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Midwest Swine Nutrition Conference

Schedule of Presentations

8:15 am	Registration
9:00	Welcome and Introductions *Merlin Lindemann, University of Kentucky*
9:05	Values, Trust and Science—Building Trust in Today's Food System in an Era of Radical Transparency *Terry Fleck, Center for Food Integrity*
9:50	Recent Findings in Essential Fatty Acid Nutrition in Relation to Seasonal Infertility in the Modern Sow *David Rosero and Dean Boyd, Hanor USA*
10:20	Break
11:00	Can Diet Affect Swine Behavior? *Jeremy Marchant-Forde, USDA at Purdue University*
11:30	Effects of Pelleting Growing-Finishing Swine Diets on Growth, Carcass, and Bacon Characteristics *Dustin Boler, University of Illinois*
12:00	Lunch
1:00 pm	The Future of the Midwest Poultry Consortium Center of Excellence: What Have We Learned in 19 Years? *Darrin Karcher, Michigan State University*
1:45	Effects of Decreasing Dietary Crude Protein with Amino Acid Supplementation on Performance, Carcass, and Nutrient Excretion of Pigs *Charles Maxwell, University of Arkansas*
2:15	Break
2:55	Betaine for Boars and Sows During Heat Stress *Kara Stewart, Purdue University*
3:25	An Overview of the 2015 Digestive Physiology of Pigs Symposium *Thomas Burkey, University of Nebraska and Merlin Lindemann, University of Kentucky*
4:00	Adjourn

Midwest Swine Nutrition Conference

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Values, Trust and Science—Building Trust in Today's Food System in an Era of Radical Transparency

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Summary

How can producers communicate when consumers don't accept what scientific consensus says is true? The Center for Food Integrity's (CFI) consumer research provides a roadmap to making complex and controversial technical information relevant and meaningful, bringing balance to the public conversation on food and helping consumers make informed decisions about the technological advances needed to produce the food we need for a rapidly growing global population. The CFI's peer-reviewed and published model for building trust in today's food system shows that "confidence" (shared values) is three to five times more important than "competence" (skills, technical expertise or science) in building consumer trust. In other words, it's not just about giving consumers more information. It's about demonstrating that today's food producers share their values when it comes to topics they care about most—safe food, quality nutrition, appropriate animal care, environmental stewardship and others.

The Social License to Operate

Every organization, no matter how large or small, operates with some level of social license. A social license (Figure 1) is the privilege of operating with minimal formalized restrictions (regulation, legislation or market based mandates) based on maintaining public trust by doing what's right. You are granted a social license when you operate in a way that is consistent with the ethics, values and expectations of your stakeholders. Your stakeholders include customers, employees, the local community, regulators, legislators and the media.

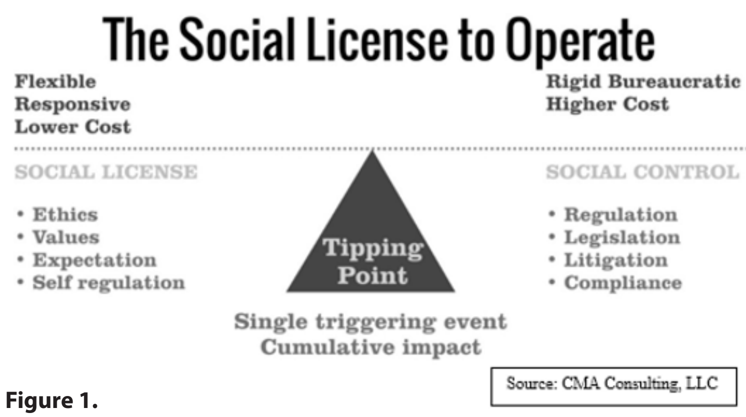

Figure 1.

Once lost, either through a single event or a series of events that reduce or eliminate public trust, social license is replaced with social control. Social control is regulation, legislation, litigation or market action designed to compel you to perform to the expectations of your stakeholders. Operating with a social license is flexible and low cost. Operating with a high degree of social control increases costs, reduces operational flexibility and increases bureaucratic compliance.

A U.S. case in point—Arthur Anderson and Enron. Prior to the collapse of Enron, public accounting firms operated with a fairly broad social license. The accounting industry had established the Financial Accounting Standards Board to regulate the implementation of Generally Accepted Accounting Principles by Certified Public Accountants. The accounting industry created a structure for self-regulation based on the expectations of their stakeholders which included investors, banks, the Securities and Exchange Commission, financial media and others.

