to highlight results of current research from this integrated programme. The objective of the conference is to ensure that results of research undertaken at the Institute are disseminated as widely as possible to local pig producers. The conference provides an indepth insight into the current research programme at AFBI, as well as providing an excellent opportunity for those closely involved in the industry to comment on our current research programme and to suggest priorities for future research.

The pig research programme at AFBI is primarily funded by the Department of Agriculture and Rural Development for Northern Ireland (DARD). However we also acknowledge the very significant practical and financial support from the wider pig industry.

It is our objective that today's conference will provide an opportunity to discuss results of the latest research work undertaken at AFBI and that the information presented will assist pig producers, and the entire industry in Northern Ireland, to move forward into a more profitable future.

Sinclair Mayne
Sustainable Agri-Food Sciences Division,
Agri-Food and Biosciences Institute (AFBI)

Overview of Pig Research Programme at AFBI Hillsborough

The cost of production remains a key challenge to the pig industry, however, an additional 'positive' challenge in recent years has been the management of highly prolific sows and their resultant very large litters.

As such key themes across the research programme at AFBI Hillsborough in recent times have included sow productivity as well as nutritional and managerial strategies to maximise finishing pig performance, especially when using low soya diets.

With regard to sow productivity, it is a pleasure for me to be a part of the supervision team of three highly capable PhD students working in this area, two of which will present their work today. These PhD studies on sow productivity are being funded by DARD, DAFM/Walsh Fellowship and Leeds University and the leadership and input provided by Dr Peadar Lawlor from Teagasc, Dr John O'Doherty from UCD as well as Professor Helen Millar from Leeds University is gratefully acknowledged within this collaborative effort to provide guidance in the area of 'sow and piglet nutrition and management'.

I am also delighted that Dr Giuseppe Bee from Agroscope, Switzerland has agreed to present his work in the area of 'managing runt piglets'. Giuseppe has a wealth of knowledge in the area of pig production and he is currently working within the EU FP 7 Project – ECO FCE which AFBI Hillsborough are also heavily involved in.

Other new areas and collaborations have included work on wet feeding with JMW Farms Ltd and Rektify Ltd as well as with AB Vista, QUB, HGCA, Cargill and JHI to increase our knowledge on the nutritive value of rapeseed meal and the safety of DDGS. Results from these pieces or work are presented as posters and short papers in this booklet.

In addition to these new collaborations above, we are very grateful for the continued support from our 'old faithful' collaborators and funders, namely Pig Regen Ltd (NI pig levy body) as well as our long standing research partnership with John Thompson and Sons Ltd and Devenish Nutrition and DARD.

Whilst pig production related research takes place at the AFBI Hillsborough site, the AFBI Stormont site also plays a significant role in serving the local industry. Aside from the statutory analysis the Veterinary Sciences Division at Stormont are undertaking a large research project in the area of 'Pleurisy'. Recent findings from this work will be presented.

With such a broad and varied programme of information, it is sincerely hoped that the findings from research reported at this conference will be adopted by the industry or will spark initiative to make changes which will improve the sustainability of pig production.

Elizabeth Magowan
Project leader of Pig Systems Research
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Biographies

Kathryn Reid


Kathryn Reid

Kathryn Reid is a PhD student on the OPTIPIG project which aims are to investigate methods of optimising annual sow output by increasing the number of viable piglets born alive and minimising pre-weaning piglet mortality through sow nutritional strategies. This project is a collaboration between AFBI, Teagasc and University College Dublin. Kathryn is currently based in Moorepark, Co. Cork and will undertake the majority of her research on a commercial farm in Birr, Co. Offaly. Her supervisors include Dr Elizabeth Magowan of AFBI, Dr Peadar Lawlor and Dr Keelin O'Driscoll of Teagasc and Prof. John O'Doherty of UCD. Kathryn graduated from Queens University with a 1st class honours in Agricultural Technology in 2014.

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Dr Giuseppe Bee


Dr Guiseppe Bee

Dr Giuseppe Bee works at the Agroscope Institute for Livestock sciences in Switzerland. Giuseppe's main area of work is currently focusing in Challenges in entire male production: nutrition and boar taint; Effect of prenatal and early postnatal development on growth performance, carcass characteristics and meat quality; Effect of swine production systems on muscle fiber distribution in swine determined by histochemistry and SDS-PAGE and their effects on meat quality. Giuseppe delivers undergraduate teaching at AgroScope in the areas of animal nutrition and physiology as well as pig science and he has supervised over 10 PhD students. Giuseppe has served on a number of committees including the scientific committee of the Euro Fed Lipid Congress, the Editorial board of Journal of Animal Science, the Editorial board of ANIMAL (Product Quality, Human Health and Well-Being), the PIG COMMISSION of the EAAP and he was the Chair and vice-chair of the Meat quality and Muscle biology scientific committee of the American Society of Animal Science.

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Aimee-Louise Craig


Aimee Louise Craig

Aimee-Louise Craig is a second year PhD student studying at AFBI, Hillsborough and Queens University, Belfast under the supervision of Dr. Elizabeth Magowan and Dr. Niamh O'Connell. She graduated from Queens University in 2013 after completing a degree in Agricultural Technology with Professional studies. As part of her placement year, Aimee came to the pig research unit at AFBI Hillsborough and became involved in pig research, particularly with young pigs. From that placement she completed her final year dissertation which focused on creep feeding of piglets. The focus of her current research, which is a DARD PhD scholarship, is to improve piglet lifetime performance through improving weaning weight through sow lactation nutrition and also management of runt pigs during the nursery period.

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Sam Smyth


Sam Smyth

Brought up on a pig farm in Co Antrim, Sam was educated at QUB and qualified with an Honours degrees in Biochemistry and Agricultural Science, specialising in Pig Nutrition. With over 20 years' experience in Monogastric Nutrition, feed milling and research and development, Sam has recently returned to John Thompson & Sons Limited in Belfast as a Business Development Manager. Sam started his career with John Thompson and Sons in 1995 as a trainee nutritionist and held a number of positions including Pig Nutritionist and Quality Assurance Manager. His current role is to support the company's vision of feeding innovation. Through collaborative research & development partnerships, alignment with research institutions and commercial partners throughout the supply chain the aim is to fast track new products & nutritional innovations into the market place that deliver customer focused commercial outcomes.

Previous to this Sam spent 10 years with Devenish UK & Ireland, where his most recent role was Director of Poultry. In that role he was responsible for all technical, commercial and research and development aspects of the company's local poultry business.

He also spent some time working for NIEA as an IPPC inspector, working in the areas of intensive pig and poultry farming, feed milling and slaughtering and rendering.

Biographies

Natalie Brush

Natalie Brush

Natalie Brush is currently a final year PhD student at Queen's University Belfast under the supervison of Dr. John McKillen (AFBI) and Dr. Ultan Power (QUB). Natalie graduated from Queen's University Belfast with a BSc (Hons) in Biological Sciences in 2012 and completed a PgC in Molecular Basis of Disease from Staffordshire University in 2013.

Natalie secured a DARD PhD scholarship to complete a project entitled "Investigation into the extent of pleurisy in pigs in Northern Ireland and the associated management and disease risk factors." She presented her findings at national veterinary meetings and was awarded best poster in 2014 for her presentation at The Association for Veterinary Teaching and Research Work (AVTRW) annual conference.

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Dr Violet Beattie

Dr Violet Beattie

Dr Violet Beattie graduated with a PhD from Queen's University Belfast. Before joining Devenish, Violet was a lecturer in Queen's and was head of pig research in the Department of Agriculture and Rural Development Science Service. She has spoken at scientific conferences across the world and has published over 70 peer reviewed papers. Violet has sat on numerous committees and is a previous chair and board member of two non-departmental public bodies. She was nominated a Fellow of the Royal Agricultural Society in recognition of her services to the pig industry. Currently Research and Technical Services Manager, Violet heads up research in nutrition, production and product development in the pig sector.

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Dr Elizabeth Magowan

Dr Elizabeth Magowan

Dr Elizabeth Magowan leads the monogastric research programme at the Agri-Food and Biosciences Institute, Northern Ireland. Elizabeth completed a PhD in dairy nutrition and subsequently joined AFBI as a pig research scientist. Elizabeth has developed the AFBI pig and research programme in recent years whose main aim is to optimise pig production performance through management and nutritional strategies whilst reducing their environmental impact. Over the past 11 years Elizabeth has gained much experience working in industry/academic collaborative studies and has presented her work across the UK and at international conferences as well as publications in journals. A key focus of Elizabeth's work in AFBI has been the optimisation and understanding of feed use efficiency. Aside from managing a wide portfolio of research projects, Elizabeth is currently a council member of the British Society of Animal Science, is heavily involved in the formation of a UK Centre of Excellence for Livestock and is deputy coordinator of an EU FP 7 project entitled ECO FCE.

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Optimising annual output per sow by increasing the number of viable piglets born alive and minimising pre-weaning mortality through sow nutrition

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Key Messages:

- L Arginine, and especially L Carnitine, appear to be beneficial supplements to improve sow reproduction and piglet viability. However, success is dependent on timeframe of gestational supplementation with periods between early/mid gestation (~28days) and farrowing being most promising.
- The literature is highly inconsistent with regard to the effect of feed allowance during gestation. No clear message can be drawn but there is a major need to investigate this area with large numbers of animals which are highly prolific.

Introduction

Tight profit margins and societal pressure are extremely strong drivers to improve the efficiency of pork production. In an attempt to increase output per sow (number of pigs produced per sow per year), changes to the genetics of modern pigs have resulted in significant increases in litter size compared with wild ancestors (Campos *et al.*, 2012). However large litters can result in problems for both the sow and piglets with regard to health and production performance. The most significant issues for piglets include low birth weight and greater within litter variation, as well as poor vigour (Lawlor *et al.*, 2002) . These problems can have a negative impact on subsequent production performance.

National and international sow output

The components of output per sow are ovulation rate, embryonic and foetal survival, numbers born alive, numbers weaned per sow per year, number of pigs produced per sow per year and the number of litters per sow per year (Lund *et al.*, 2002). In Ireland, sow output has increased significantly in the last decade from an average of 21.6 pigs per sow per year in 2003 to 24.5 in 2013 (+2.9) with the top 10% of farms having an output of 28.2 pigs per sow per year in 2013. It was found that these increases were obtained primarily through an increase in the number of piglets born alive as well as lower pre-weaning, weaning and finishing mortalities (O'Driscoll and Lawlor, 2014). However, compared to our European competitors sow output in Ireland is low. Although improving, Ireland is also the least competitive in terms of the number of pigs born alive. However pre-weaning mortality in Irish herds is superior to that of other European countries (Table 1). In fact Denmark, which has the highest number of piglets born alive, also has the highest pre-weaning, rearing and finishing mortalities.

Table 1: Comparison of sow performance between Ireland, Denmark, France and The Netherlands (INTERPIG, 2014)

	Denmark	France	Netherlands	Ireland
Litters/sow/year	2.26	2.34	2.38	2.31
Pigs born alive per litter	14.80	13.20	13.60	12.33
Pigs weaned per litter	12.74	11.40	11.86	11.01
Pigs sold per sow/year	26.93	25.19	26.97	24.11
Pre weaning mortality (%)	13.9%	13.6%	12.8%	10.7%
Rearing mortality (%)	2.9%	2.2%	2.1%	2.5%
Finishing mortality (%)	3.7%	3.4%	2.4%	2.7%

Consequences of increasing output

Litter size is negatively correlated with birth weight, possibly due to crowding in the uterus, and consequent growth retardation (intra-uterine growth retardation; IUGR). Insufficient space for piglets in the uterus has a lasting 'stunting' effect (Bérard *et al.*, 2010). An increased number of piglets also leads to an increase in birth weight variation, which is positively correlated with pre-weaning mortality. Low birth weight (LBW) and weight variation also contribute to an increased number of still births (Damgaard *et al.*, 2003), impaired piglet viability at birth (Baxter *et al.*, 2008) and poorer lifetime performance (Beaulieu *et al.*, 2010).

Nutritional intervention

L-Arginine

The arginine family of amino acids are essential for all mammals. L-arginine is the natural, biologically active form of arginine, in comparison with D-arginine which is the synthetic version of the amino acid (Böger, 2007). L-arginine amino acids are interconvertible via inter organ metabolism. L-arginine metabolises to form proline, glutamine, asparagine, glutamate, aspartate, ornithine and citrulline. The primary sites for their metabolism are within the small intestine, liver and kidneys (Wu *et al.*, 2007).

During the conversion of L-arginine to ornithine, both spermidine and spermine (polyamines) are produced within the cell. Spermidine and spermine have important responsibilities in cell proliferation and are crucial in the growth of tissues. Nitric oxide (NO) (endogenous relaxant which is involved in the vasodilation process) is also synthesised during the catabolism of L-arginine.

The L-arginine family of amino acids are generally abundant in plant and animal tissue (soybean meal, corn, fish and bone meal). Pigs are unable to synthesise L-arginine, which is why L-arginine is classed as an essential amino acid for pigs but dietary intakes are often inadequate to meet requirements, particularly during periods of increased demand, such as during gestation (Che *et al.*, 2013).

Effects in utero

L-arginine is primarily required for protein synthesis and ammonia detoxification. The break down products of L-arginine have a particularly profound effect during gestation. NO and polyamines play an essential role in facilitating ovulation, embryonic implantation and placental growth in the sow. During the gestation period the amount of L-arginine that passes from mother to foetus is generally insufficient to meet the requirement for rapid postnatal growth. Impaired placental production of NO and polyamines causes intra uterine growth retardation (IUGR) (Gao *et al.*, 2012). NO is a vasodilator and promotes angiogenesis (formation of new blood vessels). The placenta goes through a period of exponential angiogenesis between d20-60 of gestation and peaks around d70 (Robinson *et al.*, 1995). Vascular development of the placenta (as measured by the density of larger blood vessels) increases 200% from mid to late gestation (Vonnahme *et al.*, 2001). Promoting angiogenesis increases placental-foetal blood flow which improves transportation of nutrients, oxygen, ammonia and metabolic waste. Placental efficiency is vital in promoting foetal survival and development in swine (Gao *et al.*, 2012). The efficiency of the angiogenesis process is impacted upon by placental blood flow rates which are dependent on vasodilation. L-arginine has a biological responsibility for both placental and foetal development, thus inclusion of L-arginine in the diet is vital during gestation, especially in hyper prolific sows to maximise growth within the uterus (Li *et al.*, 2010).

Supplementation time frame

Although several studies have investigated L-arginine supplementation there is no definitive time frame (e.g. early, mid or late gestation) which has consistently yielded optimal results with regard to enhancing reproductive and piglet performance. Various studies have supplemented sows during early, mid or late gestation, as well as from early gestation to farrowing. It is also worth noting that sows supplemented in these trials have had previously smaller numbers born alive (<13) in comparison to larger litter sizes now evident on most commercial farms.

Early

A commercially available L-arginine supplement (Progenos) has been found to be successful in enhancing pig reproductive performance. Effects were observed for both primiparous and multiparous sows offered 100g/day of Progenos from d14 to 28 of gestation. Progenos has 25% L-arginine, so 25g per day of L-arginine was supplemented. In multiparous sows litter size increased (+0.8piglets/litter) as well as farrowing rate (+11.6%). However within-litter standard deviation for birth weight increased by 31g. Further work in this study revealed that Progenos increased the number of total born piglets from primiparous (1.25/litter) and multiparous sows (1.18/litter) as well as the number of piglets born alive by 0.8/litter and 0.93/litter respectively. The improvement in reproductive performance in these experiments was thought to be due to the fact that L-arginine stimulates angiogenesis and therefore influences placental efficiency, meaning that piglets that would not normally live actually do tend to survive (Ramaekers *et al.*, 2006).

Early/Mid-Late

Results from a further study carried out on a commercial farm by Gao *et al.* (2012) concluded that 1% L-arginine supplementation from d22 – 114 of gestation increased the total number of piglets per litter by 1.31 and the number of piglets born alive by 1.10. Birth weight and litter birth weight for piglets born alive increased by 1.36kg and 1.70kg respectively in both primiparous and multiparous sows. Placental growth was also enhanced compared to control sows by 0.49kg. In fact Myatt (2006) reported that low placental weight and low foetal weight are positively correlated.

Mateo *et al.* (2007) found that supplementation with 1% L-arginine between d30-114 of gestation was successful in reducing embryo and foetal mortality in gilts. During a similar period of supplementation (d30-114 of gestation) by Wu *et al.* (2007) an increase in the number of piglets born alive and piglet birth weight was also noted. Mateo *et al.* (2007) found that this length of L-arginine supplementation on first parity sows increased the number of piglets born alive by 22% (from 9.37 to 11.4) and total live litter birth weights, based on the total number of piglets born alive per litter, increased by 24% (from 13.19kg to 16.38kg). However no effect was observed in relation to the total number born per litter or birth weight variation. Wu *et al.* (2010), Gao *et al.* (2012) and Che *et al.* (2013) acquired similar findings in their respective studies, and concur that dietary supplementation of gilts with 0.83% L-arginine on d14-28 or d30-144 of gestation increased the number piglets born alive as well as litter birth weight.

Late

A trial carried out by Liu *et al.* (2012) revealed that sows offered 0.8% L-arginine during the late stages of gestation (d90 to farrowing) had an improved gestation outcome. Compared with non-supplemented sows, L-arginine supplemented sows had increased numbers of piglets born alive and total litter weight of those piglets born alive.

However average individual birth weights were not significantly different to those piglets born from control sows. It was concluded that this was due to improved nutritional efficiency of the sows which in turn created a more optimal uterine environment. Additionally Quesnel *et al*. (2014) also observed a reduction in variation of litter birth weights as an outcome of late pregnancy supplementation.

Wu *et al*. (2012) supplemented sows with L-arginine from d90 to farrowing and found that L-arginine supplementation increased litter size and improved foetal survival. The results suggest that the outcome is possibly due to elevated levels of endothelial nitric oxide synthase (eNOS), vascular endothelial growth factor (VEGFA) and placental growth factor 1 (PIGF1) in placental surface vessels which were measured during the study, which then promotes nutrient supply to the unborn piglets. Che *et al*. (2013) found that L-arginine supplemented between d30-114 of gestation enhanced the immune response in supplemented sows which was indicated by the levels of the porcine reproductive and respiratory syndrome virus (PRRSV) - specific antibodies and immunoglobulins in the blood serum.

Negative impacts

L-arginine supplementation may not always have beneficial effects on reproductive performance. De Blasio *et al*. (2009) found that offering 1% L-arginine from d14 of gestation decreased the number of piglets born alive (-1.4piglets/litter) and increased the number of stillborn piglets in sows (+0.7piglets). Nevertheless this study found that supplementing gilts from d16 tended to increase the numbers born alive (+0.6piglets), and administering the supplement from d17 further increased the numbers born alive by 1.2piglets. Thus it can be deduced that L-arginine appears to impact upon sows and gilts in different ways, and that timing of supplementation needs to be more extensively researched.

L-Carnitine

Carnitine exists in the form of two stereoisomers. L-carnitine is the biologically active form whereas D-carnitine is biologically inactive (Liedtke *et al*., 1982). L-carnitine is the form this review focuses on. L-carnitine (3-hydroxy-4-N-trimethylammoniobutanoate) is synthesised from two amino acids: lysine and methionine. The amount of lysine and methionine in the diet impacts the biosynthesis of L-carnitine. Sufficient L-carnitine is biosynthesised within the liver and kidneys of adult pigs. However dietary L-carnitine is necessary for the sow during pregnancy to achieve adequate levels of L-carnitine in new-born piglets. Dietary sources of L-carnitine are not essential, but are important for the general L-carnitine levels in the body. 75% of L-carnitine originates from food sources of lysine, methionine and L-carnitine (Rebouche and Seim, 1998).

L-carnitine is a co-substrate of L-carnitine palmitoyltransferase, an enzyme that regulates fatty acid oxidation. L-carnitine transports fatty acids across the mitochondrial membrane to be processed via B-oxidation to generate energy. Consequently L-carnitine has the ability to impact utilisation of fatty acids as metabolic fuel (Coffey *et al*., 1991). L-carnitine also has a role to play in glucose homeostasis (Gaetano *et al*., 1999).

Mechanism of action

Sow

The precise mode of action for L-carnitine's ability to enhance foetal development is generally unknown. It has been hypothesised that it is primarily due to its effect on energy metabolism, increasing levels of sow insulin-like growth factor I and influencing sow leptin concentrations which are all important in maintaining or boosting sow energy levels (Musser *et al*., 1999; Owen *et al*., 2001). Woodworth *et al*. (2004) observed that when gestating sows were supplemented with L-carnitine, glucose utilisation was enhanced after feeding and fatty acid utilisation enhanced during fasting. The same study also found that L-carnitine sows had greater circulating leptin at d28 of gestation. Increasing leptin concentrations are associated with greater energy reserves which implies that L-carnitine increases energy status of sows. Feeding 100mg/day of L-carnitine from d108 to weaning has also been linked with increasing sow body weight gain and back fat thickness, which suggests that L-carnitine also improved nutrient utilisation of the sow. However the beneficial effects of L-carnitine on the body condition of the sow were only observed when the gestation diet was supplemented as opposed to the lactation diet (Musser *et al*., 1999).

Piglet

Birkenfeld *et al*. (2006) hypothesised that piglets from L-carnitine supplemented sows are able to 'switch on' fatty acid oxidation more rapidly, meaning they have more energy not only for heat production but also to get up and suckle. B-oxidation also favours the formation of protein rather than fat accretion which also helps improve growth rate. L-carnitine supplementation of the sow throughout the entire duration of pregnancy and lactation contributes to faster growth rates and improved feed utilisation in piglets pre-weaning. The effects are particularly profound in light piglets (Birkenfeld *et al*., 2005).

Maternal supplementation of L-carnitine also affects the gene expression of the key growth factor and transcription factor genes, which actually regulates the proliferation and differentiation status of myogenic precursor cells. This results in a greater number of muscle fibres at birth due to an increased number of embryonic myoblasts which then contributes to a reduced number of still born piglets as well as improved post-natal performance through increased birth weights and muscle development (Waylan *et al*., 2005). Further studies have also revealed that L-carnitine supplementation has contributed to a leaner finishing pig. A study by Musser *et al*. (1999) confirmed that L-carnitine also improved muscle fibre development of the offspring which was evident right to the point of slaughter. Offspring from supplemented sows had greater loin depth

(59.4 vs 57.0 mm) and percentage lean (55.1 vs 54.5%). The most probable reason for this is due to higher maternal plasma concentrations of the insulin-like growth factor-1 (Brown *et al.*, 2007). A further study by Musser *et al.* (2007) confirmed that piglets born from sows fed diets containing L-carnitine during gestation had up to 27.8% more muscle fibres compared to piglets from non-supplemented sows.

Time frame for supplementation

In terms of improving swine reproductive performance Waylan *et al.* (2005) found that the number of foetuses per litter increased in sows supplemented with L-carnitine between d1-60 of gestation. Interestingly, this study also found that the litter size did not increase at the expense of foetal growth, which would normally be the case, and is a major issue in modern, highly prolific sows. A review by DeRouchey *et al.* (2009) reported similar effects, that supplementing a pregnant sow's diet with L-carnitine has a positive impact on foetal growth and development. The benefits were particularly pronounced in larger litters where piglets tended to have a lower average birth weight.

Musser *et al.* (2007) supplemented sows with L-carnitine from breeding until d110 of gestation, and found no effect on the number of pigs born or on piglet birth weight. However, several studies have shown that sows supplemented with L-carnitine have fewer stillborn piglets, more piglets born alive, greater litter weights (i.e. a reduction in the number of non-viable piglets, (piglets born less than 0.8kg (Eder, 2001; Birkenfeld *et al.*, 2005). Interestingly Musser *et al.* (1999) supplemented sows with L-carnitine between d5-112 of gestation and found no effect on reproductive performance compared with non-supplemented sows. However, in subsequent litters, supplemented sows had an increased number of pigs born alive and their offspring had faster growth rates.

Colostrum/milk

New-born piglets can only synthesise a small amount of L-carnitine. Therefore by supplementing the sows the concentration of L-carnitine in the piglets diet is also increased through elevated concentrations in the colostrum/milk. Due to L-carnitine's mode of action in energy metabolism, exposing piglets to elevated amounts would mean that the piglets can more rapidly 'switch on' fatty acid oxidation to produce energy. This energy boost means that piglets have the strength to get up and suckle more frequently, consuming a greater amount of milk which leads to improved growth rates (Ramanau *et al.*, 2004).

Milk production from a sow is highly influenced by litter size, litter weight and suckling frequency (Birkenfeld *et al.*, 2006). Sows which experience an increased suckling demand produce more milk (King *et al.*, 1997). With L-carnitine giving piglets more energy to suckle more frequently with shorter intervals between sucklings, more milk is obtained by the piglets which prompts the sows to step up milk production. Using the weigh-suckle-weigh method, Ramanau *et al.* (2004) were able to demonstrate that piglets from sows supplemented with L-carnitine between breeding and d110 of gestation are better able to suckle milk from the sow in comparison to piglets from control sows. These piglets were also able to suckle for longer periods of time, which possibly explains the increased growth rate during the suckling period. L-carnitine does not alter the energy, nutrient or fatty acid content of the milk. Therefore the expected reason for increased postnatal growth is due to the fact that piglets born to supplemented sows (supplemented during d30-110 of gestation) are more vigorous and able to massage and suckle the teats for longer, thus able to stimulate an increased flow of milk in the early suckling period. These piglets tend to obtain more milk and grow faster during the first 14 days of life and often obtain a higher weaning weight at approximately 28d (Birkenfeld *et al.*, 2006).

It is clear that L-carnitine has multiple beneficial functions in relation to both the sow and offspring. However, as with L-arginine, further large scale research is needed to substantiate these benefits and determine the optimal supplementation period.

Increasing feed intake in late gestation

Sow effects

Nutrient supply during gestation should meet the energy demands of both the sow and developing piglets. Nutrient requirements increase exponentially towards the end of the gestation period, which coincides with a surge in litter growth (Le Cozler *et al.*, 1999). Nutritional recommendations for pregnant sows have been calculated based on the needs of sows a lot less prolific than the average modern sow with lower numbers of piglets born alive (<13) (Ball *et al.*, 2008). However higher nutritional requirements come in conjunction with higher prolificacy, to support the metabolic needs of an increased number of foetuses (Kim *et al.*, 2008).

Maternal nutrition throughout gestation has been found to influence foetal growth and development and permanently 'programme' the life-long growth of piglets (McNamara *et al.*, 2011). A typical feed allowance for commercial sows throughout gestation is 2.9kg/d. Feed allowance is generally restricted to approximately 2.55kg/d at d30 of gestation and increased to 3.75kg/d by d110 of gestation to maintain a suitable body condition score for farrowing (Kruse *et al.*, 2011).

Samuel *et al.* (2007) found that when fed a diet containing 31.2 MJ DE/day, a sow's total energy expenditure was greater than her intake from d105 of gestation. Mid to late gestation coincides with considerable foetal weight gain and mammary gland development. Dietary energy at this time also influences subsequent lactation and litter weight gain. Additional feed or energy during late gestation marginally enhances birth weight, but these positive effects are inconsistent between studies (Campos *et al.*, 2012). Smits *et al.* (1997) concluded that an overall increase in feed intake of 63kg throughout gestation, with a high-low-high phase feeding programme, increased piglet birth weight on average from 1.30 to 1.38kg. Primary muscle fibres form from d25-50 of gestation and secondary muscle fibres from d50-80 of gestation. Increasing nutrition during mid-gestation for sows has been found to increase the ratio of secondary to primary muscle fibres in progeny. This could result in enhanced growth rate and feed conversion efficiency in the latter stages of growth (Dwyer *et al.*, 1993; Gatford *et al.*, 2003).

Overall there are reasonably few recent large studies that have been undertaken in terms of increasing feed intake in late gestation on sow and litter performance, and the results of studies that exist are inconsistent. These studies also focus on the more immediate effects on the sow than on piglet performance and subsequent farrowing rate. It is known that the nutrient needs for foetal growth increase after d69 of gestation. Protein accretion in particular was found to be 3.0g/d before 69d and 55.6g/d after 69d of gestation which is approximately a 19 fold increase (McPherson *et al.*, 2004). It is thought that increasing feed allowance during early to mid-gestation may help to alleviate the negative impact of intra uterine growth retardation. Benefits would be seen particularly in the lighter litter mates who have lower numbers of muscle fibres and could benefit from the additional supply of nutrients. However, further research is required.

Piglet effects

The two major risk factors for stillbirths are duration of farrowing and weight at birth. New-born piglets have very limited energy reserves and the energy they do have is used up maintaining optimal body temperature and competing with litter mates at the udder. If reserves are insufficient the piglet will become hypoglycaemic, leading to hypothermia and possibly death. It is hypothesised that enhancing sow energy status at farrowing by increasing feed intake to give her more energy to exert greater force and reduce the duration of farrowing may reduce stillbirths. With regard to pre-weaning mortality, an association has been found relating pre-weaning survival rate to piglet liver glycogen stores at birth. The latter can possibly be modified by maternal nutrition during gestation. The foetus has the ability to begin storing glycogen within the liver from approximately 80d of pregnancy; therefore it could prove positive to boost nutrient supply from around 5-6 weeks before farrowing (Canario *et al.*, 2006). McNamara *et al.* (2011) trialled increasing feed intake throughout multiple periods of gestation (d25-50, d50-80 and d25-80). For each stage feed intake was doubled (from 2.3kg/day to 4.6kg/day). Specific time frames were chosen to coincide with the critical developmental stages of primary and secondary muscle fibres in utero. Results found that doubling intake from d25-50 reduced offspring growth. Studies by Heyer *et al.* (2004) and Bee (2004) had similar results i.e. progeny growth rate was inhibited. Increasing feed intake levels from d25-80 had the same effect as the control treatment incidentally and finally the third time frame (d50-80) had a detrimental effect on pig growth. Therefore it can be said that no beneficial effect was elicited to offspring by increasing feeding provisions.

Lawlor *et al.* (2007) found that although farrowing rate tended to increase with increasing feed allowance, particularly when provided during late gestation (d80-110), there was little or no effect on piglet birth weight, within-litter birth weight variation or weaning weight. Almost double the numbers of piglets were born dead in comparison to control treatments when feed intake was doubled from 30MJ to 60 MJ/day at d50-80 of gestation. However even though this study reported a reduction in appetite no increase in weight loss was exhibited. McNamara *et al.* (2012) found that increasing feed intake from d80 had no effect on developing muscle fibre in the developing foetuses, thus no effect on birth weight, but did enhance subsequent farrowing rate such as the study by Lawlor *et al.* (2007). Additionally Redmer *et al.* (2004) found a suppressed expression of angiogenic growth promoters, which indicates lower placental growth and decreased umbilical and uterine blood flow, in young ewes that were allocated higher amount of nutrients from d40-80 of gestation.

In a trial by Hughes and van Wettere (2012) sows had their feed intake increased by 0.7kg from 94d of gestation to farrowing (i.e. the remaining 21 days of gestation) or for the final 42 days of gestation. No effect was found on either level of feed intake in terms of placental: foetal ratio, stillbirth rate, litter size, within litter weight variation, birth weight, preweaning survival or sow weight or back fat. However litter size weaned tended to increase with increased gestation feeding, but a significantly negative correlation was detected between litter size weaned and the size of the subsequent litter. This particular study concluded that no effect could be substantiated in offering sows a higher plane of nutrition in late gestation. Musser *et al.* (2006) found that increased feed intake from d30-50 of gestation (3.63kg/day) resulted in heavier pigs at slaughter although lower total number of piglets born and born alive in comparison to feeding 1.81kg/day. Quesnel *et al.* (2010) doubled the feed intake of sows from 2kg/day to 4kg/day during the early stages of gestation (7 days after insemination). This had no effect on embryo survival, size or variability. Nissen *et al.* (2003) provided an ad-lib diet during two stages of gestation (d25-50 and d25-70), similar to McNamara *et al.* (2011). No beneficial effect was observed on mean birth weight, litter size at birth or weaning. Furthermore no differences were found on the variation of within-litter birth and weaning weights when sows were fed an additional 50% extra of their diet between d45-85 of gestation (Cerisuelo *et al.*, 2008).

Miller *et al.* (2000) also failed to find any effect of increasing feed intake (3.9kg/day / an additional 20.2 MJ DE/day) in late gestation (d100 to farrowing) on piglet performance after one gestation. What was established from this experiment, however, was that increasing feed intake in late gestation reduced sow back fat loss throughout the reproductive cycle.

Cottney *et al*. (2012) who also increased feed intake also found no effect on litter or birth weight, but did observe an increase in sow weight. What was interesting from the Cottney *et al*. (2012) study was that after blood sampling there was no difference in terms of serum creatine concentration which is indicative of muscle catabolism. NEFA concentrations did not differ either which would have been a measure of negative energy balance between those provided with extra feed and the control group. Cromwell *et al*. (1989) gave sows an additional 1.36kg from d90 to farrowing. The response after two consecutive gestations was that total litter birth weight was increased (an additional 0.7kg), weaning weight also increased (0.17g extra) as well as individual birth weights (0.04kg) in comparison to control groups. These sows with the additional feed intake also produced more piglets and more live piglets per litter. Similarly Close and Cole (2000) reported that piglet birth weight increased by c. 8g for each 1.0MJ DE/day up to a threshold a certain point at which energy level throughout gestation has no effect on birth weight. King *et al*. (2006) found that for piglets whose birth weight was already above 1.5kg there was no significant response to energy intake above an average 31 MJ DE/day. Indeed, it appears the additional energy is deposited as maternal gain.

Goodband *et al*. (2013) reported that Soto *et al*. (2011) provided gilts an extra 0.9 or 1.8kg of gestation feed daily from d100 to farrowing, which enhanced piglet birth weight from 1.31 to 1.39 and 1.44kg respectively. Shelton *et al*. (2009) also trialled an additional 0.9kg in late gestation and found that piglet birth weight actually decreased.

Maternal impact

Increasing feed levels during mid to late gestation (d66-101) can increase sow live weight gain prior to farrowing, without any change in back fat. However King *et al*. (2006) found that live weight gain during lactation decreased in response to the increase in feeding level in the preceeding gestation. The increased feed intake during this time frame linearly reduced voluntary feed intake in the subsequent lactation presenting a strong inverse relationship between voluntary feed intake in lactation and energy intake between d66-101 of gestation (King *et al*., 2006). This can suppress lactation feed intake which contributes to weight loss during this critical period which can have deleterious effects on subsequent reproductive performance (Thaker and Bilkei, 2005). Long *et al*. (2010) also found that the provision of extra feed during late gestation supressed lactation feed intake. Indeed Dourmad (1991) calculated that daily feed intake in lactation decreased by 40g per 1MJ DE/day additional intake per day. Close and Cole (2000) reported that second parity sows feed intake decreased by 170g for every 1 MJ DE/day increase in gestation energy intake. Back fat loss tended to accelerate once the increased feed intake stopped at d101 up to the point of weaning. When either feed level or protein content was increased no significant effect on litter birth weight, mean piglet birth weight or within litter weight variation was observed. Furthermore no significant effect was found on litter size weaned, litter/individual weaning weights, within litter weight variation at weaning or subsequent litter size

Neil (1996) supplied the diet *ad libitum* (ad-lib) during 3 phases of late gestation; 4 days before the expected date of farrowing, on the day of farrowing and 3 days after farrowing. Sows fed ad-lib before and on the day of farrowing had deeper ultrasonic back fat than those pigs that had their feed allowance increased after farrowing. Litter size, piglet mortality, piglet live weight and creep feed intake did not differ amongst treatments. Cools *et al*. (2014) also fed sows ad-lib during the perinatal stage (maximum 9 kg/day from d105 of gestation to d8 of lactation). Voluntary feed intake of these sows was almost twice the amount offered to control sows. Close to farrowing their intakes reduced voluntarily without suffering from hypophagia afterwards and no difference could be detected in terms of weight loss at weaning. Neil (1996) also experienced this and found that feed intake reduced on the day of farrowing when fed ad lib. Both trials here report that when fed ad-lib during the perinatal stage the amount of back fat mobilised was actually reduced. It was revealed that during the perinatal period lean sows (<18mm) had the smallest percentage back fat loss and fat sows (> 22mm) had the greatest. However the fat sows then try to compensate for this loss during the lactation period at the expense of piglet growth. Regardless of feed intake Cools *et al*. (2014) found that mobilisation of lean tissue could not be prevented. After farrowing all sows mobilised comparable amounts of lean tissue, indicating that this process will occur regardless of feed intake or body condition. At d112 of gestation the greatest difference in terms of feed intake was observed amongst the two groups. Those sows on restricted intake were more catabolic than those fed to appetite. In general reproductive traits remained unaffected, however, a reduction in the total number of piglets was observed for those sows with a moderate amount of back fat (18mm ≤ BF ≤ 22mm). Those sows with a BF under 22mm at late gestation tended to have heavier piglets at weaning when fed ad-lib because feed intake during lactation was maximised which limited the excessive loss of body reserves, improving litter growth (Guedes and Nogueira, 2001).

In a trial by Heo *et al*. (2007) sows were fed differing amounts of energy from d80 of gestation to farrowing (low, medium and high energy; 3265 ME/kg, 3330 ME/kg and 3400 ME/kg respectively). During lactation those sows on high energy had a reduction in back fat loss. Number of total piglets born was not affected and litter performance during lactation also remained unaffected. Sows in high energy intake produced higher fat and lactose concentration in both colostrum and milk. Feeding a further 9% fat to sows also resulted in a shorter weaning to oestrus interval. Sows with lower feed intake, which are in the most negative energy balance in early lactation mobilise their body reserves during gestation which is possibly related to increased insulin resistance during lactation. Insulin resistance in late gestation can induce the mobilisation of body reserves which can impair subsequent feed intake and metabolic status of sows during lactation (Mosnier *et al*., 2010).

There is great controversy with regard to the effect of increasing feed intake throughout gestation, with no one time frame proving to be most beneficial. However early and mid-gestation have been more thoroughly researched than late gestation. There is insufficient large scale, recent research to determine the impact of increasing feed intake in late gestation on sow and litter performance. More work is certainly required to definitively answer the lingering debate as to whether increasing feed intake in late gestation has a positive influence on piglet performance, in particular birth weight, sow energy balance, lactation feed intake and subsequent farrowing rate, or why feed allowance alterations work in some situations and not in others.

Conclusion

The majority of studies reported above used litter sizes which were markedly smaller than those being experienced in commercial practice. Therefore research is required to assess effects when using highly prolific sows. Nonetheless, there does appear to be opportunity to improve piglet viability using the supplements of L-Arginine and especially L-Carnitine. These supplements may have an even greater impact in studies using large litters since the challenge within these litters is greater. With regard to feed allowances, the information in the literature is very conflicting and clear messages cannot be drawn. Additional feed or energy during late gestation marginally enhances birth weight, but these positive effects are inconsistent between studies.

It is strongly recommended that studies going forward in each of these three areas should be conducted with large numbers of animals to ensure sufficient replication as well as using highly prolific sows since piglet survival is now a greater issue than increasing the numbers of piglets born.

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Nutritional approach to improve survival rate and performance of low birth weight pigs in early lactation

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Key Messages:

- Increase in litter size will result in an increased number of underprivileged low birth weight piglets with lower chance of survival
- Low birth weight pigs display inefficient growth performance, carcass characteristics and meat quality
- Artificial rearing with milk replacer helps to markedly reduce the mortality of low birth weight pigs
- By offering *ad libitum* access to a milk replacer, low birth weight pigs can reach acceptable weaning weights
- Supplementation of a milk replacer with L-arginine or L-carnitine had a significant positive impact on muscle maturation whereas growth performance was only numerically improved.

Keywords: birth weight, litter size, artificial rearing, L-arginine, L-carnitine

Introduction

Including litter size in the breeding goal as a way to improve efficiency of sow reproduction and optimize profit (amount and cost of gestation feed, cost of labour, housing and equipment per piglet born alive per sow) resulted not only in an increased number of piglets born per litter but also in a lower average litter birth weight (BtW), a greater number of low BtW pigs and a greater intra-litter BtW variability (Milligan *et al*. 2002; Martineau and Badouard 2009; Wientjes *et al*. 2012). One of the consistent consequences of low BtW is the greater early postnatal mortality. Quiniou *et al*. (2002) reported survival rates as low as 52 and 15% when BtW was < 0.8 kg and 0.8 to 1.2 kg BtW, respectively. Similarly, Fix *et al*. (2010) and Wientjes *et al*. (2012) found a negative impact of BtW on pre-weaning and nursery survival. Less consistent are the results regarding the effect of low BtW on carcass characteristics and meat quality. Various authors reported not only impaired growth performance but also lower carcass and meat quality in terms of greater fat deposition rate, lower water holding capacity and meat tenderness in low BtW pigs compared to their heavier littermates (Gondret *et al*. 2005; Rehfeldt and Kuhn 2006). Others found also that lighter BtW pigs took longer to reach market weight whereas the impact on carcass composition, meat quality or final eating quality of the pork when slaughtered at the same body weight was minimal (Bérard *et al*. 2008; Beaulieu *et al*. 2010; Pardo *et al*. 2013c). It has to be pointed out that there is no clear rule of how low BtW is defined, which might explain some of the differences in the outcome of the studies. For instance, Gondret *et al*. (2006) defined low BtW by a weight range of 0.75 to 1.25 kg and and De Vos *et al*. (2015) as a BtW < 1.0 kg whereas Milligan *et al*. (2002) used the approach of Roberts and Deen (1996), where low BtW was mainly based on the average litter BtW. In that case a low BtW pigs weigh at least 300 g less or 200–300 g less than the litter's mean BtW and at least 100 g less than the immediately larger member of the litter. Furthermore, low BtW might be either the result of naturally occurring differences in prenatal growth or caused by intra-uterine crowding resulting in intra-uterine growth retardation. The latter hampers the innate genetic potential for tissue growth and ultimately may have long lasting negative effects on postnatal growth efficiency (Foxcroft *et al*. 2007).

Under practical conditions, dealing with large litters and/or low BtW pigs is a great challenge. Sows do not always have sufficient teats to suckle all piglets or soon after farrowing milk production is inadequate for maximal pig growth (Zijlstra *et al*. 1996). A common approach to deal with this kind of issue is cross-fostering of piglets or the use of foster sows. The latter option can be problematic because the all-in-all-out procedure can be compromised. In a herd with a great number of hyperprolific sows, cross fostering isn't always practical leaving producers with no other option than letting all piglets be nursed by their own dam with the greater risk to witness lower survival, lower daily gain and consequently lower weaning weight especially of weak low BtW pigs. Artificial rearing in the early postnatal period is one possible strategy to increase the chance of supernumerary and underprivileged piglets to reach weaning and ultimately slaughter weight (Azain *et al*. 1996; Jans-Wenstrup and Hoy 2015). Using milk replacer will offer not only *ad libitum* access to energy, macro- and micronutrients but also gives the opportunity to add specific nutrients, which might be lacking in sow milk thereby limiting pre-weaning growth (Boyd *et al*. 1995; Kim *et al*. 2001). This short review will discuss possible dietary strategies which have been already used, the challenges they entail and the consequences they might have on relevant performance and carcass quality traits.

Reasons for low birth weight pigs and its impact on growth efficiency?

Ovulation rate, pre- and postimplantation embryonic/foetal losses, uterine capacity and placental development are determinant factors for establishing the number of piglets born (Foxcroft *et al*. 2007). Mean ovulation rates in contemporary gilts were reported to be 17.1 (Almeida *et al*. 2000) and increase to more than 26 in greater parity sows (Vonnahme *et al*. 2002). That this has even increased can be concluded from a recent study of Bérard and Bee (2010) reporting ovulation rates of over 31 in first parity sows.

Despite the high fecundation success and ovulation rate, the number of pigs born are not proportionally increasing due also to increasing postimplantation foetal losses with greater parity (as reviewed by Foxcroft *et al*. 2006). Especially the time point of foetal losses occurring after implantation, when placental insufficiency starts to be the main cause for decreased foetal development (Knight *et al*. 1977), is a critical period because it coincides with the time span when primary (d 35 to 60 of gestation) and secondary myofibers (d 55 to 95 of gestation) are formed (Wigmore and Stickland 1983). Thus, especially in a highly crowded uterine environment embryonic and foetal losses affect muscle ontogenesis (Bérard *et al*. 2010; Pardo *et al*. 2013a). One of the consequences is that formation of myofibers (myofiber hyperplasia) is impaired in low compared to their heavier BtW littermates (Wigmore and Stickland 1983; Rehfeldt *et al*. 2011; Pardo *et al*. 2013a). Differences in the number of prenatally formed myofibers is believed to be one of the reasons for the observed BtW dependent differences in growth performance, carcass and meat quality (Nissen *et al*. 2004; Gondret *et al*. 2006; Rehfeldt and Kuhn 2006; Bérard *et al*. 2008). Rehfeldt and Kuhn (2006) proposed a model regarding the relationship between myofiber growth, myofiber number and lean growth and meat quality, which is based on the assumption that a certain plateau of myofiber size is not exceeded. In low BtW pigs the increase in myofiber size is faster because of the low myofiber number, and the plateau of myofiber growth is therefore attained at earlier age. Under this assumption, dietary energy would no longer be used for muscle growth but for fat deposition instead. In contrast, high BtW pigs with a high myofiber number attain this plateau at later age and may therefore have a greater potential for muscle accretion. The same authors found that compared to medium and high BtW pigs, those with a low BtW develop more myofibers of extreme size ("giant myofibers") because they are probably closer to the plateau of myofiber growth at slaughter. The number of giant myofibers was also negatively correlated to the water holding capacity of meat (Rehfeldt and Kuhn 2006).

Because Wigmore and Stickland (1983) hypothesized that myofiber hyperplasia in pigs is completed before birth, led to the conclusion that no postnatal nutritional intervention will alleviate this problem (Foxcroft *et al*. 2006). However, recent data question the hypothesis of fixed myofiber number at birth (Rehfeldt *et al*. 2008; Lopez *et al*. 2010). It is well known that determining the exact number of myofibers in a muscle is a difficult task and subjected to a substantial error of estimation. However, the results of the study of Rehfeldt *et al*. (2008) suggested a doubling in the total number of myofibers from birth to weaning, which was beyond a possible error of estimation. It has been suggested that postnatal hyperplasia was caused by a third generation of very small myofibers that form shortly after birth (0 to 15 d postnatally) and express developmental myosin (Mascarello *et al*. 1992; Lefaucheur *et al*. 1995; Bérard *et al*. 2011). This finding opens the question of whether specific feeding strategies or supplementation of specific nutrients to the milk replacer could help boost early postnatal growth and myofiber hyperplasia especially of underprivileged and/or supernumerary low BtW pigs.

General considerations of artificial rearing

As previously discussed, when dealing with large litters there are mainly three options which can be envisaged to improve litter survival rate, to obtain adequate litter weaning weights and, in addition, to avoid excessive body reserve losses of the sow. The options are 1) cross-fostering (if possible), 2) use of foster sows and 3) artificial rearing with milk replacer. In the case of milk replacer, they can either be offered to early weaned pigs [e.g. weaning at 3 d of age; Rzezniczek *et al*. (2015)] in separate rescue decks or in farrowing pens during lactation.
For the latter, results of various studies are available which differed mainly in the duration of milk replacer supply.

Table 1 Nutrient composition (g/kg dry matter) and amino acid to lysine ratio of mature sow milk collected at d 21 of lactation[1] and amino acid to lysine ratio of the whole body of piglets with a body weight (BW) of 1.55 and 8.50 kg

Ingredients				
----------- Sow milk -----------			-- Whole body[2] --	
Dry matter, g/kg	194.0			
Fat	390.5			
Protein	323.1			
		---- amino acid:lys ratio ----		
		Sow milk	1.55 kg BW	8.50 kg BW
Lys	25.69	1.00	1.00	1.00
Met	3.89	0.15	0.20	0.30
Cys	1.87	0.07	0.18	0.22
Thr	13.09	0.51	0.58	0.64
Val	17.16	0.67	0.68	0.76
Ile	13.58	0.53	0.45	0.60
Leu	29.36	1.14	0.98	1.18
Phe	12.87	0.50	0.58	0.61
Tyr	6.85	0.27	0.38	0.52
His	9.73	0.38	0.39	0.42
Arg	15.25	0.59	0.65	0.96
Ala	12.48	0.49	0.98	0.99
Pro	39.66	1.54	1.03	0.88
Asp	28.70	1.12	1.17	1.37
Glu	72.33	2.82	1.80	2.13
Ser	14.27	0.56	0.61	0.67
Gly	11.01	0.43	1.52	1.21

[1] Average of 175 milk samples
[2] Data obtained from Mahan and Shields (1998)

For instance, Jans-Wenstrup and Hoy (2015), Park *et al*. (2014), Miller *et al*. (2012) and Wolter *et al*. (2002) provided the litters with milk replacer during the whole lactation of 26, 17, 21 and 18 d, respectively. Others made the milk replacer available in the second half of lactation for 11 (Wang *et al*. 2005) or 10 d (Dunshea *et al*. 1999). In all these studies provision of additional nutrients via the milk replacer resulted in greater body weight gain at the end of the provision period.

In earlier studies, Boyd *et al*. (1995) estimated that the biological potential for neonatal pig growth is at least 400 g/d (average to 21 d of age) vs. 230 g/d for sow-reared piglets (+70%). In the same study, the authors could show that suckling piglets exhibit submaximal growth from d 8 after birth. One possible explanation for the sub-optimal growth performance could be the inadequate intake of energy, protein and/or some specific amino acids with the sow milk. Based on the amino acid pattern of the sow milk and the whole body of piglets as well as the arginine supply with sow's milk vs. the estimated arginine requirement of piglets for growth and metabolic function (Wu and Knabe 1994, 1995), Wu *et al*. (2004b) concluded that mature sow milk is deficient in arginine. In their experiments they found an arginine to lysine ratio of 0.30 and 0.97 in sow's whole milk (d 8 of lactation) and 7-d-old pigs, respectively. In a recent unpublished study, the fat and protein content together with the amino acid profile were determined in 175 mature milk samples collected at d 21 of lactation from sows of the Agroscope research herd (Table 1). When comparing the amino acid profile (expressed in relation to the lysine content) of the milk to that of the whole body of new born and weaned pigs (data from Mahan and Shields 1998), it is evident that some of the essential as well as semi-essential amino acids are deficient, strengthening the assumption of not fully adequate amino acid composition of the sow milk.

Taking into account the arginine intake plus arginine accretion and catabolism, Wu *et al*. (2004b) estimated that sow's milk provides ≤ 40% of arginine requirements by the 1-wk-old pig. To test whether arginine is deficient in milk-fed young pigs, Kim and Wu (2004) performed a study with artificially reared 7-d old piglets. They could show that by supplementing a milk replacer with 0.2 and 0.4% L-arginine piglets grew significantly faster by 28 and 66% (230 and 298 g/d) and reached after 14 d a greater weaning body weight of 15 and 32% (6.11 and 7.05 kg), respectively, compared with control piglets (180 g/d and 5.33 kg). More recently, Wang *et al*. (2014) determined also that average daily gain increased by up to 31% in a dose-dependent manner when a milk replacer supplemented with 0, 0.5, 1 and 2% glycine (241, 264, 288, 316 g/d) was offered for 14 d to 14-d-old piglets.

Based on previous findings indicating that supplementing pregnant and lactating sows with L-carnitine increased litter BtW, weaning BW and post weaning performance (Musser *et al*. 1999; Rincker *et al*. 2003; Ramanau *et al*. 2004), stimulate prenatal myofiber formation (Musser *et al*. 2001) and increased protein accretion and percentage of lean in growing and finishing pigs (Owen *et al*. 2001a; Owen *et al*. 2001b), Loesel *et al*. (2009) investigated whether L-carnitine had the potential to affect early postnatal myofiber formation, muscle growth, and body composition of suckling piglets of low and medium BtW. The observed levels in glucose and non-esterified fatty acid levels in blood at d 28 of age suggested that energy balance was improved through intensified fatty acid oxidation. In the muscle they observed greater DNA concentrations and DNA:protein ratios, which led them to conclude that myogenic proliferation was stimulated and may have contributed to the compensatory increase in myofiber number by 12% compared to the unsupplemented group. Interestingly, this effect has been observed primarily in low BtW piglets suggesting that particularly those could profit from an early postnatal L-carnitine supplementation.

However, all the aforementioned studies were not done with low BtW offspring born from hyperprolific sows. Thus, in the EU-project ECO-FCE (grant agreement No. 311794), we aimed to assess whether the aforementioned approaches would be suitable for underprivileged piglets, known to have suffered from intra-uterine growth retardation.

Studies in the framework of ECO FCE

Experiment 1

The aim of the first study was to investigate the impact of a milk replacer supplemented with either l-arginine or l-carnitine compared to a non-supplemented milk replacer on growth performance and muscle metabolism of low BtW piglets in the early postnatal period (Mueller *et al*. 2014).

Material and Methods

The experiment was performed with 30 purebred Large White piglets (16 castrates and 14 females) with a BtW ≤ 1.2 kg and originating from litters with ≥ 15 piglets born. At 7 d of age, piglets were randomly allocated to one of 3 dietary treatments: control diet (Ctr), control diet + 1.08 g l-arginine/kg body weight/d [ARG; based on Wu *et al*. (2004a)] and the control diet + 400 mg l-carnitine/d [CAR; based on Loesel *et al*. (2009)]. The control diet was formulated based on the diet used by Kim and Wu (2004) and contained whey powder, full milk powder, milk protein, glucose, dicalcium phosphate dehydrate, dl-methionine, l-lysine-HCl and a mineral-vitamin-premix. The piglets were housed in pairs in rescue decks.

The experimental diets were offered 6 times per day, every 3 h, starting from 7 am. Piglets had *ad libitum* access to water but no additional creep-feed was offered. Piglets were weighed every morning and the amount of milk replacer was allocated based on this BW. Prior to each meal, the amount of residual milk replacer was recorded. On d 28, piglets were slaughtered after being anesthetized for 5 min using isoflurane and then euthanized by exsanguination. Spleen, liver, lung, heart, kidneys, brain as well as the right Semitendinosus muscle (STM) and the adrenal glands were excised and weighed. In the STM metabolic properties were assessed by measuring the activity of key enzymes involved in the oxidative (citrate synthase) and glycolytic pathways (lactate dehydrogenase).

Data were analysed using the Mixed procedure of SAS (version 9.2 SAS Inst. Inc., Cary, NC, USA) considering treatment, sex and treatment × sex interaction as fixed effects and sow nested within experimental series as random effect. Differences with $P < 0.05$ were considered significant and $0.05 \leq P \leq 0.10$ as a trend.

Results and Discussion

According to the experimental design, BtW did not differ among the 3 experimental groups (Figure 1). Likewise, the BW at the beginning (d 7 of age), at d 14 after birth, as well as at the end of the experiment (d 28 of age) was not different among treatment groups. Accordingly, the supplementation of l-arginine and l-carnitine did not affect the growth rate in the period from d 7 to 28 of age. However, at 21 d of age, CAR piglets had a greater ($P < 0.05$) BW compared to the Ctr piglets, with intermediate values for ARG piglets. This difference was the result of a greater ($P < 0.05$) feed intake of the CAR piglets compared to the Ctr and ARG piglets in the second week of the experiment (d 14 to 21). The lack of effect of CAR on growth performance from d 7 to 28 d of age is in accordance with the results presented by Loesel *et al.* (2009) where they did not observe a clear improvement in growth in low- and medium BtW piglets. In contrast to the present results, Kim and Wu (2004) found a 33% greater BW at d 21 and a 66% greater ADG when piglets were offered a milk replacer supplemented with 0.4% L-arginine for 14 d. These improvements occurred without ingesting more feed. One major difference between the current study and the one of Kim and Wu (2004) is the BW at d 7 of age which was on average 2900 g and therefore by almost 1200 g greater compared to the present study.

At slaughter, numerically heavier STM muscles were found in CAR and ARG piglets compared to Ctr (12.9, 12.7 and 12.0 g). This coincides with the numerically heavier slaughter weight of CAR and ARG piglets (4.86 and 4.73 vs. 4.30 kg). Dietary treatment had no impact on organ, brain and adrenal gland weights. Furthermore the brain:liver and the brain:STM weight ratios, traits used to evaluate brain sparing effects, were similar in the 3 treatment groups. Assuming that brain development is independent of nutrition, these findings suggest that neither l-arginine nor l-carnitine had a positive impact on liver and muscle growth.