Stakeholders relied on the industry to operate in a way that maintained public trust and in return the public was willing to grant accountants broad social license. The Enron debacle cost the accounting profession its social license. That single event was the tipping point that compelled Congress to replace the social license of the accounting profession with the Sarbanes-Oxley Act, a law that requires extensive reporting and verification of financial information by publicly traded companies. According to research by Foley & Lardner, the average cost for a public company to comply with Sarbanes-Oxley is between $10 and $15 million per year. Those are costs that could have been returned to shareholders as dividends, or reinvested in research and development.

The same principles apply to the food system. The social license once enjoyed by food companies is at risk as a growing group of stakeholders raise questions about whether or not today's food system is worthy of public trust. Once public trust is lost, the tipping point is crossed and high cost, social control replaces flexible, lower cost social license. Once social control is in place it can be modified, but social license is never fully recovered. Maintaining social license has real economic value. It is not just the right thing to do, it is enlightened self-interest.

The question then becomes, what can be done to maintain public trust that grants the social license and protects freedom to operate?

A New Model for Building Trust

In 2006, CMA Consulting, LLC commissioned a meta-analysis of all the available research on the question of trust in the food system. Through that analysis, done in partnership with Dr. Stephen Sapp, Department of Sociology, Iowa State University, we were able to determine three primary elements that drive trust in the food system. Those three elements are confidence, competence and influential others (Figure 2).

Confidence is related to perceived shared values and ethics and a belief that an individual or group will do the right thing. Competence is about skills, ability and technical capacity. Historically this is where we have focused our communication about food, under the assumption that stakeholders will make logical data based decisions if provided credible information. Influential others includes family and friends as well as respected, credentialed individuals like doctors and veterinarians.

In late 2007, CMA launched a nationwide consumer survey on behalf of The Center for Food Integrity (**CFI**) to determine the role that confidence, competence and influential others play in creating and maintaining trust. We specifically asked consumers to rate their level of confidence, competence and trust in various groups of influential others in the food system. We asked questions related to food safety, environmental protection, nutrition, animal well-being and worker care.

The results of the survey were consistent and conclusive. On every single issue, confidence, or shared

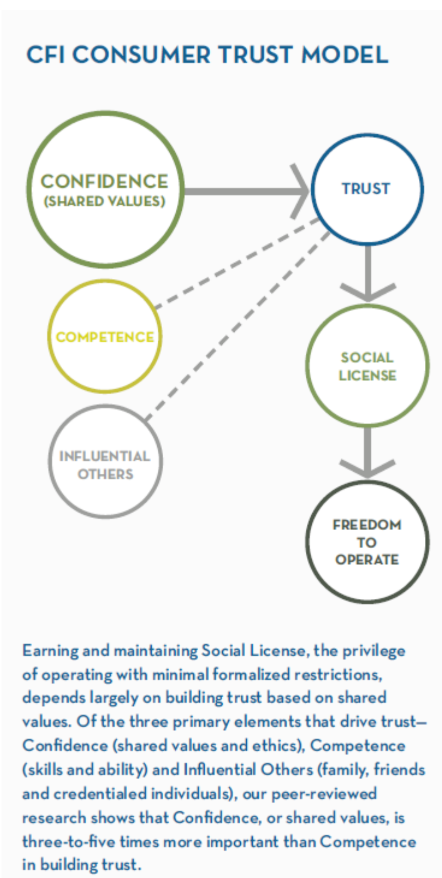

Figure 2.