During the first postnatal week a dramatic increase in protein concentration and glycolytic capacity, and a

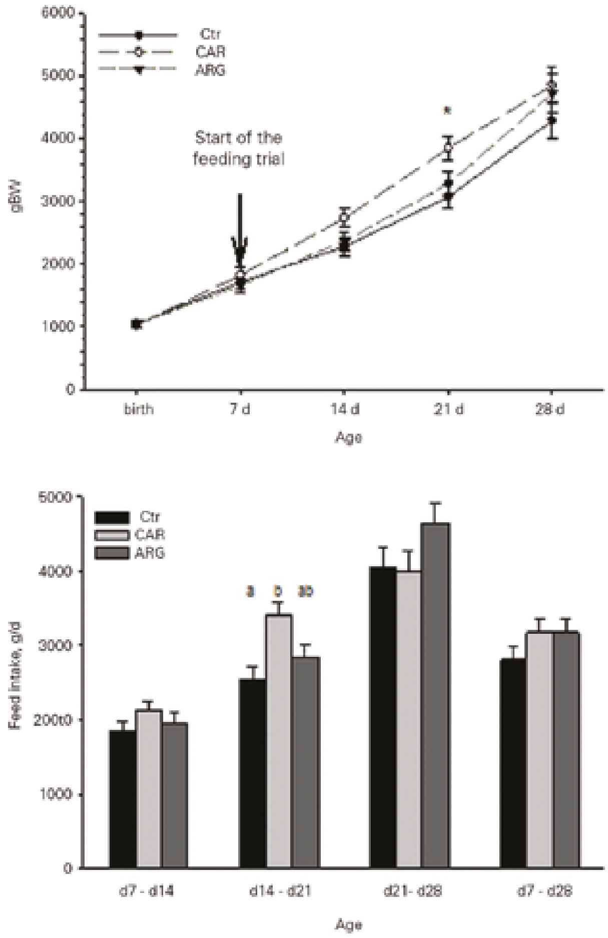

Figure 1 Development of BW and daily feed intake from birth to 28 d and 7 to 28 d of age, respectively, of early weaned piglets fed an unsupplemented milk replacer (Ctrl) or a milk replacer supplemented with L-carnitine (CAR) or L-arginine (ARG). ab Least squares means without a common superscript differ ($P < 0.05$). xy Least squares means without a common superscript differ ($P < 0.10$)

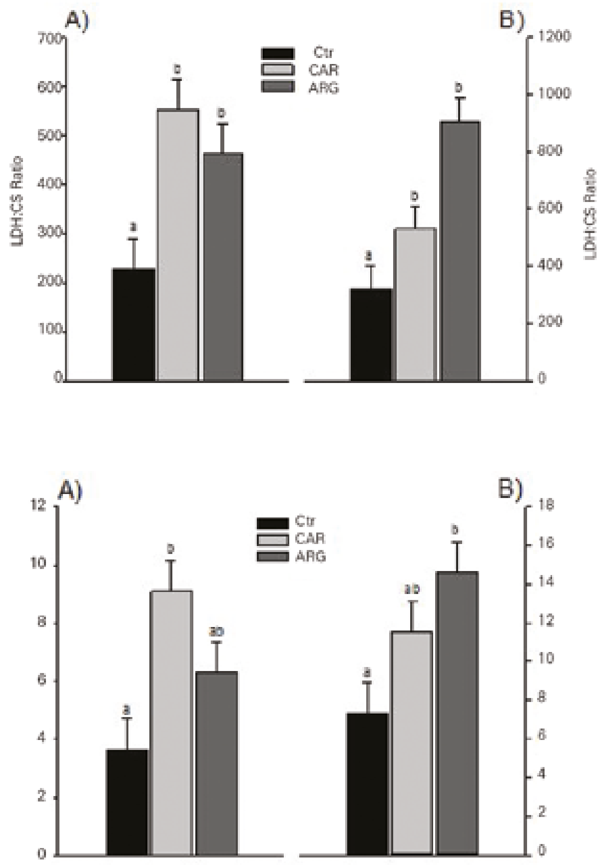

Figure 2 Lactate dehydrogenase to citrate ratio (LDH:CS) and lactate dehydrogenase to β-hydroxyacyl-CoA dehydrogenase (LDH:HAD), depicting the relative importance of the glycolytic compared to the oxidative pathway in the dark and light portion of the Semitendinosus muscle of early weaned piglets fed an unsupplemented milk replacer (Ctr) or a milk replacer supplemented with L-carnitine (CAR) or L-arginine (ARG). ab Least squares means without a common superscript differ ($P < 0.05$).

decrease in the fetal myosin heavy chain isoform occur in pig skeletal muscle (Lefaucheur and Vigneron 1986; Lefaucheur and Gerrard 1998; Lefaucheur *et al*. 2001). All of these characteristics can be used as markers of animal maturity. For instance, 7 d old piglets displayed decreased LDH/CS ratio after restricted colostrum intake denoting a more oxidative metabolism using fewer carbohydrates and more lipids in restricted piglets, as suggested by the increased activity of HAD (Lefaucheur *et al*. 2003). Contrarily, in the present study the relative importance of the glycolytic compared to the oxidative pathway was greater in the STM of CAR and ARG compared to Ctr piglets (Figure 2). This suggested that, through their respective metabolic pathways, l-carnitine (b-oxidation) and l-arginine (protein synthesis) were beneficial for metabolic maturation of the muscle fibres.

In conclusion, regardless of the dietary treatments it was not possible to obtain BW at weaning, which usually can be expected from piglets of normal BtW reared by the sow for 28 d. As in the present study feed was offered only 6 times a day, the question remains whether growth performance can be increased in the same period if piglets have *ad libitum* access to the milk replacer. Still, data of experiment 1 suggested that L-carnitine and L-arginine supplemented to a milk replacer had some (numerical) beneficial impact on growth performance and enhanced muscle maturation in the early postnatal period. Furthermore, none of the 30 low BtW piglets died in the rescue desk, a fact, which rarely can be observed with underprivileged piglets reared by the sow.

Experiment 2

The aim of the second study was to use the same nutritional approach as in experiment 1 but using a milk cup system (Figure 3), which allowed the low BtW piglets to have *ad libitum* access to the milk replacer (Madsen *et al*. 2015).

Material and Methods

Thirty-six low BtW piglets (≤ 1.2 kg) originating from litters (≥ 15 piglets born) were artificially reared in rescue decks from d 7 to 28 of age with a milk replacer, which was either unsupplemented (Ctr) or supplemented with l-arginine (ARG, 2.18 g/kg DM) or l-carnitine (CAR, 0.48 g/d per pig). Feed was offered *ad libitum*, and body weight (BW) and feed intake were determined weekly and daily, respectively. On d 28 of age piglets were sacrificed and samples were collected as previously described. Data were analysed using the same statistical model as previously described.

Results and Discussion

As reviewed by Baxter *et al*. (2013), artificial rearing in rescue decks has the potential to improve the survival rate of piglets. In the present study, only one out of 36 piglets died during the experimental period, which in percentage (2.7%) is substantially lower compared to the conventionally reared piglets (~17%) from the same herd. Due to the *ad libitum* access to the milk replacer, piglets achieved independent of the experimental treatments greater weaning weights in the experiment 2 compared with experiment 1 (6.26 vs. 4.63 kg). Comparing the dietary treatments, ARG but not CAR piglets displayed, numerically, 7.5% greater BW at d 28 (6.4 kg), 2.6% greater average daily gain (ADG) (196 g/d), 7.8% greater feed intake (236 g/d), and similar feed efficiency compared to Ctr. As in experiment 1, CAR piglets displayed a more mature STM as indicated by the numerically greater relative importance of glycolytic versus overall oxidative capacity compared to ARG and Ctr piglets. Furthermore, CAR piglets displayed numerically larger type I and IIA myofibers in the dark portion of the STM and ARG piglets displayed larger type IIA fibers in the light portion of the STM. Furthermore, the STM of CAR piglets had a greater TNF followed by ARG and Ctr piglets, which suggest that myofiber hyperplasia occurs in early postnatal life (Loesel *et al*. 2009).

Future prospects

Although both supplements failed to display significant effects when supplemented separately, the observed numerical differences provides enough indications for further investigations. Because CAR and ARG are involved in different metabolic pathways, such as β-oxidation and protein synthesis, respectively, in future experiments the supplementation of a milk replacer with both supplements combined will be studied. In these experiments not only performance in early life but also growth performance in the post weaning, grower and finisher period, carcass characteristics and meat quality at slaughter will be assessed. These traits will be assessed in underprivileged piglets from large litters either fed the milk replacer or reared only by the sow. Because there is scientific evidence that natural behaviour of early weaned piglets is affected by early weaning and rearing in rescue decks (Rzezniczek *et al*. 2015) and it cannot be excluded that this also affect their growth, in future studies supplemented and unsupplemented milk replacer will be offered to the large litters in the farrowing pen.

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Impact of increased energy and amino acids in the lactating sow diet on piglet performance in large litters.

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Key Messages:

- The potential of piglets to grow pre weaning is greater than the sow can support and as such the performance of the lactating sow is a key driver of whole farm efficiency.
- Consumption of 108MJ DE and 77g of lysine per day can enable sows to wean 13 pigs to an average wean weight of 8.5kg.
- A phase feeding regime improved pig weight at weaning by 220g per piglet, or 2.6%, compared to flat rate feeding.
- A high Lysine to Valine ratio (1 : 1.1) increased piglet weight at day 14 by 140g (3%) compared to a 'normal' Lysine to Valine ratio (1 : 0.68) and this weight advantage was sustained until weaning.

Introduction

The weaning weight of a piglet is one of the most critical factors in determining it's lifetime performance (Campbell 1990; Miller *et al*., 1999; Mahan and Lepine, 1991; Le Dividich *et al*., 2015). Cole and Close (2001) reported that an extra 1kg in weight at weaning could reduce the days to slaughter by 10. However, there is concern that larger litter sizes achieved through recent genetic selection for prolificacy have had a negative impact on individual piglet weaning weight. This is due to the negative correlation between litter size and birth weight (Quiniou, 2002), and the subsequent positive correlation between birth weight and weaning weight (Dunshea *et al*., 2003).

Another complication in achieving the optimum weaning weight is that the sow's milk yield is the limiting factor with regard to piglet growth. Suckling piglets have the potential to gain 576g/day if fed *ad libitum* (Hodge, 1974), but when suckling the sow piglet gains average 240g/day. In order for milk to meet piglet potential, either milk yield needs to increase or the concentration of nutrients in the milk needs to increase, especially in the later stages of lactation.

Previous studies have shown that total litter weaning weight can be improved through increasing the energy (Park *et al*., 2008; Walsh *et al*., 2012; Xue *et al*., 2012; Smits *et al*., 2013) and lysine (Heo *et al*., 2008; Yang *et al*., 2009; Xue *et al*., 2012) content of the sow lactation diet. The amino acid valine has also received some attention since it has been found to increase piglet weight gain when offered at higher than recommended levels in lactating sow diets (Riechert *et al*., 1996; Moser *et al*., 2000; Paulicks *et al*., 2003). This may be due to valine having the greatest oxidation rate in the mammary gland of any amino acid (Trottier *et al*., 1997). Kim *et al*. (2001) reported that the valine content of the lactating mammary gland increased 91.3% when the number of pigs sucking the sow doubled from 6 to 12. In comparison, lysine and theonine increased by 86.7 and 88.2% respectively. As a result, Kim *et al*. (2001) concluded that valine becomes the second most limiting amino acid when sows do not mobilise body tissues. Furthermore, and more importantly with regard to increased litter size, it appears that the valine requirement may increase in relation to lysine with increasing litter sizes and therefore milk yield (Kim *et al*., 2001)

A major limitation across the aforementioned studies is the fact they all used 'small' litter sizes which are not reflective of current commercial production. Overall very few papers report nutritional requirements for sows based on litter sizes over 11.5 (Craig *et al*., 2015). In 2013, the EU average for piglets born alive per litter was 13, with six countries attaining more than 13 pigs born alive per litter, the highest being Denmark at 15.4 (BPEX, 2014). Therefore, further research into the nutritional requirements of this generation of prolific lactating sows is needed to sustain piglet growth and weaning output and ultimately lifetime performance of the slaughter generation herd. As such this study aimed to investigate the impact of dietary energy concentration and lysine:valine ratio on litter and piglet performance.

Materials and Methods

Animals

Sows representing parity 2-6 (n=109) were selected and balanced across treatment according to weight and body condition score. Sows were PIC F1 cross (Large White x Landrace) or PIC purebred Landrace sows. PIC 337 was the terminal sire used.

Gestation Feeding and Management

During the first 28 days of gestation sows were kept in groups of four in free access cubicles with a 2.45m by 4.5m pen at the rear. After 28 days, sows were moved into a large dynamic group where they were fed by a Nedap electronic sow feeder (Nedap Livestock Management, Netherlands) until day 108 of gestation. Sows were offered 2.5kg/day of a gestation diet (12.9 MJ DE/kg, 14.8% CP, 0.7% total Lysine) in early gestation and from day 85 they were offered 3kg/day of the same gestation diet.

Lactation Feeding and Management

Sows moved into farrowing accommodation at approximately day 108 of gestation and were kept in crates with an enclosed heated creep area for piglets at the front. Temperature in the farrowing rooms and creep areas was electronically controlled and daily temperatures recorded. Sows had access to a wet and dry feeder and were offered 3kg/day of their respective lactation diet until the day of farrowing, after which feed allowance was increased by 0.5kg/day until intake reached 10kg/day. The target average feed intake over the 28 day lactation was 8kg/day. Feed allowance was recorded individually on a daily basis and the daily allowance was offered across two meals. Feed disappearance was recorded as feed intake.

Sows were induced to farrow with 2ml of Planate (cloprostenol, Intervet/Schering-Plough Animal Health) on day 114 of gestation. Piglets had their teeth clipped, tails docked and an iron injection administered within the first 12 hours of birth. Piglets also received ear tattoos to allow recordings of individual animals. Cross-fostering was completed within 24hrs of farrowing and used to standardise litters to 13-14 piglets. Mortalities were recorded after cross-fostering had been completed and piglets that died were not replaced. No creep feed was offered to the piglets, and sow troughs are sufficiently high to deter piglets from consuming sow feed. However, piglets had free access to water via nipple drinkers. Piglets were tagged, corresponding with their ear tattoo, during week 2 and they were weaned at 28 days of age.

Dietary treatments

Dietary treatments began at day 108 of gestation, on entry to the farrowing crate. Dietary treatments were arranged in a 2 x 2 + 1 design. Dietary treatments were: two dietary regimes representing a 'Flat' dietary regime (14.4 MJ/kg DE diet offered for 28 days of lactation) or 'Phased' dietary regime (14.4 MJ DE/kg diet offered until day 14 of lactation followed by a second diet containing 15MJ/kg DE, offered for the last 14 days of lactation); two diets representing normal and high lysine:valine ratios (1 : 0.68 and 1 : 1.1) and then a control diet, was also offered which contained 13.5 MJ DE/kg, 0.88% Lysine, 0.66% Valine. The feed was manufactured on the AFBI, Hillsborough site. It was offered in meal form due to the high oil content. Diet analysis was carried out by Sciantec Analytical, North Yorkshire. Table 1 details the ingredients and formulated analysis of the five diets used.

Measurements

Animal performance

The backfat depth, body condition score (BCS) and body weight of the sows were measured at transfer to the farrowing accommodation and at weaning. Backfat depth was measured at the P_2 position (65mm from the midline at the level of the last rib) with an ultrasonic backfat scanner (Pig Scan-A-Mode backfat scanner, SFK Technology, Denmark). BCS was recorded using a 5 point scale and half scores were also used. Sow weight was taken at day 108 of gestation and the birth weight of the piglets subtracted to calculate empty weight. Piglets were individually weighed at birth, 5, 7, 10, 14 ,21 and 28 days of age (weaning). Piglet average daily gain (ADG) and the coefficient of variance for ADG were also calculated.

Table 1. Ingredients and Formulated Values of Experimental Diets

		Flat		Phased	
Ingredient (%)	**Control**	**Normal Valine**	**High Valine**	**Normal Valine**	**High Valine**
Barley	49.	10	7.5	5.45	6.62
Soya Meal	19.05	28	28	28	28
Wheat	15.0	26.64	33.25	33.22	30.83
Maize	12.65	30.0	25.0	25.0	25.0
Limestone	1.25	1.24	1.24	1.24	1.24
Soya Oil	1.0	2.36	2.69	4.77	5.0
MDCP	0.91	0.9	0.91	0.92	0.92
Salt	0.39	0.43	0.43	0.44	0.44
L-lysine	0.22	0.28	0.29	0.49	0.5
L-Threonine	0.04	0.07	0.08	0.18	0.18
DL-Methionine	0.03	0.06	0.06	0.12	0.51
L-Valine		0.003	0.56	0.17	0.75
Tyrptophan				0.02	0.02
Min. Vit. Premix*	2.5	2.5	2.5	2.5	2.5
Formulated Composition, as fed					
DE (MJ/kg)	13.5	14.4	14.4	15	15
CP (%)	17	19.8	19.8	19.9	20
Fibre (%)	3.6	2.7	2.6	2.5	2.5
Lysine (%)	1.0	1.25	1.25	1.4	1.4
Valine (%)	0.82	0.95	1.5	1.1	1.68
Lysine:Valine	1:0.82	1:0.76	1:1.2	1:0.79	1:1.2

*Premix provided (per tonne of finished feed): 12Miu Vit A, 2Miu Vit D3, 120gm Vit E, 2gm Vit B6, 2gm Idoine, 0.3 Selenium,100gm Iron, 45gm Manganese, 12.5gm Copper, 100gm Zinc.

Table 2: Formulated and Actual Analysis

		Flat		Phased	
	Control	Normal Valine	High Valine	Normal Valine	High Valine
Formulated Composition					
DE (MJ/kg)	13.5	14.4	14.4	15.0	15.0
CP (%)	17.0	19.8	19.8	19.9	20.0
Lysine (%)	1.0	1.3	1.3	1.4	1.4
Valine (%)	0.8	1.0	1.5	1.1	1.7
Lysine:Valine	1:0.82	1:0.76	1:1.2	1:0.79	1:1.2
Actual composition					
DE (MJ/kg)	13.6	14.1	14.4	14.9	15.1
CP (%)	14.4	15.9	17.4	15.6	16.2
Lysine (%)	0.9	0.9	1.0	1.1	1.0
Valine (%)	0.7	0.6	1.2	0.8	1.0
Lysine:Valine	1:0.76	1:0.67	1:1.2	1:0.69	1:1.07

Milk Sampling

Colostrum samples were collected within 4 hours of the first piglet being born. Milk samples were collected on day 5, 7, 10, 14, 21 and 28 of lactation. To collect milk samples, piglets were prevented from suckling for one hour and 1-2ml of oxytocin was administered intramuscularly into the neck. Approximately 30ml of milk was hand stripped from median mammary glands on both sides. Milk samples from each gland were pooled and a preservative tablet (Lactab Mark III, Thomson and Cooper Ltd., UK) added. Milk was analysed fresh where possible using UKAS accredited tests for bovine milk using a Milkoscan Model FT120 (Foss Electric, Denmark).

Blood sampling

Blood samples were taken from the jugular vein of a subset of sows (n=12/treatment) on day 21 of lactation. Serum was recovered by centrifugation (3000rpm; 15minutes) and frozen (-80oC) pending analysis. Urea was analysed using a Beckman Coulter Analyser (USA) and BUN was calculated using the following formula: Urea [mmol/L] = BUN [mg/dL of nitrogen] x 10 [dL/L] / 14x2 [mg N/mmol urea].

Statistical Analysis

Treatment effects on sow and litter performance and diet effects on milk composition were assessed by analyzing the data as per the experimental design of a 2 x 2 + 1 using Genstat (16th Edition) using the analysis of variance (ANOVA) model. Average daily feed intake (ADFI) was used as a covariate for sow performance variables. Blood urea nitrogen results were analysed using ANOVA.

Results

Diet Formulation

Within this study, actual analysis of the dietary treatments differed from the formulated analysis (see Table 2). The authors' conclusion is that full-fat soya was used instead of soya meal. This meant that the lysine content of the diets did not increase as expected between the flat and phased dietary regime treatments. Energy did increase as expected; therefore the phased treatments represent an increase in energy only as opposed to an increase in energy and lysine. This has then meant that the treatments represented different energy to lysine ratios. However, the valine content was also lower than expected and as a result the ratio of lysine to valine across treatments was as expected.

Sow Performance

Average lactation length was 28.2 days and mean sow parity was 3.6. The average number of pigs after cross-fostering (13.4) and number of pigs weaned (12.8) was not significantly different between treatments. Average daily feed intake was significantly different (P=0.003) between the control group (7.1kg) and the treatment groups (7.7kg) and was used as a covariate for production analysis.

There were no interactions found in any of the sow performance parameters, and no effect of treatment on sow back fat depth at P_2, BCS or weight change (Table 3).

Litter Performance

There were no interactions found in any of the litter performance parameters detailed in Table 3. Litter birth weight was not significantly different (P>0.05) between treatments. However, by day 14 the weight of litters on sows being offered the control diet was significantly lower

Table 3: Sow performance when fed varying levels of nutrients throughout lactation

		Flat		Phased			Effects (P Value)			
	Control	Norm Valine	High Valine	Norm Valine	High Valine	SEM	Ctrl v. Trt	Flat v. Phased	High v. Norm Val	Inter-actions
No. of Sows	22	22	21	22	22					
No. of pigs at start	13.5	13.4	13.5	13.2	13.5	0.15	0.74	0.85	0.19	0.59
No. of pigs weaned	12.6	12.9	13.0	12.4	13.0	0.24	0.46	0.29	0.20	0.36
Birth CoV	0.17	0.17	0.18	0.17	0.17	0.01	0.99	0.75	0.68	0.66
Wean CoV	0.19	0.17	0.24	0.25	0.23	0.05	0.55	0.57	0.65	0.43
P^2 at Farrowing (mm)	22.1	22.5	22.0	22.2	22.6	0.93	0.81	0.91	0.92	0.65
P^2 at Weaning (mm)	18.5	18.9	18.4	19.0	18.6	0.84	0.79	0.84	0.62	0.93
P^2 Change (mm)	-3.7	-3.7	-3.6	-3.3	-3.8	0.43	0.91	0.79	0.53	0.48
BCS at Farrowing	3.0	2.9	2.9	2.8	3.0	0.13	0.77	0.92	0.32	0.50
BCS at Weaning	2.6	2.7	2.5	2.6	2.5	0.14	0.98	0.68	0.57	0.82
BCS Change	-0.4	-0.2	-0.4	-0.3	-0.5	0.10	0.68	0.46	0.03	0.58
Weight at Farrowing (kg)	238	248	235	245	242	7.43	0.59	0.78	0.28	0.50
Weight at Weaning (kg)	242	255	241	254	248	7.53	0.42	0.68	0.20	0.59
Weight Change (kg)	4.9	7.2	6.4	9.0	6.5	2.80	0.46	0.73	0.55	0.76
Litter weight (kg)										
Day 0	19.0	21.0	19.2	19.6	19.5	0.672	0.29	0.40	0.16	0.21
Day 14	58.1	65.0	64.8	60.0	63.7	1.682	0.01	0.07	0.30	0.24
Day 28	102.1	111.0	109.3	108.0	111.7	2.490	0.01	0.88	0.70	0.27
Total weight gain	84.0	90.8	90.6	89.3	93.0	2.144	0.01	0.86	0.42	0.36
Daily Litter Gain (kg/day)										
Day 0-14	2.8	3.1	3.2	2.9	3.1	0.101	0.02	0.19	0.07	0.67
Day 14-28	3.4	3.5	3.4	3.7	3.7	0.126	0.16	0.10	0.63	0.64
Day 0-28	3.0	3.2	3.2	3.2	3.3	0.077	0.01	0.69	0.41	0.58

Sow average daily feed intake was used as covariate

(P=0.007) than those of sows offered any other treatment. By 28 days the litter weight of sows offered the control diet was 8kg lower than the average litter weight of sows offered any other treatment. (P=0.006). However, there was no significant effect of phase feeding or increased lysine:valine ratio on litter weight.

Litter ADG from birth to weaning was also improved in the treatment groups compared to control (P=0.008), with no significant effect of phase feeding or lysine:valine ratio (Table 3).

Table 4. Piglet performance when sows were fed varying levels of nutrients throughout lactation

		Flat		Phased			Effects (P Value)			
	Control	Norm Valine	High Valine	Norm Valine	High Valine	SEM	Ctrl v. Trt	Flat v. Phased	High v. Norm Val	Inter-actions
Weight (kg)										
5 day	2.11	2.11	2.15	2.10	2.12	0.02	0.62	0.15	0.06	0.51
10 day	3.91	3.91	4.04	3.93	4.01	0.04	0.08	0.95	0.004	0.52
14 day	4.70	4.70	4.90	4.83	4.91	0.04	0.01	0.12	<.001	0.19
21 day	6.54	6.61	6.86	6.84	6.88	0.06	<.001	0.05	0.02	0.10
28 day	8.22	8.32	8.59	8.65	8.70	0.08	<.001	0.01	0.05	0.18
Total Gain	6.74	6.85	7.11	7.18	7.22	0.08	<.001	0.01	0.05	0.18
Average Daily Gain (kg/day)										
Birth - 14 days	0.218	0.216	0.231	0.228	0.232	0.003	0.003	0.032	0.002	0.050
14- 28 days	0.255	0.261	0.266	0.279	0.275	0.004	<.001	<.001	0.937	0.208
Birth to 28 days	0.239	0.243	0.252	0.255	0.257	0.003	<.001	0.005	0.053	0.169

Sow feed intake, birth weight, lactation length and number weaned were used as covariates

Individual Piglet Performance

The mean piglet birth weight was 1.47 and piglet performance is detailed in Table 4. The treatment groups increased individual piglet weight by 345g at weaning (P<0.001) compared to the control group due to improved ADG (P<0.001). Phased feeding increased piglet weight at day 21 (P=0.045) compared with the flat feeding regime. By weaning, piglets from sows offered the phased feeding regime were 220g heavier than those from sows offered the flat feeding regime (P=0.007). Increased lysine:valine ratio also improved piglet weight, particularly at day 10 (P=0.004) and 21 (P=0.017). While the significance decreased at weaning, piglets suckling sows offered the high lysine:valine ratio were 160g heavier compared to the normal lysine:valine level (P=0.049).

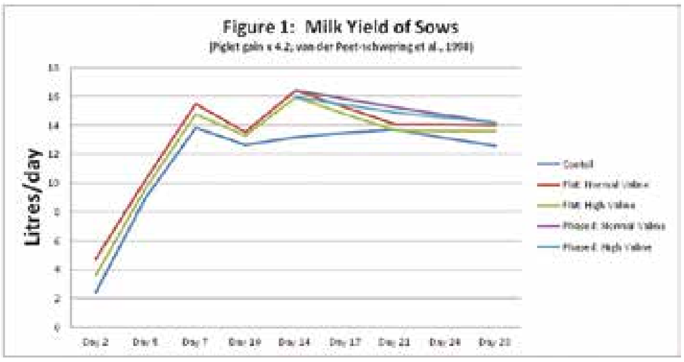
Milk Composition and Yield

The diets containing high lysine:valine ratio increased milk fat on day 21 (P<0.001) and 28 (P=0.002) of lactation (Table 5). The control group had increased urea nitrogen in milk on day 7 (P=0.03) and 10 (P=0.009) compared to the treatment groups. There was no overall effect of treatment on the protein or casein content of milk, but both were numerically higher on day 14 in the treatment groups compared to the control. Lactose content was greater in the Flat-Norm Valine than Flat-High Valine treatment on day 7. There was an interaction between feeding regime and lysine : valine ratio on milk lactose content. Within the flat feeding regime, when a normal lysine : valine ratio diet was offered the lactose content was higher than when the high lysine : valine ratio treatment was offered. However, this was only apparent on day 7.

Milk yield was calculated using the growth rate of the piglets. It was estimated to be 4.2 x piglet growth rate (mean of several studies as estimated by van der Peet-schwering *et al.*, 1998). For all treatments, milk yield peaked at day 7 but dipped at day 10 (Figure 1). The final peak was at day 14 after which milk yield slowly declined until weaning (Figure 1).

Blood Urea Nitrogen

There was no significant difference between treatments on the level of urea nitrogen in the blood, back fat depth at P_2 or BCS change. The mean level of nitrogen (BUN) in the blood was 17.1 mg/l.



Discussion

An increase in weight at weaning will reduce the time to slaughter (Campbell, 1990; Dunshea *et al.*, 2003; Cabera *et al.*, 2010). Therefore, improving piglet performance during the suckling period will increase its lifetime productivity. During the suckling period the piglet is also highly efficient at converting nutrients to lean gain (Pluske and Dong, 1998) and pig growth potential is therefore very high (Hodge, 1974). As such the pre-weaning period represents a prime opportunity to optimise the lifetime

Table 5: Effect of diet on milk composition (g/100g)

			Flat		Phased			Effects (P Value)			
		Control	Norm Valine	High Valine	Norm Valine	High Valine	SEM	Ctrl v. Trt	Flat v. Phased	High v. Norm Val	Inter-actions
Fat	Colostrum	3.9	3.9	4.1	4.3	4.0	2.88	0.674	0.608	0.919	0.378
	Day 05	7.3	7.1	8.0	7.3	7.8	3.46	0.463	0.973	0.08	0.577
	Day 07	7.4	7.6	8.2	7.3	8.0	2.49	0.124	0.315	0.011	0.949
	Day 10	7.4	7.8	7.9	8.0	7.9	2.92	0.124	0.756	0.903	0.816
	Day 14	6.8	7.0	7.5	7.1	7.3	2.28	0.11	0.868	0.114	0.549
	Day 21	6.8	6.9	7.7	7.1	8.0	2.23	0.021	0.324	<.001	0.915
	Day 28	6.7	6.4	7.7	7.2	7.5	2.57	0.059	0.275	0.002	0.062
Lactose	Colostrum	3.1	3.3	3.3	3.5	3.2	0.903	0.07	0.776	0.172	0.191
	Day 05	5.3	5.3	5.2	5.3	5.3	0.422	0.508	0.709	0.075	0.287
	Day 07	$5.5^{a,b}$	5.5^{b}	5.4^{a}	$5.4^{a,b}$	$5.5^{a,b}$	0.437	0.962	0.701	0.295	0.021
	Day 10	5.6	5.6	5.6	5.6	5.6	0.359	0.873	0.703	0.904	0.238
	Day 14	5.7	5.7	5.7	5.6	5.7	0.384	0.633	0.363	0.201	0.771
	Day 21	5.6	5.6	5.6	5.6	5.6	0.421	0.286	0.953	0.228	0.993
	Day 28	5.5	5.6	5.5	5.5	5.5	0.495	0.634	0.608	0.19	0.334
Urea Nitrogen	Colostrum	78.0	69.3	66.6	64.7	73.8	29.6	0.006	0.668	0.285	0.05
	Day 05	53.6	55.9	49.8	51.6	48.4	19.68	0.331	0.15	0.022	0.461
	Day 07	54.0	49.4	45.4	51.6	48.8	21.83	0.030	0.203	0.118	0.781
	Day 10	51.2	43.4	45.5	42.7	41.2	27.1	0.009	0.348	0.923	0.515
	Day 14	49.1	51.1	43.4	51.4	49.7	26.1	0.946	0.208	0.075	0.251
	Day 21	54.3	52.3	52.1	53.3	53.5	22.12	0.556	0.595	0.979	0.93
	Day 28	57.1	58.8	53.7	57.2	57.6	28.2	0.934	0.693	0.417	0.332
Protein	Colostrum	15.3	12.9	13.8	12.3	14.1	5.64	0.002	0.785	0.019	0.37
	Day 05	4.9	4.8	5.0	5.0	5.0	0.76	0.44	0.108	0.524	0.349
	Day 07	4.6	4.6	4.6	4.7	4.6	0.51	0.767	0.069	0.465	0.242
	Day 10	4.6	4.5	4.6	4.6	4.5	0.701	0.723	0.661	0.947	0.053
	Day 14	4.4	4.5	4.6	4.6	4.6	0.687	0.01	0.302	0.838	0.204
	Day 21	4.7	4.8	4.9	4.9	4.8	0.809	0.073	0.947	0.521	0.258
	Day 28	4.8	4.9	5.0	5.0	5.1	0.766	0.058	0.136	0.336	0.825
Casein	Colostrum	8.8	7.5	8.0	7.2	8.2	2.93	0.002	0.832	0.018	0.4
	Day 05	3.7	3.7	3.8	3.8	3.8	0.396	0.144	0.109	0.386	0.335
	Day 07	3.6	3.6	3.6	3.7	3.7	0.286	0.367	0.198	0.854	0.7
	Day 10	3.6	3.6	3.7	3.7	3.6	0.41	0.369	0.898	0.974	0.203
	Day 14	3.5	3.6	3.7	3.7	3.7	0.401	0.012	0.704	0.172	0.067
	Day 21	3.7	3.7	3.8	3.8	3.8	0.461	0.061	1	0.076	0.196
	Day 28	3.7	3.8	3.8	3.8	3.9	0.417	0.035	0.186	0.146	0.449

Values with different superscripts are significantly different ($P<0.05$)

growth rate potential of pigs and whole farm efficiency. Therefore, the lactating sow is of utmost importance in the economics of pig farming. Unfortunately, sow milk yield (and perhaps sow milk composition) is currently a limiting factor in achieving high piglet weaning weights (over 8kg at 28days). However, this experiment has demonstrated how sow nutrient intake, milk yield and subsequently piglet weight can be increased through lactation nutrition.

The nutrient levels for the flat feeding regime were calculated by using the requirement tables found in BSAS Nutrient Requirement Standards for Pigs 2003. From these tables the authors calculated the energy and lysine needs of a sow rearing 13 piglets to 8.5kg by extrapolating the assumptions and calculations provided. As such, the BSAS Nutrient Requirement Standards recommended an intake of 108MJ DE and 77g of lysine per day to achieve the desired performance of 13 piglets weaned at 8.5kg on a 28 day lactation. This work confirmed this relationship between nutrient intake and piglet performance for large litters.

It is noteworthy that the intakes achieved in this study are likely to be higher than what is often found on commercial farms. Treatment sows were able to consume an average of 7.7kg of feed per day over the suckling period. This facilitated the high nutrient intake achieved. An explanation for the higher intakes achieved could be that the farrowing houses were kept cool (18^{o}C) and a fully enclosed, covered heated box was provided for the piglets to shelter in. Therefore, the piglet environmental needs were attended to while the sow was comfortable so as not to depress intake.

This study clearly shows that increasing energy and lysine levels above 13.6 MJ DE and 0.88% lysine (control) in the lactation diet enabled sows to raise a large litter to an acceptable weaning weight without compromising body condition and tissue breakdown. Indeed, the treatment sows produced an average of 8kg more of litter weight compared to the control sows, which is an improvement of 7.8%. This is in agreement with Walsh *et al*. (2012) and Smits *et al*., (2013) who also found that increasing the nutrient density of energy and protein in the diet, tended to improve average daily gain and weaning weight. However, the response of the animals in these two papers was not as great as in the present study despite a comparable range of nutrient densities. However, due to the high intake of the animals in this present study, actual energy and lysine intake differed significantly. For example, Smits *et al*. (2013) fed sows up to 71.6 MJ DE and 65.6g of lysine per day. In the current study the control sows consumed 96.6 MJ DE and 62.5g lysine per day with the treatment sows consuming more. Therefore, the higher intakes may have contributed to the greater response in sow and litter performance in this study.

The phased feeding regime did not improve performance at litter level. However, at an individual piglet level the phased feeding regime improved performance by 220g per piglet, compared to flat rate feeding, which is an improvement of 2.6%. This would equate to an increase of 2.9kg in litter weight for a litter of 13. In a study by Harrell *et al* (1993), artificially-reared piglets began to outstrip their sow-reared counterparts at around day 8-10 of lactation in terms of voluntary food intake; however, despite this, the authors were reluctant to introduce diets with such high oil and protein contents too early in lactation due to risk of diarrhoea in the piglets. Therefore, if the second stage diet had been introduced earlier in lactation the potential for growth may have been increased. Indeed, this is an area that warrants further study.

Increasing the lysine:valine ratio in the lactation diet above the recommended levels did not improve performance at a litter level. Richert *et al*. (1997) and Moser *et al*. (2000) all found significant litter gains (2-3kg heavier litter weight at weaning) when lysine:valine ratios were increased in the diet comparably to those used in the current study. Intake of valine ranged from 29.9 to 64.9g/day in Richert *et al*. (1997) and 46.1g/d to 66.2g/d in Moser *et al*. (2000), but in the current study valine intake ranged from 47.6g/d to 92g/day which may indicate that valine was oversupplied, or that the effect of valine plateaus.

However, at individual piglet level the higher lysine:valine ratio increased growth in the early stages of lactation. As the protein content of the milk was not increased in the high lysine:valine treatments, we assume that the high lysine:valine ratio increased milk production between day 10 and 21. After this period the magnitude in significance decreased. However, significance was still evident at weaning with the piglets on the high lysine:valine treatments having an improved weaning weight by 160g per piglet. This was an improvement of 1.8% compared to the normal lysine:valine treatments.

The compositional changes of milk in this study are comparable to Laws *et al*. (2009) and as reviewed by Darragh and Moughan (1998). The diets containing high lysine:valine ratio increased milk fat on day 21 ($P<0.001$) and 28 ($P=0.002$) of lactation (Table 5). However, Moser *et al*. (2000) and Paulicks *et al*. (2003) found no effect of valine level on milk fat. It is known that valine is used by the mammary gland for things other than protein synthesis. Therefore, over supplied valine may have been upregulated some fat synthesis mechanism. Piglets from the high lysine:valine treatments grew faster in early lactation, but by day 21 the effect had been reduced. Therefore this additional fat in the milk did not seem to further improve piglet performance from day 21 to 28.

Sows on the control diet did not mobilise more body tissues than those fed treatment diets, indicated by no significant difference in blood urea nitrogen at day 21, backfat depth or BCS. This may indicate that the sows in this study did not utilise body reserves to produce milk, but rather the increase in piglet performance was solely due to diet. This opposes previous studies which indicate the sow is able to mobilise body reserves to make up a deficiency in the diet (NRC, 1998). This is an area which warrants further research as it appears our modern sow has changed in her willingness to sacrifice body reserves for milk production. That said, the control group had increased milk urea nitrogen on day 7 (P=0.03) and 10 (P=0.009) compared to the treatment groups which may indicate a poor protein balance in the diet or some body reserves being broken down.

Sow potential

This study uncovered some outstanding performance at an individual sow level. The top 25% of sows in this study, irrespective of treatment, achieved an average of 122kg litter weight at weaning. The top 5% achieved an average litter weaning weight of 131kg. This indicates that sows have much more potential to milk than assumed. This potential must be utilised to enable modern sows to play their role in farm economics.

Conclusion

In conclusion, this study demonstrates the fact that sows are able, if given the correct balance of nutrients, to achieve weaning outputs of 110kg per litter. In practice, this equates to 13 pigs weaned at 8.5kg which is acceptable for good lifetime performance. Consumption of 108MJ DE and 77g of lysine per day are effective at achieving this performance, and increasing this intake has potential to further improve performance. Phased feeding regimes increased piglet performance by 220g at weaning. A higher lysine:valine ratio of 1;1.1 also increased piglet weaning weight by 160g per piglet.

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Success of Collaborative Research

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Introduction

The local pig industry in Northern Ireland has endured many challenges over the years, with the most widely discussed and frequent challenges being volatility in prices of pork products and feed ingredients which impact directly on profitability. However more and more so we are facing new challenges of environmental pressures, concerns over food safety, new disease risks and increasing public concerns over the use of antibiotics in intensive livestock production. This is all on top of the day to day challenges of running our pig farms as efficiently and productively as possible.

Yet despite these challenges the local pig industry remains resilient and many producers are keen to expand and invest in their businesses to become more efficient and build for the future.

Government also appears keen to support local growth and supports the Agri-Food Strategy Board's "*Going for Growth*" report and the need to grow a sustainable, profitable and integrated supply chain focused on delivering the needs of the market by 2020. In doing so it has set out a series of targets which include the challenge of growing the local sow herd by 40% up to 53,000 sows.

Table 1. Agrifood Strategy Board "*Going for Growth*" Targets

Pig 2020 Targets		
Grow turnover	By 48%	To £360m
Grow added value	By 19%	To £37m
Grow external sales	By 57%	To £240m
Grow employment	By 7%	To 1400 full time equivalents
Grow sow heard	By 40%	To 53000

It was these challenges which pig producers face that encouraged John Thompson and Sons Ltd, Devenish and the Agri-Food and Biosciences Institute to form a research consortium 18 years ago. With co-funding from the Department of Agriculture and Rural Development and industrial support from the pig producer group, PCM, the key focus of the group has been to investigate environmental, nutritional and managerial strategies to support the long term growth and profitability of local producers.

Collaborative Local Research

At the time of its inception, a unique attribute of the group was that it represented the first time that academia based research from QUB and AFBI worked on an ongoing basis with industry to deliver benefits to local producers. Over previous years each organisation was doing their own form of research, but coming together added much strength to the quality and more importantly the relevance of the information generated.

The two main issues were that quite often scientific research lacked credibility at local producer level, with producers not always believing the results that were published from university facilities, in that they didn't always reflect how pigs were grown on individual farms. Often resource levels, hygiene, biosecurity, housing quality and design, feeding systems, stocking density would be very different at these research institutes compared to commercial farms, meaning responses to different diets and treatments seen in research trials could be very different when replicated on a commercial farm. On the flip side the information and research carried out by commercial nutrition and feed companies at farm level, often lacked the science and statistics to give the confidence that the response or sometimes lack of response seen on a farm trial was indeed as a result of the changes made to the feed or feeding programme.

Bringing both forms of research together ensured that the type of research being carried out was relevant to local producers and crucially could be implemented and delivered with confidence at producer level. The projects carried out by the group have always been designed on the basis of the nearby and future challenges of local producers and have taken into consideration feedback at farm level, via farmers themselves, DARD advisors and feed company representatives. Science has underpinned all the trials and the involvement by AFBI and QUB scientists has allowed access to digestibility and balance facilities which is a major advantage when it comes to understanding the responses in performance observed due to different types of diets. Then having the ability and access to a large commercial pig production base via Devenish and Thompson customers, has enabled the validation of the science at a commercial level over large numbers of pigs across a large range of management styles, genetics and health status. This approach has ultimately created information that had been scientifically designed, statistically analysed and then commercially validated before being rolled out and implemented to a wider pig producer base.

Delivering With Confidence

A couple of projects conducted by the collaboration have really highlighted the importance of having access to scientific trials to compliment commercial farm trials. The performance variability often seen at farm level can really compromise the confidence of decision making. Given the financial implications of decisions around specifications and types of diets fed, it's vital that the information being used to make these decisions is based on science and good data rather than using historic or batch to batch results from farm. We often accept variability as the norm without fully understanding why and what it could be costing. The key to controlling this variation is to initially quantify it, then understand its origin and the contributing factors after which strategies can be developed to either reduce it or manage it.

One initial study identified eight farms, four with perceived good performance and four with perceived poor performance. A sub group of piglets were tagged on each farm and their growth rate was monitored throughout their lifetime. The results highlighted that the average performance of pigs on the best two farms was superior right from birth and overall pigs on the best two farms reached a slaughter weight of 100kg on average 18 days earlier than pigs on the poorest performing two herds. The impact on economics of this poorer growth performance was £32,000 per annum for a typical 200 sow herd or £7 per pig. Two common features of the poorer performing herds were a perceived greater disease challenge and also a more variable growth rate between pigs within the herd.

More recently, with the increased use of contract finishing 'bed and breakfast' units, and with collaboration from CAFRE pig technologists, it has now been possible to perform a similar exercise focusing on feed use efficiency. In this study, a total of 5 producers were recruited and therefore pigs originated from five sources where genetics, health and rearing system to approximately 30 kg was similar. Pigs supplied from these 5 breeding units were finished on a total of 17 finishing units. Data was collected from a total of 79 batches of pigs reared through these finishing units over an 18 month period during 2012 and 2013. In this study, health status was considered good and a mean mortality of 1.8% was found across all batches.

In this study pigs were reared from an average start weight of 39kg to an average slaughter weight of 112kg. The mean feed conversion ratio (FCR) in the study was 2.66 but there was much variation between the different batches of pigs reared within each unit (Figure 1, individual batch data represented by an 'x' with vertical lines representing

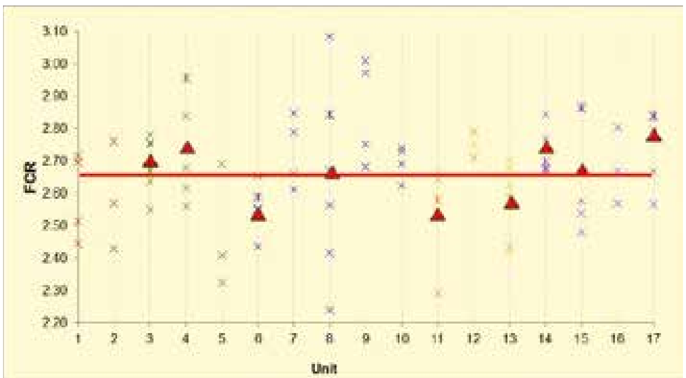

Figure 1. Spread in FCR between batches within the 17 finishing pig units and between units

each unit). When batch data was averaged for each unit, FCR ranged from 2.47 to 2.85 (Figure 1, average unit data represented by a 'triangle'). It was calculated that every 0.05 shift in FCR equated to a difference in return of 1.6 p/kg of deadweight. Therefore economically the difference between the best and worst unit, in terms of FCR, equated to approximately 12p/kg of dead weight or £34,000 per year in profitability (assuming 5200 pigs finished per year).

Meeting Environmental Challenges

In its early years work focused on the nitrogen and phosphorus requirements of pigs, as well as the use of phytase in pig diets. The main aim was to reduce the amount of nitrogen, phosphorus and ammonia being excreted into the local ecosystem from pig production. The work of the group showed that with a correctly balanced formulation, the crude protein and total phosphorus content of the diet could be reduced with no detrimental effect on performance. Most importantly, these dietary changes reduced the environmental impact of local pig production. Producers intending to expand must still comply with environmental legislation, so careful consideration and efficient management of key nutrient inputs and outputs is ever more critical. Ongoing research in this area is fundamental to pig producers who must comply with the current Nitrates Action Plan and IPPC legislation and also to plan for growth into the future.

Phosphorus

Phosphorus is one of those things which we can't live with nor live without. It is essential for bone strength and growth in pigs. Unfortunately pigs are not very efficient at phosphorus digestion and absorption, hence we have to manage phosphorus nutrition very efficiently and be conscious of phosphorus excretion and the potential impact this may have on local waterways.

To answer this issue definitively the research group set out to establish the true phosphorus requirements of pigs. Growing and finishing pigs were offered diets formulated to contain 0.45, 0.5 or 0.6% of phosphorus. There was no effect of phosphorus level on growth performance but pigs offered diets with low phosphorus (0.45%) had weaker legs which could lead to an increase in breakages and compromise animal welfare. When the diet containing 0.5% phosphorus was offered, soluble phosphorus excretion was reduced by 50% compared to when a diet containing 0.6% was offered. These findings were adopted by the industry and as a result the soluble phosphorus being excreted to the environment has been halved. This reduction means that soluble phosphorus excretion is currently over 80 tonnes less per year in N. Ireland due to pig production than if this research had not been completed.

Work followed on phytase enzymes which showed that inclusion of phytase was not a simple matter of addition but many factors influenced its effectiveness i.e. level of inorganic phosphorus in the diet, level of inbound organic phosphorus in the diet, form of phytase, heat stability of phytase and level of inclusion. Get any of these wrong and phosphorus excretion can increase and pig performance can be compromised.

Nitrogen

Early work by the consortium showed that the crude protein in diets could be reduced from 21% to 19% for pigs up to 40kg. Later work took this onto finishers and successfully dropped crude protein in the later period down to 16%. What was evident in the research was the importance of amino acid balance and the importance of knowing the transfer weights of finishers. Introducing low protein finisher diets with an inadequate amino acid balance at too early a stage was found to be costly in terms of performance, nitrogen excretion and economics. However, this work showed that getting diet formulation right in the finishing period reduced nitrogen excretion by 680g of Nitrogen/pig without compromising performance. This locally produced research data was taken to DEFRA and Brussels and resulted in the acceptance of a 25% reduction in land required for spreading pig slurry and revised Nitrates Action Plan Figures for Northern Ireland (Table 2).

Table 2. Revised Land Requirements

	Original NAP Figures (2007)		Revised NAP Figures (2011)	
	Nitrogen Excretion per pig	Land required for 2000 pigs	Nitrogen Excretion per pig	Land required for 2000 pigs
Finishing Pig	2.69 kg	31.7 Ha	2.01 kg	23.7 ha
Wean to Finish	3.41 kg	40.1 Ha	2.39 kg	28.1 ha

Nitrogen and Phosphorus are fundamental nutrients supporting pig performance. To reduce these vital nutrients with the aim of improving the environment and not impacting on performance or welfare requires knowledge. Get it wrong and the pig, the environment and the producer's pocket will suffer. Get it right and everyone wins. It is only through collaborative research that we can be confident in making radical changes to diet formulation in order to meet the requirement of environmental legislation.

Alternative Ingredients

The group has also investigated the use of various alternative raw materials to supply energy and protein in diets. Early work looked at non-cereal energy sources for finisher pigs and highlighted the pros and cons of reducing or replacing cereals when cereal costs are high. More recent work in this area has focused on alternative protein sources such as rapeseed meal and dried distillers' grains with solubles (DDGS).

The questions to be answered included; do these alternative ingredients affect performance, at what level could these be used in diets, is their use economically viable.

The first work looked at by-products such as pollard and maize gluten with additional oil against cereal and soya diets. Growth rate of pigs offered the cereal and soya diet was 4% better than that of pigs offered the by-product diets. However, for feed efficiency there was no difference. Having quantified the difference in performance, we now can make qualified decisions on the relative economic value of these raw materials on overall cost of production (Figure 2)

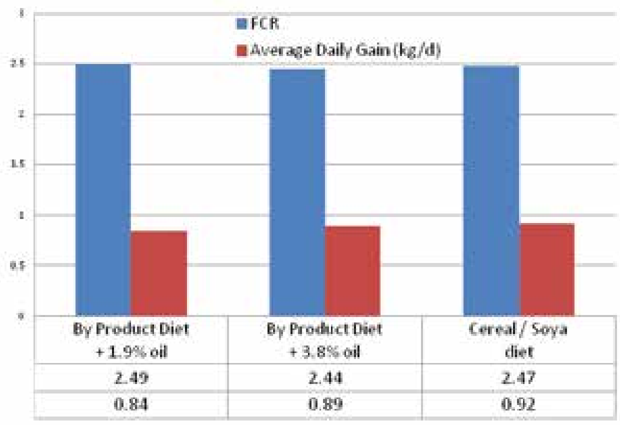

Figure 2. Finisher performance of cereal and by-product diets

Rapeseed meal (RSM) is the protein we know most about after soya. Using good quality rapeseed meal (analysed to ensure low anti nutritive properties); the consortium evaluated its inclusion in finisher diets up to 21%. Results were inconsistent across trials but showed that rapeseed meal can be included at conservative levels in finisher feeds with no impact on performance. With regard to distillers dried grains with solubles (DDGS), the use of both wheat and maize DDGS at inclusion levels up to 30% have been compared for finishing pigs. Diets containing incremental inclusion levels of both European Wheat and US maize DDGS were formulated. Pig performance was not affected by inclusion of DDGS but diet digestibility was poorer. Importantly this programme of work has highlighted opportunities as well as 'risks' when using RSM or DDGS but overall it does support their responsible inclusion in pig diets when formulated correctly into diets.

Summary

This long established research relationship has influenced policy and legislation, reduced the environmental footprint of pig production in NI, provided solutions and advice for grass route producers, has developed innovative nutritional products and has overall been a key cornerstone in the sustainable progression of the local NI pig industry. The research which has driven all of these outcomes has been thorough, detailed and well accepted by both the technical and scientific communities. During its lifetime the consortium has reported the findings of its research in open forums to producers through seminars and farmers meetings as well as through scientific abstracts to academics and peer reviewed publications. It is estimated that the group have conducted over 25 scientific trials.

Key topics which will be of consideration for the group going forward include odour emissions from pigs as well as addressing the question of 'is our current nutrition adequate for modern high performing finishing pigs?'. In order to answer these questions the group hope to use the unique climate chambers at AFBI Hillsborough as well as the unique 'feed intake' research facility. As has been past practice research findings will be validated on commercial farms and results will be disseminated for the greater good of the whole industry.

Overall it is the goal of all parties within the consortium to continue to deliver relevant and robust information which will support the sustainable advancement of the local pig industry.

The prevalence and trends of economically important porcine production diseases in Northern Ireland

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Key Messages:

- Abattoir surveillance data is an important tool for disease monitoring and the detection of animal welfare conditions. The Northern Ireland voluntary pig health scheme recorded the presence of eight macroscopic lesions detected in the pluck and on the skin of slaughter pigs. These economically significant sub-clinical infections can be considered to be performance indicators.

- Animal and herd-level prevalences of each of the different pathologies monitored at slaughter have been recorded for Northern Ireland and associations between the different pathologies have also been identified. Seasonal variation in prevalence is presented for each condition. Correlations between respiratory conditions have been identified as have those between lesions caused by parasitic infection. The prevalence of enzootic pneumonia-like lesions and lung abscesses has significantly decreased over time, whilst a statistically significant increase in pericarditis has occurred. No clear seasonal pattern emerged between 2013 and 2014 but analysis of data from a wider timeframe may reveal season trends

- Health conditions often result in significant financial losses to the pig industry and meat inspection post-slaughter provides an ideal opportunity for overall pig herd health to be assessed

.
- This work is part of a larger study that is focusing on the extent of pleurisy in Northern Ireland pigs by examining the microbiological, management and environmental risk factors associated with production diseases.

1. Introduction

Abattoir surveillance data is an essential disease monitoring tool and provides an opportunity for pig health to be assessed (Elbers *et al.*, 1992). Inspection of carcasses post-slaughter ensures the detection of disease that can pose health risks, result in economic losses and highlight animal welfare conditions. The Northern Ireland voluntary pig health scheme monitors abattoirs routinely to assess the conditions associated with economically significant sub-clinical herd infections. Veterinarians report the presence of eight different macroscopic lesions found in the pluck and on the skin of slaughter pigs. Meat inspection can be used to provide pig processers and producers with detailed herd health information. This information can potentially contribute to reduced economic losses and higher animal welfare standards (Harley *et al.*, 2012a).

Respiratory diseases are some of the most common and expensive diseases that affect pigs reared under confined and intensive conditions (Fablet *et al.*, 2011). They can result in severe economic losses due to poor growth, reduced feed efficiency and reduced carcass quality. Respiratory diseases also have an adverse effect on animal welfare (Sorensen *et al.*, 2006). The most prevalent respiratory conditions observed in pigs during routine surveillance at slaughter are enzootic pneumonia and pleurisy (Merialdi *et al.*, 2012).

Enzootic pneumonia is a chronic respiratory disease that is characterised by cranioventral pulmonary consolidation of the lungs (Merialdi *et al.*, 2012). *Mycoplasma hyopneumoniae* is considered to be the causal agent of enzootic pneumonia-like lesions in slaughter pigs (Thacker *et al.*, 2006). Pleurisy, an inflammatory lung disease, is caused by infection from multiple pathogens; viruses such as porcine reproductive and respiratory syndrome virus (PRRSV) and SIV are often implicated in causing disease along with the bacteria *Actinobacillus pleuropneumoniae*, *Haemophilus parasuis* and *Pasturella multocida* (Choi *et al.*, 2003). A.pleuropneumoniae is also the causative agent responsible for pleuropneumonia, a highly contagious respiratory disease (Bosse *et al.*, 2002). Lung abscesses are thought to be associated with secondary bacterial infections, such as ascending infections as a result from tail biting in commercial piggeries (Pijoan *et al.*, 2006).

As well as having the same disease-causing pathogens, shared management and environmental risk factors are thought to contribute to respiratory disease development (Sanchez-Vazquez *et al.*, 2012).

There are several non-respiratory conditions that are monitored in slaughter pigs as part of the Northern Ireland voluntary pig health scheme, and these too are often associated with economic losses.

Milk spot livers are indicative of infection from Ascaris suum, one of the most important gastrointestinal parasites to infect pigs (Sanchez-Vazquez *et al.*, 2010). Papular dermatitis can result from infection with *Sarcoptes scabeii,* which causes a disease known as sarcoptic mange. Pericarditis is a condition resulting from inflammation of the pericardium, the sac that surrounds the heart. Disease can be caused from infection by multiple different bacterial agents, mainly *M. hyopneumoniae*, *Streptococcus suis* (Buttenschon *et al.*, 1997) and *H. parasuis* (Nedbalcova *et al.*, 2006).