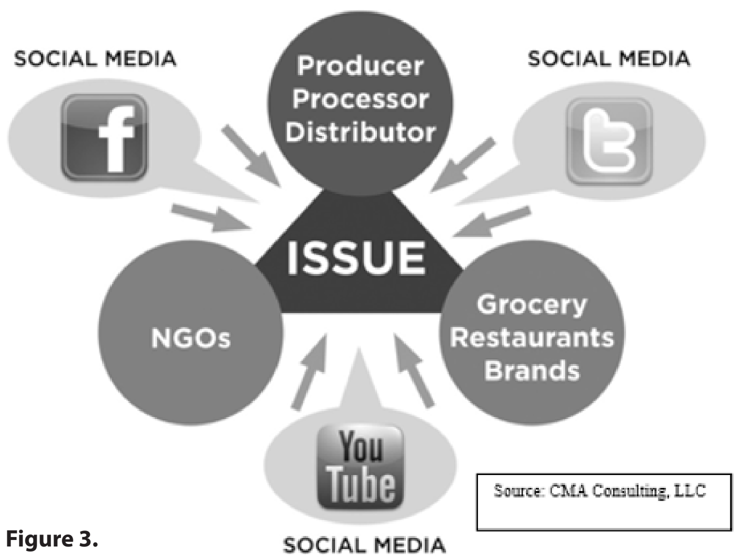

Figure 3.

values, was three to five times more important than competence for consumers in determining who they will trust in the food system. That research has been peer reviewed and was published in December, 2009 in *The Journal of Rural Sociology*.

These results should serve as a call to action for those in the food system. No longer is it sufficient to rely solely on science or to attack our attackers as a means of protecting self-interest. This new environment requires new ways of engaging and new methods of communicating if we want to build trust, earn and maintain social license and protect our freedom to operate.

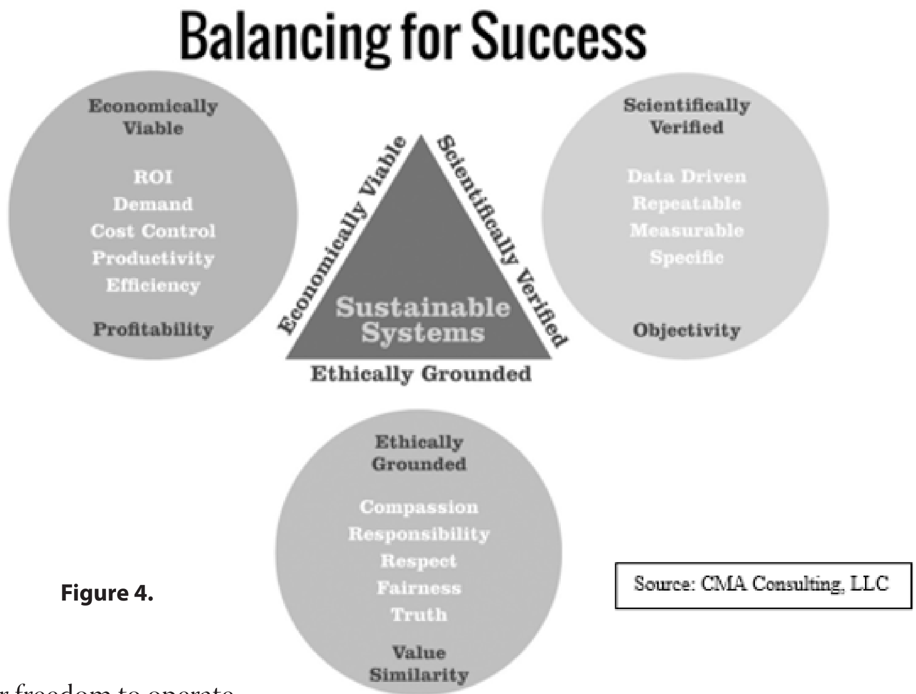

Figure 4.

Transparency is No Longer Optional

Today, anyone with a cell phone is a cinematographer. Research over the past four years clearly indicates that consumers increasingly go online to look for information to answer their questions about food. The power of social media to change the food system became clear in 2012 when concern over Lean Finely Textured Beef (LFTB) by a mommy blogger in Houston created an online firestorm that drove leading branded food companies, restaurants and grocery chains to eliminate a product that was supported by science.

In today's age of unbridled social media food system stakeholders have to develop new models for authentic engagement. Growing skepticism about food safety and the use of technology fuel online communities that are raising issues and making their voices heard with increasing volume and frequency. In this dynamic new environment (Figure 3) producers, processors and distributors are inextricably linked to their customers and non-governmental organizations interested in food issues. The question for food companies is no longer *"will you be transparent,"* but rather, *"how will you protect your social license in an age of radical transparency?"*

Figure 5.

New Models for Building Trust

The food system has an incredible challenge and opportunity ahead. By mid-century we have to more than double food production to meet the needs of more than 9 billion people. We have to produce more food by the end of this century than we've produced in the last 10,000 years combined. To meet that challenge we have to embrace new models of public engagement that build and maintain public trust and our social license to operate.