Table 1. Summary of the scoring system and associated pathology for each condition monitored at slaughter

Lesion	Pathology	Scoring system
Enzootic pneumonia	Red/tan/grey lung consolidation affecting the cranioventral regions	Goodwin-Muirhead 55 point scoring system (Goodwin *et al.*, 1969)
Pleurisy	Fibrinous or fibrous adhesions on the lung and/ or between the lung and chest wall	0 (no lesions) to 5. Score increasing with severity.
Pleuro-pneumonia	Focal areas of lung consolidation usually affecting the caudal lobes	Presence/Absence
Pericarditis	Fibrinous or fibrous adhesions on the pericardium	Presence/Absence
Lung abscess	Localised abscess within the lung	Presence/Absence
Milk spots	White areas of healing foci on hepatic tissue	Presence/Absence
Papular dermatitis	Red papules found widespread across the skin	0 (no lesions) to 3. Score increasing with severity.
Tail bite	Damage to the tail (recent or old)	Presence/Absence

Tail biting amongst pigs is considered to be a welfare indicating measurement, highlighting problems within the herd (Harley *et al.*, 2012b).

These eight macroscopic lesions are also included in other abattoir surveillance schemes including Wholesome Pigs Scotland (WPS) and the British Pig Executive (BPEX) Pig Health Scheme (BPHS) for England and Wales.

This study reports prevalences, correlations and seasonal trends of porcine production diseases in Northern Ireland from 2013-2014 using abattoir surveillance data collected from veterinary inspection. Trends over time were analysed based on average prevalences from 2008 to 2014.

2. Methods

2.1 Data collection

A total of 90,938 pigs from 1145 batches were subject to lesion monitoring over a 2-year period from 2013-2014. This data was collected as part of the Northern Ireland health and welfare checks conducted by Pig Regen Ltd. Eight lesions are assessed by veterinary inspection as part of the scheme and include; enzootic pneumonia-like lesions, pleurisy, pleuropneumonia, lung abscess, milk spot livers, papular dermatitis, pericarditis and tail bite. The pathology and scoring system used are described in table 1. Average prevalence data was obtained over a total of 16 seasons from 2008 to 2012 to allow for analysis of trends over time. This data set is separate from the data obtained for 2013 and 2014, as only average prevalences were available for analysis. The monitoring of pleuropneumonia lesions did not occur in Northern Ireland prior to 2009. Lesion monitoring occurred twice yearly until 2012 and has since increased to a 3 times yearly assessment (quarterly monitoring commenced in 2015).

2.2 Data analysis

A descriptive analysis of the data set was compiled and used to calculate the observed prevalences of each lesion. For herd-level prevalences a generalised linear model (GLM) binomial distribution was fitted with a logit link function. The effect of season was assessed by comparing the deviance of the explanatory variable (season) against the appropriate χ^2 distribution. Correlations between lesions at slaughter were analysed using a Pearson's product-moment correlation co-efficient to determine the size of the correlations observed, followed by an equivalent probability two-sided test of correlations to determine significance. An analysis of variance (ANOVA) was used to compare mean prevalences between seasons and was assessed using a F-distribution. Overall effect of season was further examined using a Fisher's Least Significant difference (LSD) test. Time trend analysis was performed using a Mann-Kendall Trend Test (Kendall, 1970; Mann, 1945) to assess the trend in prevalences over time. All data was statistically analysed using the programme Genstat (Release 16.2). VSN International Ltd., Hemel Hempstead, UK.

3. Results

3.1 Prevalence of lesions

The prevalence of porcine production diseases monitored at slaughter in Northern Ireland between 2013 and 2014 are presented in tables 2 and 3.

3.1.1 Animal-level prevalence

Milk spot lesions were the most prevalent condition with a prevalence of 15.97% recorded. Pleurisy was the second most common condition with an average of 9.22% of pigs presenting with lesions at slaughter. The prevalence of enzootic pneumonia-like lesions was 6.69%, followed by pericarditis that had an average of 4.26%. The prevalence of pleuropneumonia, lung abscess, papular dermatitis and

Table 2. The percentage (%) of pigs with lesions; prevalences for 2013 and 2014.

Lesion	Year		
	2013	2014	2013-14
Enzootic pneumonia	58.98	54.08	56.54
Pleurisy	75.26	71.10	73.72
Pleuropneumonia	10.14	10.64	10.38
Pericarditis	72.63	71.10	71.73
Lung abscess	13.75	10.28	12.04
Milk spots	61.52	62.60	62.05
Papular dermatitis	4.469	4.078	4.277
Tail bite	20.10	16.13	18.15

Table 3. The percentage (%) of herds with lesions; prevalences for 2013 and 2014.

Lesion	Year		
	2013	2014	2013-14
Enzootic pneumonia	6.83	6.54	6.69
Pleurisy	10.10	8.34	9.21
Pleuropneumonia	0.28	0.28	0.28
Pericarditis	4.09	4.45	4.27
Lung abscess	0.21	0.19	0.20
Milk spots	15.1	16.82	15.97
Papular dermatitis	0.55	0.64	0.60
Tail bite	0.79	0.40	0.60

tail bite lesions were low, with prevalences for each <1%. Lung abscesses were the least frequently observed over the study period.

3.1.2 Herd-level prevalence

Pleurisy is the most prevalent condition with 73.72% of herds affected, followed closely by pericarditis with a herd-level prevalence of 71.73%. Herds affected by milk spot lesions were the third most common with 62.05% of herds positive. Enzootic pneumonia-like lesions were observed in 56.54% of herds, tail bite in 18.15%, lung abscess in 12.04%, pleuropneumonia in 10.38% and papular dermatitis in <5% of herds. Papular dermatitis was the least frequently observed condition at herd-level over the study period with an average of 4.27% of herds affected.

3.2 Correlations between lesions

A Pearson's product-moment correlation analysis was carried out on the eight different lesions observed at slaughter between 2013 and 2014 to determine if associations between conditions could be determined. This analysis was then followed by an equivalent probability two-sided test of correlations to determine significance. The probability of significance of these correlations is presented (table 4). Significant values are those ≤0.05 and represent a relationship that has not occurred by chance.

Associations were found between the different respiratory lesions, lesions caused by parasitic infections and between tail biting and lung lesions. Enzootic pneumonia-like lesions were found to be associated with pleurisy (p<0.001), pericarditis (p<0.05), lung abscesses (p<0.001) and papular dermatitis (p=0.083) lesions. Pleurisy lesions were similarly correlated with enzootic pneumonia, pericarditis (p<0.001) and pleuropneumonia (p=0.0034) lesions, and a correlation was also found between pleurisy lesions and tail bite (p=0.037). In addition to pleurisy, pleuropneumonia lesions were also associated with lung abscesses (p<0.001). Milk spot lesions were found to have a relationship with papular dermatitis (p=0.0052).

Table 4. Probability (p) of significance for each correlation coefficient observed between lesions recorded in pigs at slaughter over 2 years in Northern Ireland (2013-2014).

Lesion	Enzootic pneumonia	Pleurisy	Pleuro-pneumonia	Pericarditis	Lung abscess	Milk spot	Papular dermatitis	Tail bite
Enzootic pneumonia	-	<0.001***	0.1261	<0.001***	<0.001***	0.5118	0.0083*	0.0589
Pleurisy	<0.001***	-	0.0034*	<0.001***	0.0021*	0.6827	0.0789	0.0307*
Pleuro-pneumonia	0.1261	0.0034*	-	0.0511	<0.001***	0.3950	0.4995	0.4920
Pericarditis	<0.001***	<0.001***	0.0511	-	0.3945	0.0597	0.4302	0.8571
Lung abscess	<0.001***	0.0021*	<0.001***	0.3945	-	0.1070	0.4816	<0.001***
Milk spot	0.5118	0.6827	0.3950	0.0597	0.1070	-	0.0052*	0.4222
Papular dermatitis	0.0083*	0.0789	0.4995	0.4302	0.4816	0.0052*	-	0.3761
Tail bite	0.0589	0.0307*	0.4920	0.8571	<0.001***	0.4222	0.3761	-

*Significant at p<0.05; *** significant at p<0.001

Table 5. Seasonal prevalences (%) of lesions monitored in individual pigs at slaughter.

Lesion	Spring 2013	Summer 2013	Autumn 2013	Spring 2014	Summer 2014	Autumn 2014
Enzootic pneumonia	6.54	7.21	6.79	7.93	6.69	5.01
Pleurisy	8.42[ab]	12.54[c]	9.50[b]	8.45[ab]	9.72[b]	6.85[a]
Pleuro-pneumonia	0.232	0.23	0.39	0.18	0.21	0.44
Pericarditis	4.26[a]	4.15[a]	3.83[a]	3.93[a]	5.37[b]	4.04[a]
Lung abscess	0.20	0.20	0.24	0.26	0.15	0.16
Milk spot	14.34	15.22	15.97	15.08	19.91	15.39
Papular dermatitis	0.58	0.57	0.51	1.06	0.37	0.49
Tail bite	0.64[a]	0.54[a]	1.18[b]	0.40[a]	0.35[a]	0.45[a]

Means with a common superscript are not significantly different from each other.

3.3 Seasonal trend

An analysis of variance (ANOVA) was carried out to determine if there were significant differences between the prevalence of lesions observed between seasons from spring 2013 to autumn 2014. Seasonal prevalences for each condition monitored at slaughter are presented in table 5.

The analysis revealed that there were no significant seasonal differences in the prevalence of lesions for enzootic pneumonia, pleuropneumonia, lung abscesses, milk spots or papular dermatitis at slaughter.

Prevalence of pleurisy was highest in the summer although this observation was statistically significant only for 2013. Although not statistically significant, pleuropneumonia lesions were found to be more prevalent in autumn. Pericarditis lesions were found to peak in prevalence during summer 2014. The prevalence of tail bite lesions peaked in autumn 2013 before dropping back to levels similar to that of the previous seasons.

3.4 Trend over time

A Mann-Kendall time trend analysis was carried out on the average prevalence of lesions observed in pigs at slaughter from autumn 2008 to autumn 2014 to determine if statistically significant differences in prevalence could be discerned over time (Table 6).

A negative trend was observed in the prevalence of enzootic pneumonia-like lesions ($p<0.001$) over time and in the prevalence of lung abscesses ($p=0.007$). A positive trend was found for pericarditis lesions with an increase in prevalence observed over time ($p=0.003$). There was no trend over time observed for the prevalences of pleurisy, pleuropneumonia, milk spot, papular dermatitis or tail bite lesions.

4. Discussion

This study has provided valuable information on the prevalence of important production diseases within the pig industry in Northern Ireland. Prevalences of each of the

Table 6. Trend in lesion prevalence observed over 16 seasons from pigs slaughtered in Northern Ireland (2008-2014).

Lesions	Probability	Trend
Enzootic pneumonia	<0.001***	Negative
Pleurisy	0.253	None
Pleuro-pneumonia†	0.995	None
Lung abscesses	0.007*	Negative
Pericarditis	0.003*	Positive
Milk spots	-0.7331	None
Papular dermatitis	0.083	None
Tail bite	0.334	None

*Significant at $p<0.05$; *** significant at $p<0.001$

†Pleuropneumonia lesions were not recorded prior to autumn 2009

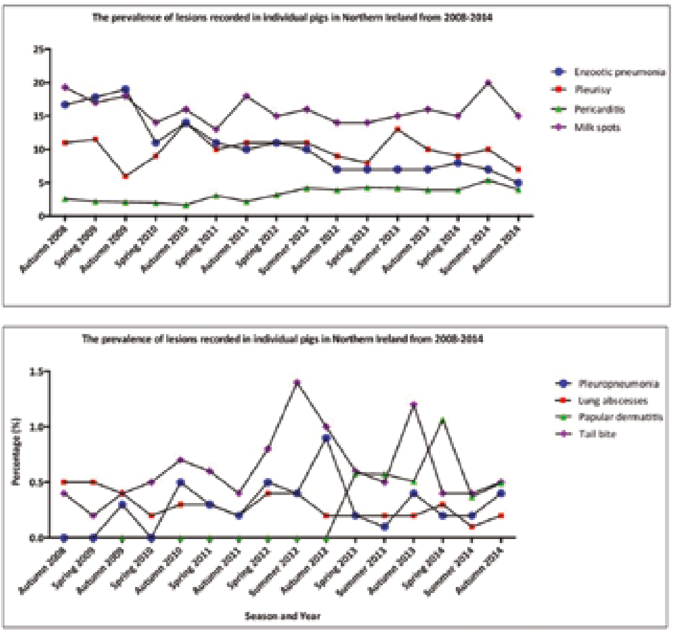

Figure 1. Trend in prevalences of each different lesion recorded in individual pigs at slaughter over a 6 year period from 2008-2014. Figure 1(a) presents the most common lesions observed at slaughter, and figure 1(b) shows the least common lesions observed at slaughter.

eight lesions were reported at both the animal and herd-level, correlations between lesions were determined in animals at slaughter and seasonal trends were examined. This analysis has demonstrated the importance of routine abattoir inspection post-slaughter to identify herd health issues and trends related to specific lesions.

4.1 Respiratory lesions

4.1.1 Prevalence

The prevalence of enzootic pneumonia-like lesions is lower in Northern Ireland than those prevalences observed for England and Wales, and Scotland between 2005-2012. In Scotland, England and Wales, the prevalence of enzootic pneumonia was reported at 22.7% and 29% respectively (Eze *et al.*, 2015). This current study has reported a much lower prevalence of 6.69% between 2013 and 2014.

The prevalence of pleurisy lesions in Northern Ireland (11% of pigs in 2012, 9.21% across 2013-2014) are however similar to those observed in England and Wales (11.53% in 2012), and lower than in Scotland (15.47% in 2012) (Eze *et al.*, 2015). Pleuropneumonia and lung abscess were reported at very low levels and are similar to those prevalences reported by Eze *et al.* (2015) for the rest of the UK.

4.1.2 Correlations

Correlations were found between a number of respiratory conditions, in particular, between pleurisy and enzootic pneumonia-like lesions. Enzootic pneumonia was also found to be associated with lung abscesses and pericarditis, and pleurisy was found to be associated with pleuropneumonia and pericarditis lesions. This supports the findings of Mayns *et al.* (2011) who found that there was a close association between respiratory lesions due to their likely shared causal factors.

4.1.3 Seasonal variation

No clear seasonal differences were observed over 2013 and 2014. This may be due to the short time span and such trends may be observed when the seasonal data is evaluated from 2008. However, statistically significant peaks were observed for pleurisy in the summer of 2013, for pericarditis during the summer of 2014 and for tail bite lesions in autumn 2013.

Other studies have reported seasonal variation for pleurisy lesions, with the highest prevalences observed in the spring and summer months (Maes *et al.*, 2001; Cleveland-Nielsen *et al.*, 2002). The peak prevalence of pleurisy in Northern Ireland in the summer of 2013 coincided with a PRRSV outbreak on the island of Ireland in March/April of the same year. Although not statistically significant, pleuropneumonia lesions did appear to be more prevalent during the autumn, and this pattern is similar to those patterns also observed in England and Wales, and Scotland (Eze *et al.*, 2015).

4.1.4 Trend over time

A decrease in enzootic-pneumonia-like lesions and lung abscesses has been observed in Northern Ireland pigs, whereas no trend over time was established for either pleurisy or pleuropneumonia lesions in pigs at slaughter. It would be expected that enzootic pneumonia and pleurisy follow the same trend as they share management and environmental risk factors (Sanchez-Vazquez *et al.*, 2012) and similar pathogens are often implicated in causing disease. The decrease in enzootic pneumonia lesions may be explained by an increase in vaccination against *M. hyopneumoniae*, however further research would be needed to fully explore this. The decrease in lung abscess prevalence in more recent years is similar to trends observed in England and Wales (Eze *et al.*, 2015).

4.2 Non-respiratory lesions

4.2.1 Prevalence

Milk spots are the most prevalent lesions observed in animals at slaughter in Northern Ireland (15.97% of animals average 2013-2014), which is in contrast to the continued decrease reported in the UK (<5% between 2005 and 2012) (BPHS, 2012). In comparison with other European countries, the prevalence of milk spot lesions is high; a recent study by Ondrejkova *et al.* (2012) reported the prevalence of milk spot lesions to be 6.85% in Slovakia in 2009. This high prevalence is considered to be uncharacteristic for an indoor production system, as evidence suggests outdoor systems are more susceptible to internal parasitic infection (Nansen and Roepstorff, 1999). Growing resistance to anthelminthic treatments is suggested to be a factor behind the high levels of milk spot lesions.

The prevalence of pericarditis in Northern Ireland (4.27% average 2013-2014) is similar to that of reported prevalences for other European countries (Nielsen *et al.*, 2015).

Papular dermatitis was reported at very low levels, with lesions observed in <1% of animals and <5% of herds. This is consistent with reports from the BPHS (2012) that the prevalence of papular dermatitis in England and Wales is decreasing.

The prevalence of tail bite lesions in Northern Ireland (0.6%) is lower than reported values for other European countries. Valros *et al*. (2004) reported fresh tail biting in 11.7% and severe tail biting in 1.3% of pigs in Finland. However, the severity of tail biting was not considered in this study.

4.2.2 Correlations

Correlations have been observed between milk spot lesions and papular dermatitis, which is indicative of poor parasitic control on farms. It has been suggested that poor husbandry and sub-optimal levels of hygiene may contribute to disease development as reported by Sanchez-Vazquez *et al*. (2012), who found similar associations between lesions caused by parasitic infection.

Pericarditis was found to be associated with two respiratory lesions, pleurisy and enzootic pneumonia. This relationship is reflective of the shared causal influences for disease development, such as environmental and managerial factors.

Correlations were found between tail biting and the presence of pleurisy lesions. Associations between tail biting and respiratory lesions have previously been identified (Kritas *et al*., 2007) and it is thought that tail bites offer a route for bacterial infection (Pijoan *et al*., 2006). Tail biting is commonly associated with pig welfare and considered to be an important economic issue for porcine production (Valros *et al*., 2004). In Northern Ireland tail-biting prevalence is observed in <1% of pigs and could reflect high welfare standards within the industry.

4.2.3 Seasonal variation

A clear seasonal trend has not been established for pericarditis lesions, however there was a peak in prevalence observed in summer 2014. No seasonal trend has been identified for milk spots, papular dermatitis or tail bite lesions over the duration of this study. The lack of seasonal variation in the prevalences of the above lesions indicates that season is not a driving factor in these conditions in Northern Ireland pigs.

4.2.4 Trend over time

No trends over time were observed for milk spot lesions, papular dermatitis or tail bite lesions over the duration of this study. There has however been a significant increase in the prevalence of pericarditis lesions over time in Northern Ireland, which corresponds with increasing pericarditis reports in the UK from BPHS (2012).

5. Conclusion

The prevalence of eight macroscopic lesions assessed in Northern Ireland pigs have been reported at animal and herd-level between 2013 and 2014. Correlations between respiratory lesions and lesions caused by parasitic infection were also reported. Enzootic pneumonia and lung abscesses have decreased over time, and an increase in pericarditis lesions has been observed.

Routine inspection of meat post-slaughter is an important and necessary application, useful for the implementation of management strategies and as an indicator of welfare problems within a herd. Understanding the extent of both respiratory and non-respiratory lesions is essential to prevent disease, improve animal productivity and help reduce costs associated with lesions at slaughter.

This work is part of a larger study that is also focusing on the management and environmental risk factors associated with disease as well as examining the dynamic of infection on farm through longitudinal studies. It is intended that the outcomes of this study will be used to inform management decisions in pig farms in Northern Ireland and will complement other work done in the RoI.

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Feeding The Finishing Pig

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Key Messages:

- The optimum time (in terms of pig performance and cost of production) to change from a grower diet to a finisher diet is when pigs are 60kg.
- However, using a phasing approach to offer the finishing diet did not reduce the variable weight of pigs at slaughter.
- With regard to wet feeding, pigs were heavier at finish when offered ad lib wet compared to ad lib dry feed.
- However wet fed pigs had a poorer KO% and as a result a poorer carcass FCR.
- Overall a differential of 2.4p on cost per kg carcass gain or £1.08 per pig was found when using dry feed compared with wet feed.

Introduction

Finishing feed accounts for approximately 70% of the feed used in a birth to bacon unit. Financially 60% of feed cost is in the finishing period. However producers and technical support still spend the largest proportion of their time with the sows and young pigs. On farm finisher pigs receive much less specialised attention or leave the farm and are contract finished. On a 500 sow unit with 24 pigs/sow/year, keeping all performance parameters the same, an improvement in feed conversion ratio (FCR) of 0.1 equates to £18,000 per year. This is equivalent to achieving 28 rather than 24 pigs per sow year in terms of profitability. Therefore, small changes in FCR during finishing can be make or break for many pig units. In a collaborative project between Devenish Nutrition, Preferred Capital Management and AFBI, with co funding from the DARD Research Challenge Fund, diet management of finishing pigs was investigated across three studies.

Study 1: Pig weight & diet change

This research was designed to identify when diets should be changed during finishing. Phase feeding is commonly used across Europe but less so in Northern Ireland. Some previous work has shown that phase feeding can lead to poorer FCR than feeding one diet throughout finishing, for example FCR deteriorated by 0.18 when the same nutrients were offered across two diets compared to one diet (MLC 2004). However, if using a single diet in finishing when should pigs move from grower to finisher? Commercially, this is often determined by when pigs move from growing to finishing accommodation since only one auger line feeds finisher houses. Hence diet and housing are changed at the same time and this is often accompanied by a drop in growth rate for approximately one week (Beattie *et al*., 2002). Transfer weights can vary greatly from farm to farm and within a batch of pigs so if a producer could offer grower diet in the finisher house the question posed is: What weight should it be fed to?

The answer to this question is determined by the growth curve of the pig. Whittemore (1986) stated that linear growth is lost as the pig matures, not because of lack of potential of the pig to grow, but because of man's influence on the pig. If adequate nutrient intake is ensured, it is difficult to prove that growth rate varies at any period in the pigs growing period.

Previous work carried out at Hillsborough (Weatherup *et al*., 1998), using individually housed pigs, found that growth rates remained constant at 1130g/d with increasing weight through the weight range (Figure 1). More recent work on commercial farms has shown, that after any initial set-back, growth rate is constant and so weight gain was linear to a final live weight of 105 Kg (Beattie et.al., 1999; Magowan *et al*., 2014) (Figure 1). The difference between the growth curves in Figure 1 is due to feed intake. Pigs at Hillsborough were eating on average 2.82 kg/d, while pigs on commercial Farm 2 consumed 2.61 kg/d and pigs on commercial Farm 1 only ate 2.39 kg/d. Given these differences in growth the issue is how to ensure nutrient intake. One indication comes from the performance of pigs on commercial Farm 1 for the first four weeks. These pigs went onto the finisher diet at approximately 34 kg while on Farm 2 pigs were on average 43 kg and in Hillsborough they were 60 kg before going onto finisher diet. This study therefore investigated the impact on animal performance by introducing the finisher diet at 40, 50, 60 or 70kg live weight.

Methodology

The study was carried out on a commercial farm. There were five dietary treatments with each being replicated eight times over four time periods. There were 15 pigs per pen and within time periods pens of pigs were

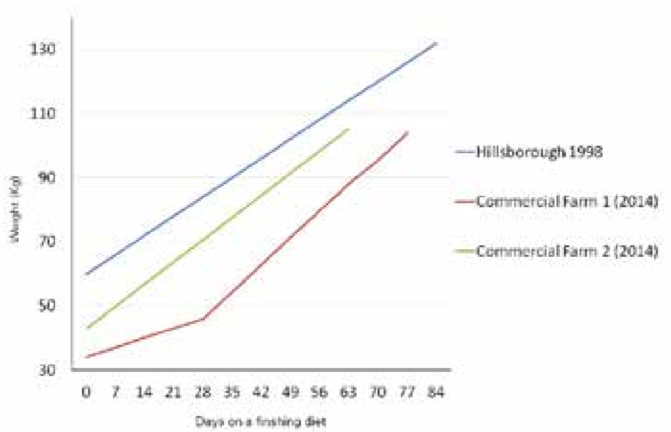

Figure 1: Growth curves of finishing pigs on commercial farms and individually housed on a research farm

balanced for weight and gender. The five treatments were based on the weight of pigs transferred from grower diet (CP 18.5%, Lysine 1.25%, DE 14.6 MJ/kg) to finisher diet (CP 17.0%, Lysine 1.0%, DE 13.8 MJ/kg) (Table 1). Diets were offered in dry pelleted form through single space wet and dry feeders with one feeder per 15 pigs.

Table 1: Treatments in Study 1

	Transfer weight from grower to finisher diet
Treatment 40	40 kg
Treatment 50	50 kg
Treatment 60	60 kg
Treatment 70	70 kg
Positive control (+ve)	Grower diet offered throughout finishing

Pens of pigs were weighed at the start (approximately 13 weeks of age) and every two weeks until the first pigs went for slaughter after which they were weighed every week. Pigs were weighed individually when being sent for slaughter. Pen feed intake was recorded daily and any feed left at the end of the trial was weighed. Cold weight and back fat depth at P_2 was recorded at the factory before chill.

Results

Over the finishing period (37 to 118kg) feed intake was similar across treatments averaging 2.48 kg/d ($P>0.05$). However there was a significant quadratic response ($P<0.05$) of diet on growth rate with growth rate increasing as transfer weight increased to 60kg but decreasing again when transfer weight was 70kg. (Figure 2)

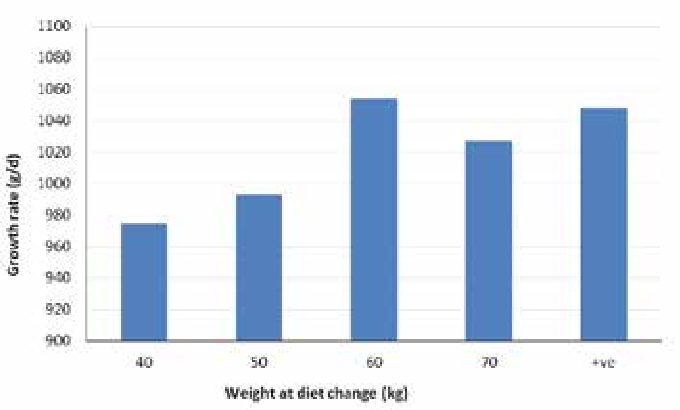

Figure 2: Growth rate of pigs changing from grower to finisher diets at different weights

FCR showed a similar quadratic response ($P<0.01$) with FCR improving as transfer weight increased to 60kg but no further improvement was noted when transfer weight was 70kg. (Table 2). There was no difference in P_2 across treatments (average of 13.8mm).

The growth rate and FCR of pigs offered the positive control was numerically comparable to those whose diet changed at 60kg but was statically similar to those pigs whose diet changed at 50, 60 or 70 kg.

When offered the grower diet (treatments 50, 60 & 70) the daily gain of pigs averaged 1099 g/d and their feed conversion ratio averaged 1.93. When these pigs moved to the finisher diet (treatments 50, 60 & 70) their growth rate averaged 1017 g/d and FCR was 2.66.

It is interesting to note that the intake of pigs which were offered finisher diet from 40kg (i.e. for the vast majority of the finishing period) had the same intake as the pigs which were offered grower diet for the whole of the finisher period (positive control treatment). However the nutrient intake on the two treatments was very different (Table 3). Pigs who were offered grower throughout consumed 6% more energy and 20% more lysine. This was reflected in performance with pigs on grower throughout growing 73 g/d faster and having 0.17 better FCR.

This would support Whittemore's argument that any deviation from linear growth is due to man's influence on the pig and the suggestion made earlier that it is nutrient intake that determines growth.

Economics

Optimum performance is one aspect but what regime is most cost effective? To calculate economic return a £30/tonne differential was used between grower and finisher diets. Using this differential the break point for cost per kg gain followed the same pattern as the performance figures with changing diet at 60 kg being optimum at 49.6p/kg while changing before 60 kg averaged 50.5p/kg (Table 4).

Conclusion

The weight at which pigs changed diet was controlled in this study on a pen by pen basis and pigs were weighed every two weeks to ensure an accurate diet changeover. However, commercially pigs are judged by eye and the change of diet will be based on an average weight for the house. Previous work by Magowan *et al*. (2006) has shown that when a group of pigs average 40 kg the range can be 25-50 kg. Therefore given the economics the optimum time to change diet is at an average weight somewhere between 50 & 60 kg. The most important aspect is to make sure the bottom 25% of pigs are definitely over 40 kg.

Table 2 Effect of transfer weight on FCR

	Weight of diet change (kg)						P Values	
	40	50	60	70	+ve	SED	Linear	Quadratic
FCR	2.51	2.48	2.41	2.40	2.33	0.055	0.874	0.005

Table 3: Nutrient intake comparison of pigs that changed to finish diet at 40 kg or did not change

	40	+ve
Feed Intake (g/d)	2454	2458
Energy Intake (MJ/d)	33.8	35.9
Lysine Intake (g/d)	24.5	30.7

Table 4: Economics of when to change from grower to finisher diet.

	Treat 40	Treat 50	Treat 60	Treat 70	+ve control
No. of pigs	120	120	120	120	120
Start wt. kg	38.77	35.87	36.39	36.45	37.28
Diet change	38.77	50.18	62.49	72.69	NA
End wt. kg	115.4	115.8	120.4	117.8	119.12
GROWER					
Feed intake (g/d)		2024	2083	2224	2458
Growth rate(g/d)		1101	1135	1060	1048
FCR		1.85	1.84	2.11	2.35
Kgs Gain		14.31	25.92	36.24	81.84
Kgs feed		26.47	47.69	76.47	192.32
Cost of feed		£6.09	£10.97	£17.59	£44.23
FINISHER					
Feed Intake (g/d)	2454	2565	2743	2683	NA
Growth rate (g/d)	975	993	1040	1018	
FCR	2.52	2.58	2.64	2.64	
Kgs gain	76.63	65.62	57.91	45.11	
Kgs feed	193.1	169.3	152.9	119.1	
Cost of feed	£38.62	£33.86	£30.58	£23.82	
Cost of feed		£39.95	£41.55	£41.41	
Kgs gain		79.93	83.83	81.35	
Cost/kg gain	50.4p	50.0p	49.6p	50.9p	54.0p

Study 2: Variation and change of diet

As mentioned above the weight variation within pens of pigs can be large. As such study 2 was designed to identify if phasing diets in finishing increased or reduced variation in finish weight compared to feeding one single diet.

Methodology

Over eight replicates (8 time periods) 640 pigs were weighed, transferred to finishing accommodation and assigned to treatment at 10 weeks of age so that pens were balanced for weight and gender (boars and gilts). Pigs were penned in groups of 20 and dietary treatments were offered from 12 weeks of age.

The four treatments were arranged in a 2 x 2 factorial manner and were:

- Low variation in pen weight and offered a single finisher diet (CP 17%, Lysine 1.0%, DE 14.0 MJ/kg) from 12 weeks of age to 120 kg.
- Low variation in pen weight and offered Phase diet 1 (CP18% Lysine 1.1% DE 14.2 MJ/kg) from 12-18 weeks of age and Phase diet 2 (CP 16%, Lysine 0.9%, DE 13.8 MJ/kg) from 18 weeks of age to 120 kg.
- High variation in pen weight and offered Single diet from 12 weeks of age to 120 kg.
- High variation in pen weight and offered Phase Diet 1 from 12 to 18 weeks of age and Phase diet 2 from 18 weeks of age to 120 kg.

The standard deviation of the high variation pen weight was aimed to be at least double that of the low pen weight. Pigs were weighed at 12, 15, 18, 21 & 24 weeks of age. Feed intake was recorded and FCR calculated.

Results

There was no effect of single or phase diets on feed intake, growth rate or FCR the averages being 2188 g/d, 905 g/d and 2.42 respectively over the finishing period (Table 5). As specified by the trial design, the co-efficient of variation for weight of the pigs at the beginning of the trial was greater for the high variance treatments. This higher co-efficient of variation remained until 18 weeks of age. However in the late finishing period the variation in weight within the pens became similar across all treatments (Table 6). Hence pigs in treatments that started with low variation, i.e. all pigs were similar in weight, began to diverge in weight gain and the weight range within the pens increased. Furthermore, where pen weight variation was high, it appeared to decrease as pigs approached slaughter weight. Therefore irrespective of whether pigs were offered one finishing diet throughout or finishing diets were offered using a 'phased approach' or whether pens started with pigs of similar weight or pigs with a high range of weights by the time pigs reached slaughter weight all pens had equal variance in weight.

Table 5:. Performance of pigs on single or two phase diets in groups with high or low variance in weight

	Phase (2 diets)		Single Diet			
	High weight variance	Low weight variance	High weight variance	Low weight variance	SED.	P-value
12 week wt. (kg) Final wt. (kg)	40.8 116	40.9 114	41.3 113	40.5 117	0.231	NS
Feed Intake (g/d) Growth Rate (g/d) FCR	2231 910 2.45	2136 893 2.40	2190 896 2.45	2195 922 2.38	61.69 24.94 0.046	NS NS NS

Table 6: Co-efficient of variation for weight of pigs throughout finishing having started with low or high variation in weight and offered single or phased diet.

	Phase (2 diets)		Single Diet			
	High weight variance	Low weight variance	High weight variance	Low weight variance	SED.	P-value
12 Weeks	0.12	0.070	0.103	0.069	0.0093	<0.001
15 Weeks	0.13	0.077	0.100	0.079	0.0095	<0.001
18 Weeks	0.123	0.94	0.104	0.084	0.0092	<0.001
21 Weeks	0.110	0.97	0.093	0.086	0.0112	NS
Final	0.103	0.099	0.095	0.088	0.0130	NS

Conclusions

In this trial pig performance was similar whether the finisher diet was offered as one diet or was 'phased'. Furthermore, pen weight variance appears to converge to approximately 9.5% at the slaughter stage regardless of whether there is high (11%) or low (7%) pen weight variation at the start of the finishing period. Offering the finisher diet as either a single diet of in a phased approach did not affect pen weight variation at slaughter.

Study 3: Wet vs dry feed for finishers

Historically wet or liquid feeding was more popular in the south of Ireland than the north. This was because co-products from food manufacture were more available in the south. However some of the larger producers in Northern Ireland now offer feed to pigs through liquid feed systems. Taking co-products out of the equation, the question was posed: What are the advantages and disadvantages of offering feed wet? Advantages include less dust and reduction in salmonella while disadvantages are the initial capital cost, inappetance of young pigs and water to feed ratios. In terms of growth rate and FCR, trials are inconclusive with some showing better performance than dry feed and some showing deterioration in performance (Gadd, 2003). However these trials were carried out mainly on long trough systems and there is now a real lack of data regarding *ad libitum* probe wet feeding. The aim of this research was to identify the performance of pigs offered feed *ad libitum* via probes (wet) or *ad libitum* via single space wet and dry feeders where feed is offered in dry pelleted form.

Methodology

The trial was conducted on a commercial farm. Pigs starting at approximately 35kg (12 weeks of age) were balanced for weight, gender and assigned into treatment groups. Treatment groups were 1) pigs offered the finisher diet in liquid form or 2) pigs offered the finisher diet in dry pelleted form. Since the 'wet feed' system used one trough between two pens, this meant that a 'dual' pen of pigs was treated as one replicate within the wet fed treatments. As such there were eight 'dual pen' replicates of wet feed and 16 pen replicates of pelleted feed with 15 pigs allocated per pen. 'Wet and dry' single space feeders were used to offer the dry pelleted feed and there was one wet and dry single space feeder per pen (i.e. per 15 pigs). The allocation of pens to treatment was randomly assigned across the room to remove any biased due to position in the room. All pigs were weighed at the beginning of the trial and weighed every four weeks throughout the duration of the trial. At slaughter, pigs which had reached the target slaughter weight were removed and pens of pigs were weighed weekly in the final weeks of the finishing period. Wet feed was fed through a Datamix multifeeder 5000 ad lib feeding system at a water to meal ratio of 3:1. Feed intake was recorded weekly for wet feed and daily for pelleted feed. Dead pigs were weighed and date of death recorded. Any feed which was left in the feeders was weighed at the end of the trial.

Results

The dry matter of the liquid feed in this trial averaged 234 g/kg. Pigs were on treatment from 12 weeks of age and the average start weight of pens of pigs was 46kg. Pigs fed the wet diet had a significantly higher ($P<0.01$) finishing weight of 110 kg compared to 107 kg for the pigs fed the dry pelleted diet though there was no significant effect on average daily gain (Table 7). Although wet fed pigs also had a 4% higher average daily gain compared with dry fed pigs, this effect was not statically significantly different. However, the feed intake of wet fed pigs was significantly increased ($P<0.05$) by 9% compared with dry fed pigs. There was no significant ($P>0.1$) effect of diet form on feed conversion ratio although dry fed pigs had a 4.5% numerical improvement over wet fed pigs.

Table 7 Finishing pig and carcass performance when offering pigs feed in dry or wet form.

	Finish wt (kg)	ADG (g/day)	ADFI (g/day)	FCR
Liquid feed	110	924	2559	2.77
Dry feed	107	887	2346	2.65
SED	0.913	22.9	79.6	0.077
P Value	0.004	0.116	0.014	0.115

Data from a sub section of pigs was used to determine effects on carcass performance. As such the finish weight of pigs was similar for wet and dry fed pigs when analysing carcass performance. However a significantly higher ($P<0.05$) kill out percentage (79.94%) was found for dry fed pigs compared with wet fed pigs (77.98%) (Table 8). Furthermore carcass FCR was significantly improved ($P<0.001$) for dry fed pigs compared with wet fed pigs (Table 8).

Table 8: Impact of wet or dry feed on carcass performance

	Wet	Dry	Sed.	P value
Live finish weight (kg)	110.9	109.3	1.626	NS
P_2 (mm)	11.60	11.73	0.460	NS
Cold weight (kg)	86.4	87.32	1.003	NS
KO%	77.98	79.94	0.8043	<0.05
Carcass FCR	3.53	3.23	0.084	<0.001

Discussion

Liquid feed delivery systems for pigs are considered to have many advantages over dry feeding e.g. improved growth rates, reduction in time to slaughter and improved feed conversion ratio (Canibe and Jensen, 2003). Jensen and Mikkelsen (1998) reviewed the performance of pigs fed dry or liquid diets within nine studies and found a 4.4 ± 5.4% improvement in average daily gain and 6.9 ± 3.5% improvement in FCR for pigs fed liquid diet in comparison to dry feed. Furthermore, Hurst *et al*. (2008) and Stotfold (2005) reported a significantly higher average daily gain and improved FCR for pigs fed liquid diets. Within this current animal study, pigs fed the liquid diet had a significantly higher feed intake and heavier weight at finish. However, pigs fed the dry diet had a numerically improved FCR during finish as compared to liquid fed pigs. As liquid fed pigs within this study had ad lib access to feed it is possible that there could have been wastage or spillage around the trough which led to the over estimation in average daily feed intake. Hurst *et al*., (2008) found that restricted liquid feeding improved FCR by 7-10% compared with ad lib liquid feeding. Once pigs swallow liquid feed the flow of digesta is quicker (Rayner and Miller, 1990) and it is thought that less energy is needed to transport it along the gut resulting in more energy being available for growth in the pig. However, Rayner and Miller (1990) also noted that whilst liquid fed pigs had a higher average daily gain compared to dry fed pigs they also had a numerically poorer FCR in live performance and a significantly poorer carcass FCR. This could be attributable to differences in gut fill between dry and liquid fed pigs (Hurst *et al*. 2008) as liquid feeding is known to distend the stomach and gut hence increased growth is due to a large gut instead of lean meat. The results of this study agree with those by Hurst *et al* (2008) and Patterson (1989) in finding a lower kill out percentage for liquid fed pigs compared to dry fed pigs.

The dry matter of the liquid feed in this study averaged 234 g/kg which is typical of liquid feed as noted by Brooks *et al*. (2001). However, the coefficient of variation in dry matter across the samples taken, which represented the different values across the housing, was 4.24% . This variation would result in inconsistency in performance between groups of grower-finisher pigs and this highlights a major disadvantage in utilising a liquid feeding system instead of dry feeding.

Economics

The four key aspects to be considered when calculating margin over feed include:

- Better growth with wet feed
- Better FCR with dry feed
- Better KO% with dry feed
- Cost of pelleting the dry feed

The cost per kg live weight gain was 55p/kg on wet feed and 54.4p/kg on dry feed (Table 9). However when the significant difference in KO% was considered the cost per kg carcass gain was 70.5p on wet feed and 68.1p on dry feed and the 'margin over feed cost' differential per pig was £1.08. Both the live weight gain costs and carcass weight costs were based on a £6 differential in diet costs to allow for pelleting costs. This economic analysis is based on the results of this trial. In reality the decision between wet and dry is more complicated.

Factors that also need to be considered are:

- Finishing accommodation; if it is tight then the extra growth rate on wet feed may be very important.
- Capital; the initial set up costs are a lot higher with a wet feed system
- Co-products; are there any available to make diet cost less in a wet feed system

Table 9: Economics of wet feed vs dry feed

	Wet	Dry
No. of Pigs	118	117
Start Weight (kg)	36.5	36.6
End Weight (kg)	109.6	107.0
Feed Intake (g/d)	2458	2255
Growth Rate (g/d)	895	854
FCR	2.75	2.64
KO %	78.0	79.9
P_2 (mm)	11.6	11.7
Diet Cost	£200	£206
Kgs Gain	73.1	70.4
Kgs Feed	201	186
Cost of Feed	£40.20	£38.32
Cost Kg/Gain	55.0 p	54.4 p
Kg Carcass Gain	57.0	56.3
Carcass FCR	3.53	3.23
Value of carcass gain at £1.15/kg	£65.55	£64.75
Margin over feed	£25.35	£26.43

Conclusions

Pigs were heavier at finish when offered ad lib wet feed compared to ad lib dry feed. However the KO% is 2% better on dry feed compared to wet. As a result the carcass FCR of dry fed pigs is 9% better compared to that of wet fed pigs. Overall a differential of 2.4p on cost per kg carcass gain or £1.08 per pig was found when using dry feed compared with wet feed.

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Growth, Feed and Economics

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Key Messages:

- Increasing the wean weight of piglets with a low birth weight improves their lifetime performance. Whilst birth weight is an important determinate of lifetime performance it is suggested that wean weight is of more importance.

- It is possible to reduce the growth check post weaning using unconventional piglet management.

- Increasing feed intake by 100g during the first 8 days after weaning increases the weight gain of pigs by 320g between weaning and 10 weeks of age.

- As litter size increases the value of the litter increases (margin over finisher feed cost increased by £44 on average for every extra piglet). As such the increase in numbers outweighed the impact of more piglets of a poorer weight in these larger litters. This is mainly due to the fact that these larger litters have comparable numbers of average and above average wean weight piglets.

- The margin over finisher feed cost was found to reduce by £1.46 for every 1kg reduction in pig wean weight.

Introduction

The papers at the start of these conference proceedings have focused on improving the birth and wean weight of pigs. However, it is not always clear if this additional effort pre weaning 'pays' off during the remainder of the pig's life, especially for low birth weight pigs. A key setback in itself is the weaning process and producers have come to accept that weaning causes a growth check which is unavoidable. However, as a research community it is our task to try and understand the main drivers within the post weaning growth check and identify how these can be overcome. Another key debate within the pig sector is the economical viability of large litters. As has already been mentioned earlier in this proceedings, the global pig industry is now managing a very different sow whose prolificacy is challenging the system of production. It is known that breeding goals have now shifted some focus onto survival of piglets as well as high pig numbers born alive. However it is well known that these larger litters have in general driven down birth and wean weights and therefore the lifetime performance of pigs and since the sow still only has 14-15 functional teats at most, the question is posed as to the economic balance between high numbers born and their future productivity both on a per pig basis as well as on a per litter basis.

The studies reported below have largely been co-funded by Pig ReGen Ltd (the Northern Ireland Pig Levy board) and the Department of Agriculture and Rural Development in Northern Ireland's Evidence and Innovation programme . The studies address the aforementioned key issues and have been designed to provide answers and guidance to some of the debates above.

Study 1 : The importance of wean weight

As evidenced by Vaclavkova *et al* (2012) the birth weight of pigs is a very important factor in the lifetime performance of pigs and we know it is possible to lift the wean weight of light birth weight piglets. However a key question is 'Does this uplift enable the pig to have improved lifetime performance'. In order to test this pigs in the AFBI Hillsborough herd were selected according to their birth and wean weight and their lifetime performance was tracked.

Five treatments were used which represented:

1. pigs born and weaned with a low weight (LL)
2. pigs born and weaned with a high weight (HH)
3. pigs born light but weaned heavy (LH)
4. pigs born heavy but weaned light (HL)
5. extremely low birth weight piglets which were reared in rescue decks pre weaning.(VLBW)

A total of 200 pigs (Tempo x (Landrace x Large White)) were monitored from birth to slaughter (110 kg) across four time periods. Cross fostering between litters was minimised. The piglets reared in rescue decks (birth weight of approximately 1 kg) were allowed to suckle their mother for 24 hrs after which they were transferred to 'Rescue Decks' and offered artificial milk *ad libitum* until weaning (28 days of age). No specific targets of weight were set but pigs were selected at weaning to represent light and heavy birth and weaning weight within the weight profile of all pigs being weaned from a normal batch of pigs (from 18 sows per time period). Post-weaning pigs were housed in groups of ten according to their weight 'treatment' above. Pigs were offered 3 kg/pig

of a commercial starter diet (Flatdeck 2000, A One) followed by 6 kg/pig of a second commercial starter diet (Flatdeck 2, A One) after which they were offered a grower diet (14 MJ/kg digestible energy, 186 g/kg crude protein, 12 g/kg lysine) until 12 weeks of age and then a finisher diet (13.5 MJ/kg digestible energy, 170 g/kg crude protein, 9.5 g/kg lysine) to a target slaughter weight of 110 kg. Pigs were weighed at 7, 10, 15 and 20 weeks of age and at slaughter. After slaughter the backfat depth at P_2 (65mm for the top line at the level of the last rib) was measured using the Ulster probe and carcass weight was recorded. Data were analysed on an individual pig basis using analysis of variance in Genstat version 10.

Results

Table 1 reports the weight and growth rate of pigs throughout their lifetime. The growth rate of very low birth weight pigs (VLBW) was poorest at all stages of growth. Furthermore, the back fat depth of VLBW pigs was significantly greater than that of other pigs (Table 1). Pigs that were born heavy and weaned heavy (HH) had the highest growth rate between weaning and 10 weeks of age with the result that they were the heaviest at 10 weeks of age. Although the average daily gain (ADG) of these pigs was similar to that of LL, LH and HL pigs between 10 weeks of age and finish, their weight advantage at 10 weeks of age equated to these pigs being heaviest at 20 weeks of age. LL pigs were the lightest at 10 weeks of age and numerically the lightest at 20 weeks of age. However, pigs which were born light but weaned heavy (LH) had a similar growth rate to those pigs born heavy and weaned light (HL). They also had the highest growth rate between 10 and 15 weeks of age with the overall result that LH pigs had a significantly greater 20-week weight compared to LL or HL pigs. The finish weight of LL, LH, HL and HH pigs was similar and averaged 109 kg. The finish weight of VLBW pigs was significantly lower ($P<0.001$) and averaged 90.7 kg. There was no effect ($P>0.05$) of birth or wean weight on KO% which averaged 74.8% but pigs with a low birth weight had a significantly greater back fat depth at P_2 than pigs with a high birth weight (Table 1).

In Tables 2 and 3 the data specific for the effect of birth weight and wean weight are reported respectively. There was a 0.6kg difference in birth weight and a 3kg difference in wean weight between the light and heavy pigs. These differences in weight represented 48% and 43% respectively. As such the 'magnitude' of difference was similar for both the birth and wean weight categories. Tables 2 and 3 demonstrate that the impact of birth weight on lifetime performance was weaker than the impact of wean weight since 1) the strength of significance decreased as pigs got older for within the effect of birth weight but the high strength of significance was maintained throughout life for the effect of wean weight on subsequent weight and 2) birth weight had no effect on the overall wean to finish average daily gain of the pigs (Table 2) but wean weight significantly improved wean to finish average daily gain by 4% (Table 3). Another interesting point to note in this work is the lack of effect during the finishing period by either birth or wean weight. The largest impact is during the growing stages although it should be noted that high wean weight pigs did have a higher growth rate (791 g/day, $P<0.001$) between 10 and 15 weeks of age compared with light wean weight piglets (713 g/day) and this contributed to the overall effect on wean to finish growth rate.

Conclusions

Whilst pigs born heavy and weaned heavy had the best lifetime performance and those born light and weaned light had the poorest, pigs which were born light but achieved a good weaning weight continued to perform at a high level (especially during the growing period) with the result that their 20-week weight was superior to pigs born heavy but weaned light. This was particularly impressive since these light weight pigs could have been considered ata disadvantage to the heavy weight piglets through the fact they were fed and managed to an age as opposed to a weight. In agreement with Fix *et al.*, (2010) these results support the fact that birth weight is important for lifetime pig performance. However, they also demonstrate the importance, and perhaps greater importance, of wean weight. The results in this work support the conclusion of Douglas *et al.* (2012) in that interventions to increase weaning weight will improve

Table 1 Effect of pig birth and wean weight on lifetime performance (Standard deviation in brackets for birth and weaning weights)

		LL	LH	HL	HH	VLBW	SED	P Value
Live wt (kg)	Birth	1.2 (0.19)	1.3 (0.13)	1.7 (0.18)	1.9 (0.15)	1.0 (0.27)	0.04	<0.001
	Weaning	7.0 (0.93)	9.6 (0.74)	7.5 (0.98)	11.0 (0.74)	4.3 (1.19)	0.21	<0.001
	7 wks	15.1^{b}	18.0^{d}	16.7^{c}	20.7^{e}	11.8^{a}	0.50	<0.001
	10 wks	27.6^{b}	31.2^{c}	30.4^{c}	39.2^{d}	21.6^{a}	1.00	<0.001
	15 wks	52.83^{b}	59.02^{c}	54.87^{bc}	64.58^{d}	41.76^{a}	1.908	<0.001
	20 wks	87.6^{b}	93.8^{c}	90.0^{b}	98.6^{d}	68.1^{a}	3.10	<0.001
ADG (g/day)	Wean - 10wks	419^{b}	441^{c}	467^{d}	577^{e}	354^{a}	18.6	<0.001
	10 - 15wks	713^{b}	760^{c}	704^{b}	713^{b}	514^{a}	45.9	<0.001
	15 - 20wks	1175^{c}	1030^{b}	1205^{d}	1156^{cd}	786^{a}	67.3	<0.001
	10 – Finish	884^{b}	906^{bc}	888b	857^{b}	698^{a}	34.4	<0.001
	Kill Out (%)	75.32	74.69	74.5	74.73	74.48	1.040	0.909
	Back Fat dept at P_2 (mm)	12.4^{bc}	12.8^{c}	11.8^{ab}	11.4^{a}	14.9^{d}	0.79	<0.01

Table 2 The effect of birth weight on lifetime performance

		Birth Wt Category			
		High	Low	SED	P Value
Live Wt (kg)	Birth	1.8	1.2	0.03	<0.001
	Wean	9.3	8.3	0.29	<0.001
	7 Wks	18.8	16.6	0.43	<0.001
	10 Wks	33.6	29.7	0.72	<0.001
	15 Wks	59.8	55.8	1.39	0.005
	20 Wks	94.7	90.4	2.00	0.031
ADG (g/day)	Wn-10	592	520	13.8	<0.001
	10-Fin	898	889	20.0	0.645
	Wn-Fin	796	771	15.9	0.117

Table 3 The effect of wean weight on lifetime performance

		Wean Wt Category			
		High	Low	SED	P Value
Live Wt (kg)	Birth wt	1.6	1.41	0.06	<0.001
	Wn Wt	10.3	7.24	0.16	<0.001
	7 Wks	19.3	15.9	0.37	<0.001
	10 Wks	34.6	28.9	0.66	<0.001
	15 Wks	61.9	53.8	1.26	<0.001
	20 Wks	96.6	88.7	1.92	<0.001
ADG (g/day)	Wn-10	582	528	14.3	<0.001
	10-Fin	910	878	19.8	0.116
	Wn-Fin	801	767	15.8	0.034

lifetime performance. It appears that increasing piglet birth weight is challenging, especially in highly prolific sows, but this work demonstrates the ability of the piglet to thrive in the first few weeks of life and for those effects to have a lasting positive effect. It is therefore recommended that whilst effort should be made to improve piglet birth weight, much effort should be placed on improving the wean weight of pigs. Unfortunately it was not possible in this study to identify how the 'light' birth weight piglets achieved a good wean weight or even why the heavy birth weight piglets had a low wean weight but this area warrants future research due to the impact it can have.

With regard to back fat depth, light birth weight pigs, regardless of their weaning weight were fatter than heavy birth weight piglets and extremely light birth weight piglets with a low lifetime performance were very fat. Whilst Poore and Fowden (2004) also found that pigs with low birth weight had an increased back fat content when adults, Fix *et al* 2010 found a tendency (P=0.07) for heavy birth weight pigs to be fatter. Whilst back fat depths of the light and heavy birth weight piglets were all deemed acceptable (except for the very low birth weight piglets), this result has important implications for the current pig population in the UK since increasing litter size, which reduces the average birth weight of pigs, could therefore increase back fat depth. This impact would be magnified when taking these animals to heavier slaughter weights than experienced in this trial.

Study 2 - Getting pigs to eat post weaning to improve growing pig performance

The study reported above noted the importance of wean weight and how it can impact lifetime performance and especially performance in the growing stage. However, when pigs are weaned they experience the biggest set back of their lives. The average daily gain of pigs pre-weaning is approxiamately 257 g/day between birth and weaning. In the 5 days after weaning growth is often seen to stop and at best the 5 day post weaning weight is often the same as the pig's weaning weight. A key factor in this situation is the lack of feed intake directly after weaning and the inability to eat is mainly due to the multiple stressors that the pigs experience at the time of weaning. The removal of the sow is the ultimate stressor but this is essential. Other key stressors include mixing with unfamiliar pigs from other litters, change of house and, introduction of a completely new way of feeding. The study reported here aimed to investigate if any one of these later stressors had a more dominant effect than another and ultimately to see if there was any opportunity to increase feed intake directly after weaning.

Materials and methods.

A total of 800 pigs were used across ten treatments over eight time periods which represented eight replicates per treatment. The study was designed as a 2 x 2 x 2 + 2. The first comparison involved the use of small circular hoppers (SCH) to offer creep feed pre-weaning (as opposed to floor feeding in the forward creep area (Floor)). This treatment aimed to familiarise pigs to the feed systems post weaning and hence encourage intake post weaning. The second comparison investigated the use of these small circular hoppers (SCH) in the post weaning accommodation compared to a normal dry multi space hopper (DMS). The third comparison looked at the impact of moving house (Move) on the day of weaning compared with 3 days later (i.e. pigs remained in the farrowing crate for 3 days after the sow was removed (Stay)). Across all these treatments pigs from different litters were mixed (Mix). In the additional two treatments pigs were not mixed (Not Mixed) with other litters and therefore the litter remained intact both pre and post weaning. These latter two treatments were offered no creep pre weaning and the difference between them was that in one the pigs were moved to stage 1 accommodation on the day of weaning and in the other the pigs remained in the farrowing accommodation and were moved to stage one accommodation three days after weaning. Sows were removed from the farrowing accommodation at 28 days of lactation.

Within each period, 16 litters due to be weaned at 28+/- 1 days of age were selected and the individual piglets were weighed at 10 days pre weaning. According to the average weight of the litters, 6 were offered creep from the floor of the forward creep area and 6 were offered creep from small circular hoppers. Creep feed was offered from 18 days of age i.e. for 10 days pre weaning. The remaining 4 litters were not offered creep feed. The average litter weight and profile of each "pre-weaning group" was similar. At weaning all pigs were weighed and vaccinated and the sows were removed from the farrowing crate. Two litters were selected from the 4 litters which did not receive creep feed and they were reduced to 10 pigs of average weight which was comparable to the average weight of the other groups formed. The remaining 8 groups of 10 pigs were formed so that each group of pigs was balanced for weight and gender and the group represented a mix of 2-3 litters. The groups were randomly assigned to the treatments above.

The temperature of the farrowing accommodation was increased to represent the stage 1 accommodation. Pigs were offered 3kg/pig of a commercial starter 1 diet followed by 6kg /pig of a commercial starter 2 diet and then a grower diet (14 MJ/kg digestible energy, 186 g/kg crude protein, 12 g/kg lysine) to ten weeks of age. The feed disappearance per group of pigs was measured daily to day 12 post weaning and again when pigs were 7 and 10 weeks of age. Pig weight was measured weekly to 7 weeks of age and again at 10 weeks of age. Data was analysed using Analysis of Variance in Genstat.

Results

There were no significant interactions so the direct effects of treatments are reported. Table 4 reports the effect of treatment on pig performance and Table 5 reports the effect of treatment on daily feed intake.

The average wean weight of pigs was 9.5kg. The average daily gain of pigs in the week after weaning was 159 g/day except for when pigs remained in their litter group and remained in the farrowing house for 3 days after the sow was removed. These pigs tended to have a better growth rate (223g/day, P=0.08) in the week after weaning. These pigs also had a higher 'feed disappearance' in day one post weaning (400g/pen, P<0.05) compared with all other treatments whose average intake was 107 g/pen (Table 5).