We need stakeholders who control social license to understand that while our systems have changed and our use of technology has increased, our commitment to doing what's right has never been stronger. We need to be able to verify our claims with objective science and we have to be able to continue to operate profitably if we want to survive. We need to adopt systems and practices that are ethically grounded, scientifically verified and economically viable (Figure 4).

It is only by achieving and maintaining this balance that we can create systems that are truly sustainable. Each side of the sustainability triangle has stakeholders focused on maintaining the strength of that side, even at the expense of maintaining balance. There may be times when stakeholders have to look beyond short term self-interest to foster truly sustainable food systems.

If food system practices are not ethically grounded, they will not achieve broad-based societal acceptance and support. If they are not scientifically verified, there is no way to evaluate and validate the claims of sustainability, and if they are not economically viable, they cannot be commercially sustained. For a system to be truly sustainable, it has to be ethically grounded, scientifically verified and economically viable. This model encourages stakeholders to look for balance in an effort to find true sustainability.

Building Trust When Science and Consumers Collide

Fortified by their own sources of information and their own interpretations of research, doubters have declared war on scientific consensus in food production. How can the food system connect with consumers who reject science?

The CFI's 2014 consumer trust research provides a model for making complex and controversial technical information relevant and meaningful—particularly to moms, millennials and foodies—bringing balance to the conversation, while helping consumers make informed decisions about food and building trust in today's food system.

Technological advances in food and agriculture have provided countless benefits to society, but more must be done. Finding better ways to support the informed public evaluation of technologies and the food production system is a challenge.

The goal should not be to win a scientific or social argument, but to find more meaningful and relevant methods to introduce science in a way that encourages thoughtful consideration and informed decision making. How technical and scientific information is introduced is key to supporting informed decision making.

A clear theme in CFI's latest survey results is that food system experts can make a difference when they choose to engage by first establishing shared values and then providing factual, technical information that is relevant and meaningful. After Confidence has been established, people are more willing to consider technical information, or Competence, in their decision-making process.

The CFI's research also looked into where Moms, Millennials and Foodies go for food system information (Figure 5). Websites were the top-ranked source of information for all three segments.

Conclusion—It's About Trust

As we increase both the distance most consumers have from farming, food processing and the level of technology we implement in food production we have to dramatically improve our ability and commitment to build trust with our customers and other stakeholders who grant social license. This will require a new way of thinking, a new way of operating and a new way of communicating.

Building trust requires an increase in early stakeholder engagement, transparency, professionalism, assessment and verification at all levels of the production and processing system. We have to give customers, policy makers, community leaders and consumers permission to believe that today's food system is consistent with their values and expectations. If we fail we will continue to see pressure to revoke our social license to operate and replace it with greater social control.

To be successful we have to build and communicate an ethical foundation for our activity and engage in value based communication if we want to build the trust that protects our freedom to operate. We need to demonstrate our commitment to practices that are ethically grounded, scientifically verified and economically viable.

To download the 2014 CFI Consumer Trust Research report or learn more log on to www.foodintegrity.org or email CFI at learnmore@foodintegrity.org.

Recent Findings in Essential Fatty Acid Nutrition in Relation to Seasonal Infertility in the Modern Sow

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Summary

Seasonal infertility represents a high cost to the U.S. swine industry because sows bred during heat stress exhibit seasonal reductions in farrowing rate, litter size, and increased non-productive sow days. Lipid nutrition during lactation has been proposed to increase caloric intake of sows and benefit the lactating sow, but studies are inconsistent. However, limited information exists in regard to the effects of supplementing lipids during lactation on seasonal infertility. Dietary lipids are also important sources of parent essential fatty acids (EFA, linoleic acid, C18:2n-6; and α-linolenic acid, C18:3n-3). Adequate consumption of EFA during lactation is critical because the lactating female secretes significant amounts of EFA in milk, even if this results in mobilization from body reserves. A nutritional deficiency of EFA during lactation negatively impacts the subsequent reproduction of sows. The net effect of supplemental EFA is to create a positive balance (intake minus secretion) during lactation and to prevent impaired fertility of sows. We demonstrated that EFA supplementation during lactation prevents a negative EFA balance, which improved subsequent farrowing rate and litter size, and reduced culling rate of sows for reproductive reasons. Conception rate was not altered (>90%), but pregnancy was maintained. Feeding programs should provide at least 100 g/d of linoleic acid or 10 g/d of α-linolenic to more than 95% of sows. Adequate EFA nutrition seems to be an effective heat abatement strategy that can ameliorate heat stress effects on fertility of sows.

Introduction

Detrimental effects of seasonality on sow reproductive efficiency costs the U.S. swine industry more than $300 million per year (Pollmann, 2010). Exposure of sows to high ambient temperature results in physiologic and metabolic changes that can lead to impaired intestinal barrier function and increased oxidative stress. An indirect effect of heat stress in sows and growing pigs is a dramatic reduction in nutrient intake. Limitation of energy and nutrient intake is challenging for the sow because mobilization of body reserves occurs to replace the nutrient deficiency. Heat stress was reported to compromise farrowing rate by 7% and increase non-productive days by 5 to 19 days per year (St-Pierre et al., 2003; Auvigne et al., 2010).

The prolific (14.6 pigs per litter) and high-producing (11.5 pigs weaned per litter) modern lactating sow (90th percentile; PigChamp, 2013) needs to produce 9 to 10 kg/d of milk to support the rapid-growing litters. Ensuring optimal nutrition of the high producing sow becomes particularly important to maximize lactation output and long-term productivity. Lipid nutrition is of particular importance in sow feeding programs because of the high energy density and low heat increment associated with its digestion and metabolism. Although, supplemental lipids are extensively used in lactation diets, their nutritional value is not limited to energy since they also provide parent essential fatty acids (**EFA**, linoleic acid, C18:2n-6; and α-linolenic acid, C18:3n-3). We expect that the latter is more important than the energy component, in full-fed lactating sows.

The biological roles of dietary EFA also include modulation of membrane fluidity and permeability, cell signaling, modulation of prostanoids, and eicosanoid secretion. These functions are critical and have been shown to support reproductive events in cattle (Santos et al., 2008; Thatcher et al., 2011). The present paper discusses recent studies that investigated the benefits of EFA nutrition on reproduction in the modern lactating sow.

Lipid Nutrition During Lactation

The use of supplemental lipids in lactating sow diets has been extensively studied over 30 years, but results from studies are inconsistent. Pettigrew and Moser (1991) reviewed published studies on lipid nutrition of the lactating sow and concluded that lipid supplementation increased caloric intake in spite of feed intake reductions stemming from external factors such as high

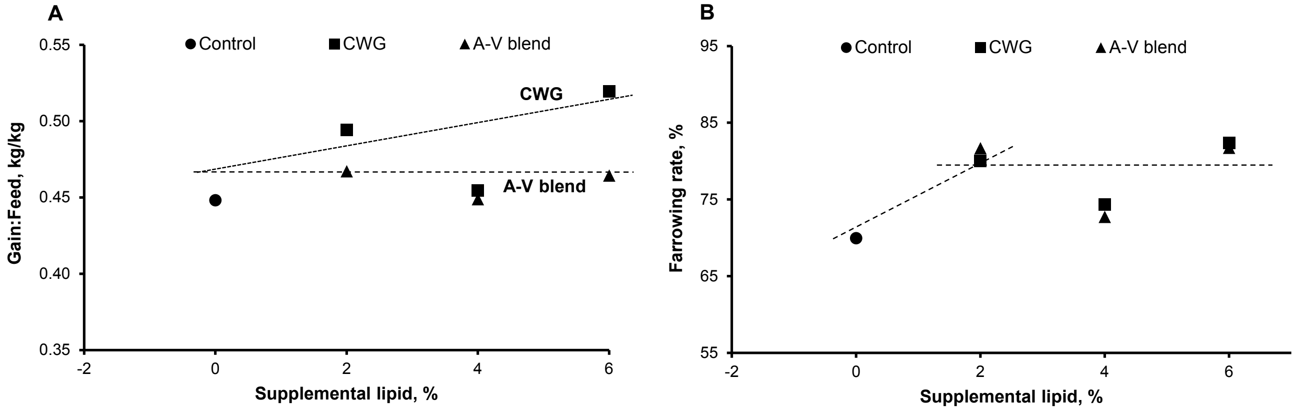


Figure 1. Effects of supplemental lipids on (A) lactating sow performance (Gain:Feed ratio) and (B) subsequent farrowing rate (percentage of sows that farrowed in the subsequent cycle) of sows. Sows were supplemented with either animal-vegetable blend (A-V blend) or choice white grease (CWG) as lipid sources.