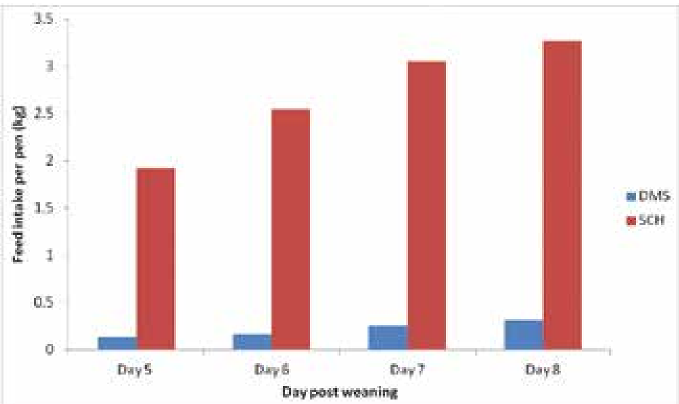

Figure 1 The intake (kg/pen) from the dry multi space feeder and the small circular hopper when birth were used in the one pen to offer feed post weaning

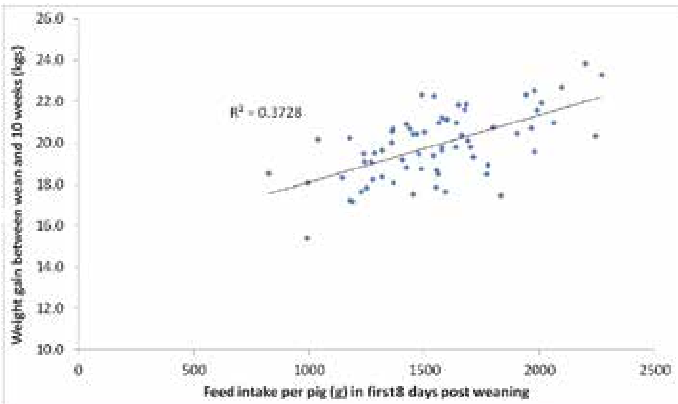

Figure 2: Correlation between feed intake (g/pig) during the first eight days post weaning and weight gain between weaning and 10 weeks of age

Whilst not statistically significantly different (P<0.05), the intake of these pigs was numerically higher for the 8 days post weaning and overall between weaning and 10 weeks of age their intake tended (P=0.09) to be the highest (799 g/day vs 727 g/day). This increased intake also resulted in these pigs having the highest 10 week weight (32.3kg, P<0.001) compared with pigs on the remaining treatments (average of 29.2kg) (Table 4)

There was no difference (P>0.05) in feed intake or pig performance post weaning when creep was offered on the floor of the forward creep area or through the small circular hopper pre weaning. There was also no difference in intake or pig performance post weaning when the move to stage one accommodation was delayed for 3 days compared to when pigs moved directly to stage one accommodation on the day of weaning.

However, the intake of pigs offered feed through the small circular hopper (SCH) post weaning along with the dry multi space hopper, as opposed to through just the dry multi space hopper was higher (P<0.01) during day one post weaning (Table 6) but there was no effect on pig growth rate. With regard to the intake specifically from the small circular hopper compared with the dry multi space hopper, feed disappearance from the SCH was higher in the days post weaning compared with that from the dry multi space hopper (Figure 1, all differences were P<0.001). This result demonstrates the importance of easy access but more importantly that even after 8 days, intake from the DMS is not compensating for intake from the SCH and it remains the preferred feeder type.

This is important since these SCH are often removed after 7 days post weaning to be used with the next batch of pigs being weaned.

It was interesting to note that the feed conversion ratio across all treatments was higher in the week after weaning compared with the period of 3 weeks post weaning. One week is too short a period to measure an accurate feed efficiency but has been included here to compare with the 3 weeks after weaning. This data indicates much wastage of feed in the week after weaning and therefore the small amount of intake that has disappeared may not even have been 'utilised' by the pigs for growth.

In this work creep feed was offered to the majority of litters and it is know that creep feeding pre weaning (especially for the 10 days before weaning) will increase feed intake post weaning. Whilst the individual treatments did not show any effects on feed intake or pig performance (except when nearly all stressors were removed) the data does show a relationship between the importance of early feed intake

Table 4 Effect of treatment on pig performance to 10 weeks of age

	Pre weaning feed delivery:	Floor	Floor	SCH	SCH		Floor	Floor	SCH	SCH			
	Post weaning feed delivery	DMS	SCH + DMS	SCH + DMS	DMS		DMS	SCH + DMS	SCH + DMS	DMS			
	Moved accommodation at weaning	Move	Move	Move	Move	Move	Stay	Stay	Stay	Stay	Stay		
	Mixing or not	Mix	Mix	Mix	Mix	Not Mix	Mix	Mix	Mix	Mix	Not Mix	SEM	P-value
Live Wt (Kg)	Wean	9.4	9.4	9.5	9.5	9.6	9.4	9.4	9.4	9.4	9.7	0.13	0.685
	5 wks	10.2	10.3	10.3	10.2	10.5	10.2	10.4	10.2	10.1	11.0	0.18	0.047
	6 wks	13.3	13.4	13.1	13.2	13.4	13.1	13.2	13.2	13.0	13.8	0.21	0.373
	7 wks	16.5	16.6	16.1	16.6	17.1	16.5	16.7	16.2	16.5	18.3	0.28	<.001
	10 wks	29.5	29.3	28.5	29.4	29.9	28.8	29.3	28.9	28.8	32.3	0.52	<.001
ADG (g/day)	Wn-5	161	168	161	151	169	154	174	138	148	228	16.55	0.035
	Wn-7	355	359	327	354	371	354	361	335	353	429	13.4	<.001
	Wn-10	490	485	465	487	495	474	483	475	473	551	12.23	<.001
ADFII (g/day)	Wn-5	180	200	192	187	190	196	210	193	188	243	12.62	0.061
	Wn-7	417	429	400	420	420	417	432	400	427	480	17.44	0.121
	Wn-10	715	718	707	729	774	730	737	691	740	799	23.78	0.093
FCR	Wn-5	1.17	1.26	1.24	1.30	1.18	1.35	1.27	1.45	1.30	1.14	0.071	0.117
	Wn-7	1.18	1.19	1.22	1.19	1.12	1.18	1.20	1.20	1.21	1.12	0.036	0.487
	Wn-10	1.46	1.48	1.52	1.50	1.56	1.54	1.53	1.46	1.57	1.45	0.038	0.241

Table 5 Effect of treatment on daily feed intake post weaning (kg/pen)

Pre weaning feed delivery:	Floor	Floor	SCH	SCH		Floor	Floor	SCH	SCH			
Post weaning feed delivery	DMS	SCH +DMS	SCH +DMS	DMS		DMS	SCH +DMS	SCH +DMS	DMS			
Moved accom. at weaning	Move	Move	Move	Move	Move	Stay	Stay	Stay	Stay	Stay		
Mixing or not	Mix	Mix	Mix	Mix	Not Mix	Mix	Mix	Mix	Mix	Not Mix	SEM	P-value
Day 1	0.04	0.18	0.09	0.02	0.14	0.13	0.17	0.10	0.09	0.40	0.067	0.021
Day 2	0.50	0.84	0.66	0.61	0.72	0.80	0.81	0.70	0.86	1.29	0.152	0.063
Day 3	1.25	1.23	1.31	1.39	1.26	1.39	1.56	1.37	1.64	1.79	0.162	0.251
Day 4	1.77	1.81	1.83	1.67	1.71	1.69	1.81	1.75	1.73	2.40	0.191	0.293
Day 5	1.92	2.19	2.12	1.99	1.88	1.86	2.10	1.85	1.67	2.64	0.192	0.069
Day 6	2.47	2.84	2.51	2.67	2.65	2.84	2.78	2.72	2.31	3.03	0.179	0.224
Day 7	3.09	3.14	3.26	3.10	3.50	3.23	3.54	3.25	3.15	3.65	0.215	0.553
Day 8	3.53	3.44	3.59	3.33	3.94	3.56	3.73	3.60	3.45	4.31	0.229	0.149

and growing pig performance as shown in Figure 2 where increased intake over the first 8 day period increased the weight gain of pigs to 10 weeks of age. The relationship found here indicates that for every 100g extra feed consumed in the first 8 days after weaning, the total weight gain between weaning and 10 weeks of age increases by 0.32 kg. When a similar correlation for intake on day 1 and intake on day 1 and 2 was made a similar trend was found and these trends had an R^2 of 0.288 and 0.330 respectively.

Conclusion

In agreement with Mavromichalis, I. (2013), improving feed intake directly after weaning will improve the weight gain of pigs in the growing period. Excluding the removal of the sow, all other stressors such as mixing and changing the feeding system appear to have a similar negative effect and the manipulation of management strategies doesn't appear to overcome the negative impact of these stressors. However, when pigs were allowed to remain in their litter and in their environment (and when they were not offered creep pre weaning) these pigs had a higher intake post

Table 6: Daily feed intake (kg/pen) when pigs were offered feed from either the small circular hopper AND the dry multispace hopperor just the dry multispace hopper

	DMS	DMS + SCH	SEM	P-Value
Day 1	0.070	0.134	0.0168	0.010
Day 2	0.694	0.753	0.0621	0.506
Day 3	1.417	1.369	0.0758	0.655
Day 4	1.716	1.799	0.0813	0.471
Day 5	1.860	2.064	0.0737	0.057
Day 6	2.574	2.714	0.0749	0.194
Day 7	3.142	3.299	0.0806	0.176
Day 8	3.467	3.590	0.0829	0.298

weaning and as a result a higher weight at 10 weeks of age. Therefore the impact of weaning, (i.e. sow removal) can be mitigated, albeit with unconventional strategies which currently would not fit with current practice. However considering that a 2.5kg weight advantage at 10 weeks of age could equate to at least a 5kg weight advantage at slaughter (and therefore potentially £5 per pig), the adoption of housing to encourage the adoption of 'low stress' weaning may be worth considering. Mavromichalis, I. (2013) noted work from Ohio state university which reported that an extra 100g per pig per day post weaning will increase weight 28 days post weaning by 1.5kg.

These results would support this. However this is very hard to achieve and at a practical level these results suggest that if an extra 100g during the first 8 days post weaning could be attained then weight gain to 10 weeks of age could be increased by 320g. Overall this should be an area of focus and effort by producers to maximize the performance of the growing pig. However, feed'disappearance' does not always equate to 'feed intake'and any management strategies adopted to increase feed intake post weaning should ensure minimisation of wastage.

Study 3 – The economics of large litters

Litter sizes of over 13 born alive are now common place. However, birth and wean weights on commercial farms have reduced as a result. The above papers and information demonstrate opportunity to improve pig performance pre weaning but the magnitude of these large litters is such that there is current concern in the industry as to the real value of larger litters due to poorer lifetime performance as a result of reduced birth and wean weights. In recent years the litter size of the AFBI Hillsborough herd has also increased. Every pig at Hillsborough is weighed at birth and weaning. A large database of information relating wean weight to subsequent animal performance is therefore available. The other unique feature of the AFBI Hillsborough data base is that it currently houses over 750 individual pig records relating finishing pig feed conversion ratio to finishing pig performance and weight at 20 weeks of age. Growth performance and feed use are the two key components in the economic calculation of pig value and as such the unique AFBI Hillsborough database has been used to try and understand the value of large litters.

Materials and Methods

The data set used:

In 2008 AFBI changed the breeding goals of the sow herd to increase prolificacy. This change had to be done via insemination and breeding over the existing herd as opposed to direct input (purchase) of highly prolific animals due to strict bio security rules. As a result the increase in prolificacy was slow and the data below represents that period of transition where a large range in litters sizes was experienced.

The birth and weaning records of piglets born into a total of 392 litters (130 gilts and 262 sows) over the period from December 2011 to January 2015 were used to establish the relationship between litter size and piglet birth and wean weight profiles. Sows were all PIC FI crosses (LW x LR) and piglets were PIC 337 terminal sire. There was a total of 4634 piglets (born alive) recorded from these sows. Sows were induced to farrow on day 114 of gestation and gilts were left to farrow naturally. Lactation length averaged 28 days.

Data recorded for farrowing sows included: number born, number born alive, individual piglet weights, piglet mortalities, number weaned and individual weaning weights. This data was subsequently categorised by weight (under 0.75kg, 0.76 – 1kg, 1.01 – 1.25kg, 1.26 – 1.5kg, 1.51 – 1.75kg, 1.76 – 2, and over 2kg). Piglets were then sorted by litter size, and the average number of piglets in each birth weight class in each litter size was calculated and formed a matrix of birth weights within litter sizes. A similar exercise was conducted on wean weight and the profile of wean weight per original litter size (Table 7) was used to complete the exercise since it better represented the range in wean weights experienced. Litter size ranged from 7 to 21, but the calculation focused on those between 11 and 19. It should be noted that in the results below the litter sizes of 11, 12, 13, 14, 15, 16, 17, 18 and 19 represent all pigs born and the respective average total number born alive was 10.7, 11.5, 12.3, 12.9, 13.7, 14.6, 15.1, 15.8, and 17.2.

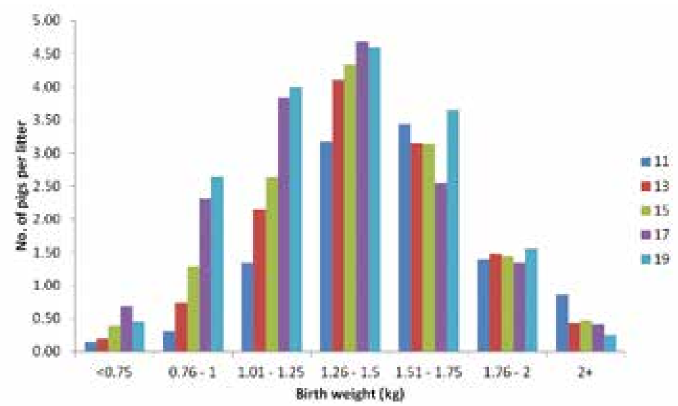

Figure 3 The birth weight profile of pigs across litter sizes of 11 to 19

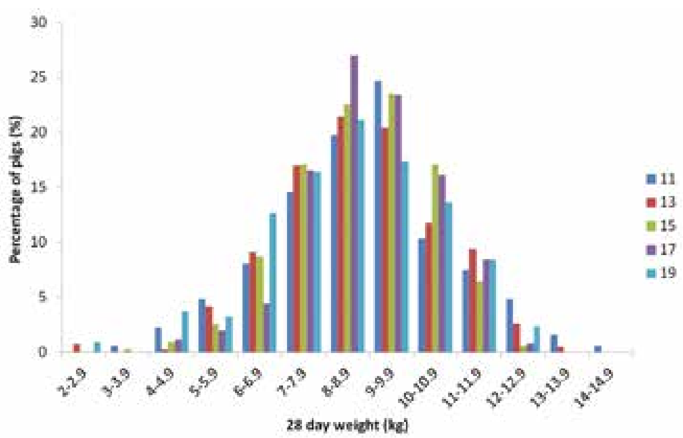

Figure 4: The wean weight profile of piglets per litter size that they were born into.

Table 7 The average number of pigs per wean weight category per litter size used to calculate the ultimate value of the litter

Litter Size	Wean weight category												
	2-2.9	3-3.9	4-4.9	5-5.9	6-6.9	7-7.9	8-8.9	9-9.9	10-10.9	11-11.9	12-12.9	13-13.9	14-14.9
11	0.00	0.07	0.25	0.54	0.89	1.61	2.18	2.71	1.14	0.82	0.54	0.18	0.07
12	0.04	0.04	0.15	0.15	0.54	1.76	3.03	2.53	1.50	1.69	0.35	0.19	0.04
13	0.10	0.00	0.03	0.56	1.22	2.27	2.86	2.72	1.57	1.25	0.35	0.07	0.00
14	0.03	0.00	0.17	0.65	1.35	2.42	3.63	2.92	1.94	0.67	0.14	0.06	0.03
15	0.00	0.05	0.15	0.39	1.31	2.56	3.39	3.53	2.56	0.97	0.10	0.00	0.00
16	0.00	0.11	0.49	0.70	1.76	2.75	3.49	3.17	1.97	1.13	0.32	0.11	0.00
17	0.00	0.00	0.21	0.34	0.75	2.81	4.59	3.98	2.74	1.44	0.14	0.00	0.00
18	0.00	0.50	0.83	1.00	2.58	3.83	3.42	3.50	1.33	0.67	0.17	0.17	0.00
19	0.16	0.00	0.64	0.56	2.17	2.82	3.62	2.98	2.33	1.45	0.40	0.00	0.00

Table 8 Range of weights and FCR values calculated from correlation equations

Wean weight (kg)	10 week weight (kg)	20 week weight (kg)	Finishing FCR	Total feed used (kg) between 10 weeks of age and 110kg
2.5	17.9	68.2	2.72	251
3.5	19.7	70.9	2.69	243
4.5	21.5	73.7	2.66	235
5.5	23.3	76.4	2.62	227
6.5	25.1	79.2	2.59	220
7.5	26.9	82.0	2.55	212
8.5	28.7	84.7	2.52	205
9.5	30.5	87.5	2.49	198
10.5	32.3	90.2	2.45	190
11.5	34.1	93.0	2.42	183
12.5	35.9	95.7	2.38	177
13.5	37.7	98.5	2.35	170
14.5	39.5	101.2	2.32	163

The correlations used:

A database of information collected from the AFBI Hillsborough herd containing the wean and 10 week weight of 11,579 pigs was used to correlate wean weight to the 10 week weight of pigs. A similar database containing the 10 and 20 week weights of 4,952 pigs was used to correlate the 10 and 20 week weight of pigs. A dataset containing the 10 and 20 week weight and feed conversion ratio of over 700 pigs between 12 weeks of age and finish was available. However it was strongly influenced by experimental treatments and as such a smaller database of 160 pig records, which took all pigs to 120 kg, was used to correlate the 20 week weight of pigs to their feed conversion ratio during the finishing period. Highly significant ($P<0.001$) correlations between wean weight and 10 week weight (10wk Wt = 13.427 + 1.8009x(Wn Wt kg); $R^2 = 0.33$), between 10 week weight and 20 week weight (20wk Wt= 40.73 + 1.5306x(10Wk Wt); $R^2 = 0.27$)) and between 20 week weight and the feed conversion ratio (FCR) of pigs during the finish period (FCR = -0.0013 x (20 wk wt kg) + 3.627); $R^2 = 0.46$) were used to generate the 10 and 20 week weights, FCR and resultant feed used during the finishing period (10 weeks of age to 110kg) (Table 8).

Table 9 Litter value (margin over finisher feed cost) due to litter size

Litter size	No. born alive	Total intake of litter (kg)[1]	Cost of finisher feed per litter(£)[2]	Litter carcass value (£)[3]	Margin over feed per litter (£)	Margin over feed per pig (£)
11.0	10.7	2154	431	1025	594	55.72
12.0	11.5	2289	458	1102	644	56.20
13.0	12.3	2485	497	1179	682	55.60
14.0	12.9	2633	527	1241	714	55.34
15.0	13.7	2775	555	1317	761	55.61
16.0	14.6	2976	595	1399	804	55.25
17.0	15.1	3022	604	1452	847	56.11
18.0	15.8	3283	657	1514	858	54.45
19.0	17.2	3508	702	1649	947	55.23

[1] Finisher period = 10 weeks of age to 110kg
[2] Feed cost = £200/tonne
[3] Carcass value assumed £1.15/kg carcass weight and a 76% kill out % of a 110kg pig

The calculation

Using the weight profiles (i.e. number of pigs per weight category) in each of the litter sizes (11, 12, 13, 14, 15, 16, 17, 18, 19) attained during 2011 to 2015 and applying the results from the equations of the correlations (in Table 8) the weight profile of pigs per litter size was mapped out for when pigs were 10 and 20 weeks of age. The feed used to reach a slaughter weight of 110kg was also calculated per weight category and this was applied to the matrix of pig numbers at weaning per weight category per litter size. The total feed used per litter to attain a weight of 110kg was subtracted from the total carcass value based on a 76% kill out percentage and all pigs reaching a slaughter weight of 110kg and all pigs attracting a value of £1.15/kg of carcass weight. This produced a litter value based on 'margin over finisher feed' and the same was calculated on a per pig basis.

Results

The birth weight profile of piglets across the different litter sizes is represented in Figure 3. It is noted that in a litter of 11 piglets the peak of the graph is represented by piglets weighing between 1.5-1.75 kg, whereas the peaks of the graphs representing litters of 13, 15, 17 and 19 had their peaks at 1.26-1.5kg. The average birth weight of pigs reduced as litter size increased which is in agreement with Quiniou *et al.* (2002) who reported that for every extra piglet born in a litter the average birth weight per piglet reduced by 35g (in litters up to 17). Figure 3 demonstrates that whilst the bell shaped curve has moved to the left for litter sizes of 13, 15, 17 and 19, it is suggested that this shift is not large. It is interesting to note that the number of piglets born in the weight categories of 1.5kg and over are not dissimilar between the litter sizes of 13, 15, 17 and 19. As expected, Figure 3 shows that the extra piglets born alive in these larger litters have a birth weight of between 0.75 and 1.25 kg. Overall, Figure 3 does not support the industry perception that the weight profile of large litters has a lower proportion of average or above average birth weight piglets, indeed litters as large as 19 can have a comparable number of piglets in the upper weight categories. The issue is more so that the increased numbers are in the lower weight categories.

In order to calculate the value of pigs the weight of pigs at weaning was used as a base point for future performance since much cross fostering and litter standardisation occurred post farrowing. Figure 4 demonstrates the wean weight profile of pigs against the original litter size the piglets were born into. Again for litters of 11 the 'peak' of the graph represented a wean weight of 9-9.9kg whereas the peak of the graph for the remaining litters sizes was between 8-8.9kg.
Table 9 outlines the resultant margin over finisher feed cost on a litter basis and on a pig basis. As litter size increased the margin over finisher feed cost on a litter basis also increased resulting in an extra £44 (on average) for every extra pig in the litter (born).

This result is mainly due to the fact that in the wean weight profile in Figure 4, the proportion of pigs in the higher weight categories was similar across litter sizes and whilst there was an increased number of pigs in lower weight categories originating from large litters, this was countered by the fact that even in smaller litter sizes pigs of low wean weights also existed. It is noted that this calculation took all pigs to a slaughter weight of 110kg and all had a code 1 value of £1.15kg, hence maximising the value of all pigs and as such the calculation could be considered as 'best case scenario'. Nonetheless, with all things equal, the overall increase in numbers in these lower weight categories did not have a large impact on overall 'litter value'.

Sensitivity of the calculation.

There are many additional assumptions and additional costs which should be included here but this has not been attempted due to the vast range of scenarios possible. It is accepted that the data in Table 9 could be considered as 'best case scenario' since under practical terms it is very difficult for the smaller pigs to reach a slaughter weight of 110kg and indeed previous research has found that it is not profitable to take such slow growing pigs to heavy slaughter weightsdue to the deterioration in feed conversion ratio at these high slaughter weights for this 'grade' of animal. However to counter this two further calculations were conducted to test the magnitude of change required to lower the margin over finisher feed costs of the large litter sizes. The two main drivers within the calculation are the matrix of wean weights per litter size and the feed conversion ratio extremes. In order to assess the magnitude of difference possible two extreme situations were compared.

1. The margin over finisher feed cost for the original data for a litter size of 11 (or 10.6 born alive) was compared to a situation where all pigs in the litter of 19 (or 17.2 born alive) were of the lowest wean weight and therefore of the lowest lifetime performance. When the carcass value of all pigs was held at £1.15/kg carcass weight, the margin over finisher feed for the litter of 11 was £594 and was £790 for the litter of 19 (total born) (which is compared to £947 above). This difference represents the extra feed consumed (almost 1 tonne per litter)in this scenario due to the poorer feed conversion ratio of these light weight pigs. In this scenario the margin over finisher feed for the litter of 17.2 'poor' pigs was still better than in litters of 14 or 15 (total born). When the carcass value of all the pigs from the litter of 19 (which again were all ranked at the lowest weight) was reduced to £1/kg carcass weight, the margin over feed was reduced to £725. Whilst unrealistic, this extreme calculation demonstrates the extreme difference required within the litter of 19 to reduce the margin over finisher feed.

2. In the second calculation, the FCR of the lightest pigs was extended to 4.7 during their finishing period and this FCR had tiered improvement to 2.37 for the heaviest pigs. The original matrix of wean weight per litter size was used and in this scenario the margin over feed for the litter of 19 remained the highest compared to the other litter sizes. However, in the unrealistic situation where all 17.2 pigs born alive were ranked as the poorest, the margin over finisher feed fell to the lowest. Again this is unrealistic but demonstrates the extreme difference required to make a large difference in margin over feed.

Effect of wean weight on margin over finisher feed on a per pig basis

In Table 9 a similar 'average pig value' per litter size was attained, again mainly due to the fact that large litters still have the potential to have good proportions of average and above average piglets. However, Figure 5 demonstrates the impact of wean weight on the margin over finisher feed on a per pig basis. As wean weight reduced the growth rate and feed efficiency of pigs got poorer. As a result, on a per pig basis, as wean weight reduced the margin over finisher feed also reduced and the relationship suggests that for every 1kg extra in wean weight, there is an extra £1.46 per pig in margin over finisher feed.

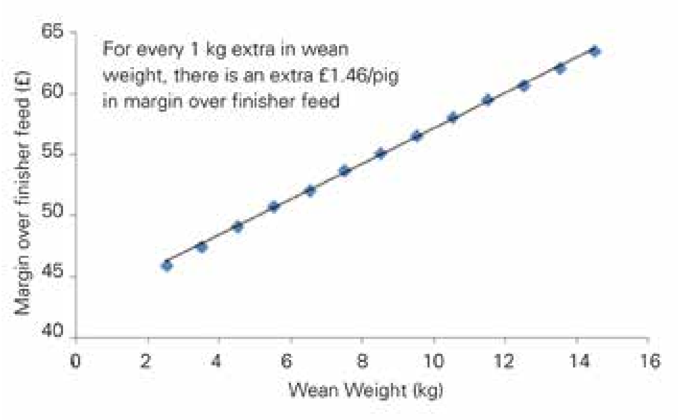

Figure 5 The relationship between wean weight and the margin over finisher feed cost.

Conclusion

Overall while additional assumptions and conditions could be applied to this data it is suggested that overall litter value improves as litter size increases (between 11 and 19 pigs born per litter). This is mainly due to the fact that the weight profile of large litters is not dramatically dissimilar to that of smaller litters with the main difference, especially at weaning, being the presence of more piglets weighing slightly below average in the larger litter sizes. Overall, the scale of numbers counteracts any negative effects of poorer performance. Furthermore, on a per pig basis within the litter, average pig value is not significantly affected by litter size. However, as individual pig wean weight increases, the margin over finisher feed also increases at a ratio of 1.46. This information supports the rearing of large litters. However, it is known that as these slower growing pigs approach very heavy weights their feed conversion ratio deteriorates and as such the 'smart' marketing of these pigs as they approach slaughter weight may further increase the 'margin over finisher feed' on a per litter basis

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Pig-House Odour – What Is It?

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Key Message:

- The most important odour compounds contributing to pig-house odour are short chain acids, sulphur compounds, phenols, indoles (e.g. skatole) and amines. Whilst more research is required in the area of odour abatement, it is suspected that more than one abatement technology will be required to eliminate odour from pig housing due to the multi factorial origin of the odour compounds.

Summary

The odour downwind from pig-houses can be offensive to nearby residents. Researchers have reported up to five hundred different volatile organic compounds emitted from pig production facilities [1, 2]. However, it remains unclear which of these many compounds make the most important contribution to the unpleasant odour.

Odour can be measured by olfactometry (using a panel of people) or by measuring the concentrations of odour compounds in the air. In this study, we determined which odour compounds contribute most to the characteristic pig-house odour through the calculation of "odour activity values" (OAV)[3]. The OAV is the concentration of a single compound divided by its odour threshold concentration. Compounds with an OAV greater than 1.0 are likely to contribute to the overall odour.

The odour thresholds reported in the scientific literature can vary considerably. Differences in reported thresholds can range by several orders of magnitude for a particular chemical compound. In order to minimize the impact of this variability, two consistent sets of odour thresholds were used [4, 5]. A meta-analysis of the published data on volatile compound concentrations from pig-houses using OAVs shows that the most important odour compounds contributing to pig-house odour are short chain acids, sulphur compounds, phenols, indoles (e.g. skatole) and amines. These compounds have the highest odour activity values and often have pungent and offensive odours. Ammonia, while a contributor, is not the major cause of pig-house odour.

The odour activity of these compounds is affected by a number of factors, including where measured (air above slurry or from the ventilation system), age of slurry, diet of pigs and presence or absence of a slurry cover. Potential mitigation factors related to slurry management or pig diets can have differential effects on these classes of odorous compounds. It is therefore unlikely that one single solution will eliminate pig-house odour. However, more research is required in the area of identifying effective odour abatement technologies that are cost effective, as well as correlating the concentrations of key odour compounds with the actual measure of odour offensiveness by olfactory.

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Expanding the knowledge base to increase the use of distiller's dried grain with solubles (DDGS) in animals diets – analysis for mycotoxins and elemental composition

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Key message

- Across 106 samples of DDGS, mixtures of 13 to 34 different mycotoxins were found. The toxicological potential of such mixtures can be an underestimated hazard for the productivity of farm animals. Heavy metals levels were rarely elevated in the DDGS samples, and even if they were, levels were well below concentrations that would raise statutory concern in feed.

Introduction

Distiller's dried grain with solubles (DDGS) is a co-product of ethanol production from starch cereals. It contains valuable amounts of protein, fat and fibre and it is used in diets of livestock, poultry and fish. The aim of this study was to analyse DDGS for mycotoxins and elemental composition in order to provide data on the safety of DDGS as an animal feed ingredient.

Materials and methods

Wheat DDGS (47), maize DDGS (52) and mixed DDGS (9) samples were obtained from the biofuel and feed industries in Europe. One biofuel plant also provided a set of 52 wheat grain and their corresponding set of 52 wheat DDGS samples. Similarly, two sets of nine barley DDGS and barley grain samples were also attained. The samples were analysed for 77 mycotoxins using validated UHPLC-MS/MS method and for 39 elements by ICP-MS, 42 elements by XRF, arsenic speciation and lead isotope analysis.

Results and discussion

Mycotoxins

Each analyzed DDGS sample contained a mixture of 13 to 34 different mycotoxins produced by Fusarium, Aspergillus, Penicillium, Alternaria and Claviceps fungi. High occurrence of deoxynivalenol in wheat DDGS and fumonisins in maize DDGS was found. Other important mycotoxins identified that often co-occurred with regulated mycotoxins were enniatins, beauvericin, mycophenolic acid, ergot alkaloids, fusaric acid and equisetin. On average DDGS was found to be more contaminated with mycotoxins than grain it was produced from. Due to the higher risk of mycotoxin contamination in DDGS it is highly recommended to routinely screen DDGS for mycotoxin content, especially for regulated mycotoxins such as deoxynivalenol and fumonisins to avoid introduction of highly contaminated batches into animal diets. More research is needed to understand the effects of cocktails of the mycotoxins, especially those regulated with those emerging as identified in this study on the performance of farm animals.

Elemental analysis

The samples were quite variable for Ca, Mn, Na and S contents between origin and DDGS type. Inorganic arsenic was quite elevated in Austrian grains, with a 4-fold difference between countries of origin. Inorganic arsenic was the only arsenic species identified - i.e. fermentation does not lead to methylation. Se was over double in US maize compared to everything else - this is to be expected as US grains generally have higher Se due to soil geochemistry. Cd was quite elevated in UK wheat DDGS but below animal food guidelines. Analysis of paired wheat grain and resultant DDGS by ICP-MS to quantify a range of elements found that production of DDGS concentrated most elements by ~3-fold, including nutrients (Cu, Fe, Mg, Mn, Mo, P, Se & Zn) and contaminants (As, Cd, & Pb) with the except of Na which was elevated 300-fold, with Na being added to grain during the process. Contaminant levels were rarely elevated in the samples, and even if they were, levels were well below concentrations that would raise statutory concern in feed.

Acknowledgements

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Alternative Protein Sources for Pigs.

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Key message:

- Rapeseed meal as well as either wheat or maize distillers grains with soluble are all very viable alternative protein sources for pigs.

- However, risks do exist with regard to their inclusion, especially in terms of anti nutritional factors and reductions in diet digestibility.

Summary of work

Pig farmers in Northern Ireland regularly face financial pressure. This is partly due to their reliance on imported energy and protein crops. As a result there has been a major focus on the utilisation of 'alternative' protein sources to both reduce pig feed costs but ultimately reduce reliance on imported soya. The two most readily available alternative protein sources that are produced in the UK are rapeseed meal (RSM) and dried distillers grains with soluble (DDGS). However both bring their own challenges. Both are by products of a process and as such are highly variable in nutritional value. Furthermore, they can both contain anti-nutritional characteristics. Knowledge on how to use them responsibly is therefore key to 'risk manage' their use in pig feed. With co funding from the Department of Agriculture and Rural Development (N. Ireland), the research consortium of John Thompson and Son's Ltd, Devenish Nutrition Ltd and AFBI have investigated their use in recent years.

With regard to RSM, three trials were completed where RSM was included at varying inclusion levels and offered to finishing pigs. The results from these three trials are more fully reported in the Proceedings of the annual British Society of Animal Science Conference, 2013. In all three trials the RSM used was deemed acceptable with regard to the level of anti-nutritive compounds (mainly glucosinolates). In two trials the level of inclusion was taken to 21% and in the third trial the level of inclusion was taken to 9%. In the first trial, pig feed intake and pig performance was not affected when the diet contained up to 21% of RSM. However in a second trial feed intake was negatively affected when RSM inclusion exceeded 7 %. Feeding behaviour data indicated that as inclusion level increased the feed became less palatable. However in the third trial when inclusion was taken to 9% pig performance improved. The variability in pig response across these three studies is in line with much of the scientific literature which is characterised by inconsistent performance from RSM inclusion.

Overall whilst inclusion of RSM largely supports pig performance there is potential for it to negatively affect feed intake due to anti nutritional factors and therefore present a 'risk' to pig productivity.
With regard to dried distillers dried grains with solubles (DDGS), the use of both wheat and maize DDGS at inclusion levels up to 30% have been compared for finishing pigs. Diets containing incremental inclusion levels of both European Wheat and US maize DDGS were formulated. Both sources of DDGS were found to contain key mycotoxins, albeit at acceptable levels, and a mycotoxin binder was included in the diets. Upon analysis the two types of DDGS differed in protein, fibre and oil content with the maize DDGS having 27.7, 6.95 and 11.3% respectively and the wheat DDGS having 29.5, 7.62 and 6.95% respectively. With regard to amino acids there was also some small differences with maize DDGS having 0.84, 0.58, 0.47, 0.94 and 0.19 % of Lysine, Methionine, Cystine, Threonine and Tryptophan respectively and wheat DDGS having 0.72, 0.47, 0.51, 0.89 and 0.22% respectively. With regard to pig performance there was no effect of DDGS type or inclusion level. However, whilst there was no effect of DDGS type, there was an effect of inclusion level on diet digestibility. As inclusion level increased to 30%, dry matter, energy and nitrogen digestibility decreased but oil digestibility increased. More detailed results from this trial will be presented at BSAS 2016. Overall, using these two sources of DDGS, there was little difference in pig performance or diet digestibility due to DDGS type (maize vs wheat) but as inclusion level increased, diet digestibility decreased.

This programme of work has highlighted opportunities as well as 'risks' when using RSM or DDGS but overall it does support their responsible inclusion in pig diets.

Investigating the potential of the intestinal microbiota to impact feed efficiency in pigs

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Key Messages:

- Relative abundance of a limited number of faecal bacterial groups differed in pigs of varying feed efficiency.

- Age-related changes in faecal microbiota and a sow influence were also observed

Summary

The intestinal microbiota of pigs has an important role to play in host immunity and nutrient digestion. Therefore, it's potential to influence production efficiency cannot be underestimated. As feed accounts for >70% of pig production costs, farmers are continually looking for ways to improve feed efficiency. Dietary manipulation of the intestinal microbiota may be one way to achieve this. The aim of this study was to examine the faecal microbiota profiles of pigs with good and poor feed efficiency in order to investigate the potential of the intestinal microbiota to impact feed efficiency in pigs.

Entire litters from seven sows were housed individually, with feed intake and weight recorded at 2-week intervals between day 42 post-weaning (pw) and slaughter at day 139 pw. Two weeks before slaughter, pigs were selected within litter as having the best, poorest and average feed efficiency (10 pigs per group). Faecal samples were collected at weaning and at day 42 and day 139 pw for microbial community analysis using high-throughput 16S rRNA gene sequencing. Data were analysed statistically with significance assumed at P≤0.05. No differences in any of the faecal bacterial phyla detected were observed between pigs selected on the basis of divergent feed efficiency. However, at the family level, the relative abundance of *Streptococcaceae* was lower and of *Campylobacteraceae* was higher in pigs with the best compared to the poorest feed efficiency (0.81 versus 2.09% and 0.63 versus 0.36%, respectively; P<0.05). These differences were reflected at the genus level, with relative abundance of *Streptococcus* and *Campylobacter* lower and higher, respectively in the more efficient pigs (0.80 versus 2.09% and 0.63 versus 0.36%, respectively; P<0.05). In addition, relative abundance of Adlercreutzia was higher and Pseudobutyrivibrio was lower in the more efficient pigs (0.000021 versus 0.000004% and 0.09 versus 0.17%, respectively; P<0.05). However, the extremely low relative abundance of the former should be noted. Relative abundance of the main bacterial phyla also changed over time (P<0.05); Firmicutes increased between day 42 and day 139 pw, Bacteroidetes and Spirochaetes increased from weaning to day 42 pw and Proteobacteria and Synergistetes decreased from weaning to day 139 pw. A maternal effect was seen for some of the major phyla (P<0.05). In conclusion, only two of the 98 bacterial families and four of the 212 genera detected within the faecal microbiota of pigs with good versus poor feed efficiency differed. However, the role of these bacterial groups may be important; for example, some species of *Streptococcus* are pathogenic to pigs and this genus was less abundant in the more efficient animals. Age-related changes in the faecal microbiota and the influence of the sow on offspring microbiota were also evident. Overall, the functional potential of the intestinal microbiota of these pigs needs to be investigated further in order to elucidate the role of the intestinal microbiota in feed efficiency.

This research is part of the ECO-FCE project which has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under Grant Agreement Number 311794.

Measuring Green House Gas emissions from finishing pigs with good and poor feed use efficiency

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Summary

Pig production accounts for 13% of the total emissions of green house gases (GHGs) from the livestock sector. GHG emissions in piggeries originate from animals through CO_2 exhalation and CH_4 enteric fermentation, and from manure through the release of CO_2, CH_4, N_2O and NH_4. Total GHG emissions are estimated to be 448.3 kg CO_2equiv. per slaughter pig produced. The fattening period accounts for more than 70% of total emissions, while the gestation, lactation and weaning periods each contribute about 10%. Pig farming also accounts for about 9% of annual ammonia emissions from the UK and 11% of those from agricultural sources. Housing and manure spreading are the largest sources contributing approximately 50% each. AFBI are working in collaboration with Teagasc to identify the impact that good or poor feed use efficiency can have on the greenhouse gas emissions from finishing pigs both in the house and during storage of the subsequent slurry. This work is currently underway but the detail below gives some information on data gathered so far.

A litter of 10 boars was identified at birth and reared in their litter group to 8 weeks of age at which point they were reared in individual penning to identify the 3 boars with the best 'residual feed intake' (RFI) (a reflection of feed use efficiency) and the three with the poorest RFI. At 16 weeks of age these 6 boars representing divergent RFI were individually housed across six metabolic respiration chambers. A typical finisher diet was offered ad-lib on a daily basis. Pigs remained in the chambers for 5 weeks to enable a build up of ammonia emissions. In the final two weeks, measurements of O_2, CO_2, CH_4, N_2O and NH_4 emissions were recorded every fourteen minutes per chamber. This was achieved by pumping air from the chamber via sampling ducts at a rate of 10 cubic metres per hour, (NCMH). Expelled air was sampled and passed to both an ADC electrochemical sensor and a GASERA photoacoustic infra-red spectrometer. Additionally, environmental conditions were continuously monitored in each chamber and externally, including atmospheric pressure, temperature, humidity and air flow rates. These data were compiled, synchronised and the gas measurements adjusted for the effect of variable environmental conditions.

Results from these initial 6 animals show that methane production from low RFI pigs (good feed use efficiency) ranged from 18.3-48.0 L/day, CO_2: 417.6-692.8L/day, N_2O: 18.2-30.7L/day and NH_3: 59.4-265.5L/day. Methane production from high RFI pigs (poor feed use efficiency) ranged from 24.1-60.8L/day, CO_2: 519.1-594.0L/day, N_2O: 27.7-34.6L/day and NH_3: 75.1-126.3L/day. These data include emissions from the slurry in addition to the pig since slurry was allowed to accumulate while pigs were in the chambers. A relationship between NH_3 and N_2O was also observed indicating evidence of microbial nitrification/denitrification processes occurring as slurry composition changed throughout the trial. The resultant slurry from each pig was stored and gaseous emissions were measured during storage. The methane and CO_2 emissions from the slurry showed major differences according to slurry sample. Heat production from the pigs was also calculated, (based on O_2 emissions only). Low RFI pigs produced an average of 17.9 MJ/day and High RFI pigs produced 18.6 MJ/day.

Further replication will enhance this dataset and will be used to inform stakeholders of how high and low feed use efficiency can affect the global warming potential of pigs.

This research is part of the ECO-FCE project which has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under Grant Agreement Number 311794.

A case study review of practical enrichment devices for pigs

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Key messages:

- Tail-biting remains an intractable problem with outbreaks hard to both control and limit on pig farms but enrichment of the pig environment is a key tool to combat tail biting.

- Practical evidence gathered from across pig farms in Europe demonstrated some enrichment strategies which have been found to be both practical and cost effective at reducing tail biting.

- This evidence also highlights that risk and mitigating factors will vary from farm to farm but a combination of enrichment and attention to detail with regard to environmental controls and/or animal management appears to provide success for some.

Summary

Tail biting is now considered as one of the most important animal welfare problems in the pig sector. Tail biting is a painful cannibalistic behaviour leading to damage and destruction of the victims' tail and rump.

Through a Department of Agriculture and Rural Development funded project, AFBI researchers identified and visited six case study commercial farms which were in Switzerland (2), Netherlands (1) and Denmark (3). Where possible, farms were chosen which reflected general pig farming practices in Northern Ireland but case study farms which were banned from tail docking (i.e. Switzerland) were also investigated. The majority of the farms routinely practiced varying degrees of tail docking and all provided various enrichment devices which all conformed to the current EU legislation requiring them to be: destructible, changeable, edible, nutritional and dung-free since the provision of enrichment devices is the cornerstone of negating tail biting.

However, tail biting has multi factorial triggers and it is becoming apparent that not one single strategy will reduce or stop tail biting. As such, a key feature on all the farms was that, none of the enrichment devices were the sole tool aimed at reducing tail biting. The farmers that were interviewed were also highly diligent about many other factors including for example, pen humidity and thermal atmosphere, ventilation, space allowance, access to natural light, feeding regime/mechanism and the general daily mood and state of agitation of pigs within each pen.

Across the case studies two types of enrichment stood out as being commonly used to negate tail biting. The first was a static permanent and routinely refilled enrichment device such as a wooden post in a loose holder or a gravity fed pellet of compressed straw. The second provided some additional novelty when pigs either became particularly agitated, had wet tails or were showing tail-in-mouth behaviour; in such cases the additional enrichment offered was akin to straw/hay in racks or natural material rope coiled in hanging buckets. Farmers would also have used these 'second' enrichment devices at known times when the incidence of tail biting flared as a preventative measure e.g. at certain ages.

The majority of the farmers interviewed reported that tail biting outbreaks had been minimised on these farms to the point of, in some cases, no visible signs of tail biting being observed on farm for some time. However this was not the case for one of the farmers interviewed.
Overall, tail biting was not completely absent from any of the farms and only three farms (which were least intensive farms and 'higher' welfare driven through marketing schemes and legislation (i.e. Switzerland)) were able to succeed in performing no tail docking at all, all other case study farms felt a degree of tail docking was still a necessary part of their management system. Some farmers docked half, or less than half, the tail by choice with a vision of taking less off progressively to reach a point where the tail would be undocked, others removed half the tail because legislation, respective to their country, restricted greater amounts from being docked.

Tail biting remains a complex problem with outbreaks occurring sporadically and unpredictably on farms. However, these European case studies did highlight some opportunity to manage tail biting on pigs farms using fully slatted systems. Risk and mitigating factors will vary from farm to farm but a combination of enrichment and attention to detail with regard to environmental controls and/or animal management appear to provide success for some.

Wet feeding sows and growing pigs

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Key Messages:

- Whilst whey permeate inclusion in grower diets at 20% was not beneficial, inclusion at 10% supported the optimum performance of growing pigs. A further addition of 10% yeast along with 10% whey permeate also supported optimum performance.

- With regard to sows, a lactation diet containing 10% whey permeate supported sow and litter performance and when a gestation diet containing 50% of a co product blend was offered no detrimental effect on sow reproduction or subsequent litter performance was observed.

Summary

Liquid feed systems are used to feed a large proportion of the NI pig herd. However, research in this area is lacking. AFBI are collaborating with JMW Farms and Rektify limited to investigate the use of various co-products in grower pig and sow diets. The facilities being used represent a 750 sow herd using liquid feeding and are therefore based on commercial practice.

Initial trials for weaner pigs investigated the optimum allowances of creep and link diets post weaning. Either 2, 3 or 4 kg/pig of creep feed was offered and either 6, 8 or 10kg/pig of link feed was offered. Pig wean weight averaged 7kg across these trials and in agreement with previous research at AFBI the optimum allowance for creep feed was found to be 2kg/pig and was 6kg/pig for link feed. An interesting finding from this work was the dramatic reduction in daily feed intake when grower diet was introduced and then the dramatic increase in 'feed disappearance' when pigs moved from stage 1 to stage 2 accommodation. As such the management practice of the farm was changed so that pigs changed to grower diet at the same stage as when they moved into stage 2 accommodation.

With regard to growing pigs, the use of increasing levels of whey permeate and yeast have been investigated. The dry matter of the whey permeate used averaged 14%. It was found that the inclusion of 20% whey permeate reduced pig feed intake and pig performance but the performance of growing pigs offered liquid feed containing 10% whey permeate had similar performance to those offered the control diet (which was simply the grower diet with water). The addition of 5 or 10% yeast in addition to the 10% of whey permeate was then investigated. It was found that pig performance was similar whether the control or the diet containing 10% whey permeate and 10% yeast was offered.

With regard to sows, a total of 272 sows were used in a lactation sow trial where the inclusion of 10% whey permeate to the lactation sow diet was compared when just water was used. The litter growth rate of sows offered diets with whey permeate was similar to that of the sows offered the control diet. Furthermore, there was no impact of the whey permeate inclusion on milk composition during lactation or on sow feed intake. In an additional trial, using 139 sows the inclusion of a co product blend was investigated. The co product blend was a composite mixture of whey permeate, potato permeate and brewers yeast. It was incorporated into the dry sow diet at a rate of 50% and this was compared to a control diet where a typical gestation diet was offered with water. Although the 'dirtiness' of sows was greater when using the co product blend, it's use did not affect litter size or litter weight at birth or sow condition score throughout gestation.

Overall, little improvements were noted when co products were used but most co products could be included in the diets without causing detrimental effects on sow or pig performance. As such they represent an opportunity to reduce the cost of the diet.

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Predicting the amino acid digestibility of rapeseed meal.

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Rapeseed meal (RSM) represents the most commonly used 'home grown' alternative protein source in pig and broiler diets in the UK. However RSM is a by product from the production of rapeseed oil and as such can be highly variable in nature. Whilst research can educate us on the effects of variation in nutrient composition and anti nutritional factors, the need to respond quickly to this variation is paramount for the feed industry to formulate diets in a knowledgeable manner. A collaborative project, being lead by AFBI and funded by AHDB Cereals and oilseeds, AB Vista and the Department of Agriculture and Rural Development in Northern Ireland is investigating the use of Near Infrared spectroscopy (NIRS) to predict the nutrient digestibility of RSM. The ability to predict nutrient digestibility will improve the precision with which diets can be formulated.

Over the past 18 months, a total of 80 samples of RSM have been collected from Cargill crushing plants in England. These samples have been formulated into semi-synthetic diets and offered to pigs and broiler chickens to determine the amino acid, fibre and energy digestibility of the RSM samples. The samples have also been scanned using two bench based NIR instruments and one hand held instrument. The RSM samples have also underwent global glucosinolate profiling.

Table 1 demonstrates the variation in rapeseed meal quality in terms of fibre, protein, oil and amino acid concentrations. Whilst the coefficient of variation for crude protein was low at 2.2%, the co efficient of variation for lysine content was high at 10.4%. Figure 1 shows the variation in Lysine digestibility in pigs from the first 19 samples. Lysine digestibility ranged from 77 to 90%. This project is due to be completed by March 2016 at which stage the amino acid digestibility for all samples will have been determined.

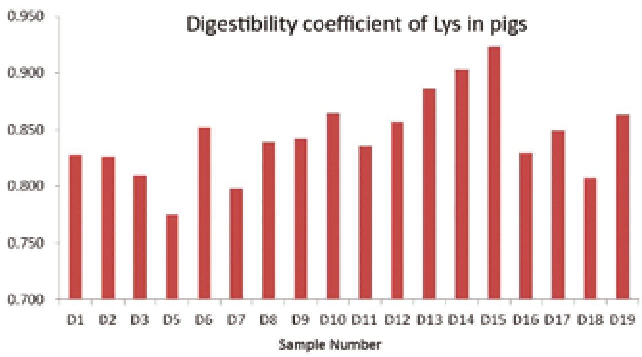

Figure 1 The variation in lysine digestibility from the initial 19 samples offered to pigs

Table 1 The variation in RSM quality across the 80 samples

	Amino Acids (concentration in the RSM (%))					Concentration (%)		
	Cystine	Lysine	Methionine	Threonine		OilB	Protein	NDF
Average	0.82	1.70	0.67	1.51		4.26	35.55	27.64
STDEV	0.057	0.177	0.038	0.068		0.565	0.783	1.368
Min	0.70	1.26	0.60	1.40		3.00	34.51	23.11
Max	1.03	2.18	0.82	1.81		6.75	37.67	29.75
CV (%)	7.0	10.4	5.8	4.5		13.3	2.2	4.9

The variation in finishing pig feed conversion efficiency between and within herds

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Key Messages:

- The average FCR of contract finish units in Northern Ireland is 2.66
- However, variation in feed use efficiency between contract finishing units in Northern Ireland can equate to differences of £34,000 per annum in profitability (based on 5200 finishing places).
- Within this dataset some herds had superior FCR due to superior growth rates whilst others had superior FCR due to reductions in ADFI and only 26% had above average FCR due to both ADG and ADFI being optimised.

Introduction

The efficient use of feed on pig farms is a key driver of profitability since feed represents at least 75% of production costs. With the increased use of contract finishing units in recent times the ability to accurately calculate finishing pig feed use efficiency (FCR) has now become possible. Through a collaborative effort between John Thompson and Sons, Devenish Nutrition Ltd, PCM, CAFRE and AFBI and with co-funding from the Department of Agriculture and Rural Development, this study aimed to quantify the magnitude of FCR variation that exists between and within finishing pig units in Northern Ireland.

Material and methods

Five producers were recruited who finished pigs across a range of different contract finish units. As such pigs originated from five sources where genetics and rearing system to approximately 30 kg were similar. These 5 sources finished pigs across a total of 17 finishing units and data was collected from a total of 79 batches of pigs reared through these units over an 18 month period during 2012 and 2013. The majority (85%) of units used single space wet and dry feeders, 10% used 'dry' feeders and the remaining 5% used liquid feed. With regard to terminal sire genetics, 25% of units represented Duroc (Danbred), 25% PIC 337, 15% Maxgro (Hermitage) and the remainder Landrace. Health status was considered good (mean mortality across all batches of 1.8%). It was not possible to obtain the digestible energy content of the diet but the crude protein of diets ranged from 19 to 16% and total lysine ranged from 1.2 to 0.9 (some units used phase feeding). Feed intake per house was measured by the amount of tonnage delivered per batch and an estimation of feed left in bins was made when pigs were removed. For the vast majority of batches pigs entered on the same day but at the end of the finishing period only a few units were cleared on the one day and the majority of pigs were sent for slaughter over a period of 4-6 weeks. The total weight of pigs removed at any given time point was recorded. The date and approximate weight of pigs that died was recorded. Simple statistics was performed on the data to calculate the mean, standard deviation (SD) and coefficient of variation (CoV) of the data. Using the batch data, a multi variate regression analysis was conducted to establish the relationship between average daily gain (ADG) and average daily feed intake (ADFI) with FCR.

Results

The profile of data for start and slaughter weight, FCR, ADG and ADFI on a per batch basis is provided in Table 1. Figure 1 demonstrates the variation in FCR both within and between units. The CoV for FCR between batches within each unit ranged from 1.45 to 11.4% (with a mean of 4.98%) indicating that some units could achieve a consistent FCR whereas on others FCR was sporadic between batches. On a per unit basis FCR ranged from

Table 1 – Simple statistics on the FCR data across the 79 batches of finishing pigs

	Av pig live wt in (kgs)	Av Livewt sold (kgs)	FCR	ADG (g/pig)	ADFI (g/pig)
Min	24.8	96.9	2.24	704	2252
Max	52.8	120.0	3.08	1142	3079
Mean	38.9	111.8	2.66	870	2314
SD	5.68	5.22	0.16	95.9	268
% CV	14.6	4.67	5.99	9.6	10.1

2.48 to 2.85 with an SD of 0.095 and CoV of 3.57%. On a per source (producer) basis FCR ranged from 2.59 to 2.71 with an SD of 0.051 and CoV of 1.93%. Economically, assuming a diet cost of £250 per tonne, a weight gain of 70 kg and a kill out percentage of 78%, it cost 1.25 p/kg gain, 1.64 p/kg carcass weight or £4.55 per tonne of feed for every 0.05 unit shift in FCR. On a unit basis, if the SD of FCR is applied to the mean FCR, then 95% (Average + / - 2 SD's) of the FCR values fell between 2.47 and 2.85 which represents a 0.38 unit range in FCR. This would equate to approximately £35 per tonne of feed, 12p/kg dead weight or at least £34,000 in profitability (Assuming 5200 pigs finished per year). The 'average' average daily gain across all batches was 869 g/day and the 'average' average daily feed intake across all batches was 2304 g/ day. 67.5% of batches of pigs with a below average FCR (2.66 or under) also had an above average ADG (869 g/ day or over) and 62.5% of these batches had a below average ADFI (2304 g/day or under). Only 26% of batches with above average FCR had both above average ADG and below average ADFI. For batches with an FCR above the average (2.66 or higher), 53.3% of these had a below average ADG and 62.2% had an above average ADFI.

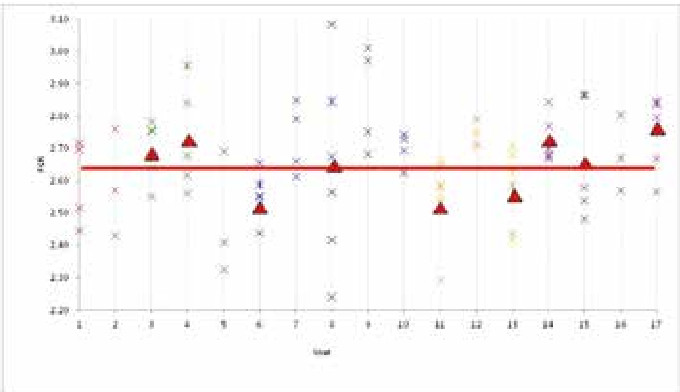

Figure 1 The variation in FCR between and within contract finish units in NI

The vertical 'x's' indicate the FCR of the individual batches per unit (horizontal axis). 'X's of a common colour were from the same source farm. The red triangles indicate the average FCR per unit, the red line indicates the average FCR across all batches.

Conclusion

As expected the variation in FCR between sources (producers) is lower than between units which is lower than between batches. A 0.64 unit range in FCR can exist between batches of pigs across contract finishing units in NI. A 0.38 unit range in average FCR exists between contract finishing units which equates to a significant difference in profitability (£34,000 per annum based on 5200 finishing pigs). Within this dataset some herds had superior FCR due to superior growth rates whilst others had superior FCR due to reductions in ADFI and only 26% had above average FCR due to both ADG and ADFI being optimised.