temperature. Increased caloric intake resulted in modest and inconsistent improvements in milk fat secretion and weaning weight of piglets. Positive responses occurred when diets were supplemented with at least 8% of lipids, in herds where pre-weaning mortality was higher than 20%, or when sows were experiencing heat stress. An important statement of context was provided by Dr. B.G. Harmon (personal communication, 2015). Their experience at Purina Mills during the 1980-1990 time frame was that body condition improvement was easier to demonstrate with a lipid supplemented diet, because many producers were limit feeding.

To further increase our knowledge on lipid nutrition of the modern lactating sow, we recently conducted two dose-response research studies to investigate the effects of supplemental lipids on the modern prolific lactating sow when exposed to high ambient temperatures (Rosero et al., 2012a,b). Sows were fed either a control diet (without supplemental lipid) or diets supplemented with animal-vegetable (**A-V**) blend or choice white grease (**CWG**), as lipid sources, in increments of 2% (up to 6%). Confirming previous observations, the addition of either lipid source increased caloric intake of sows. Extra caloric intake slightly improved (CWG) or did not improve (A-V blend) the efficiency of diet use by lactating sows (Figure 1a). Notwithstanding this divergent response in the efficiency with which each lipid type delivered in lactation, both delivered equivalent responses in subsequent reproduction (Figure 1b). This was the key observation that led to the proposition that the EFA component of lipids might deliver the most profound and reproducible result.

Lipid Nutrition and Subsequent Reproduction of Sows

Earlier evidence suggested that subsequent reproduction of sows can be modulated by nutrition during lactation. Touchette et al. (1998) demonstrated that increased lysine intake by parity 1 sows (from 32 to 52 g/d) increased

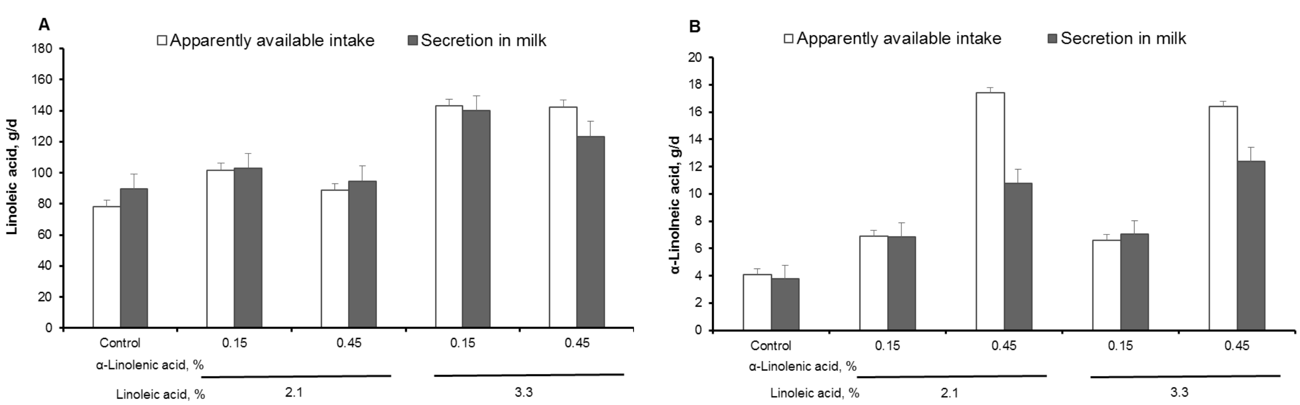


Figure 2. Effects of supplemental linoleic and α-linolenic acid on the estimated balance (apparently available EFA minus secretion in milk) of EFA during lactation. Sows fed the control diet had a negative balance of linoleic acid (-11.6 g/d) and slightly positive balance of α-linolenic acid (0.3 g/d) during lactation. Supplemental EFA increased ($P < 0.001$) the balance of α-linolenic acid, and tended to increase ($P = 0.14$) the balance of linoleic acid. Bars represent least squares means ± SEM (n = 10).

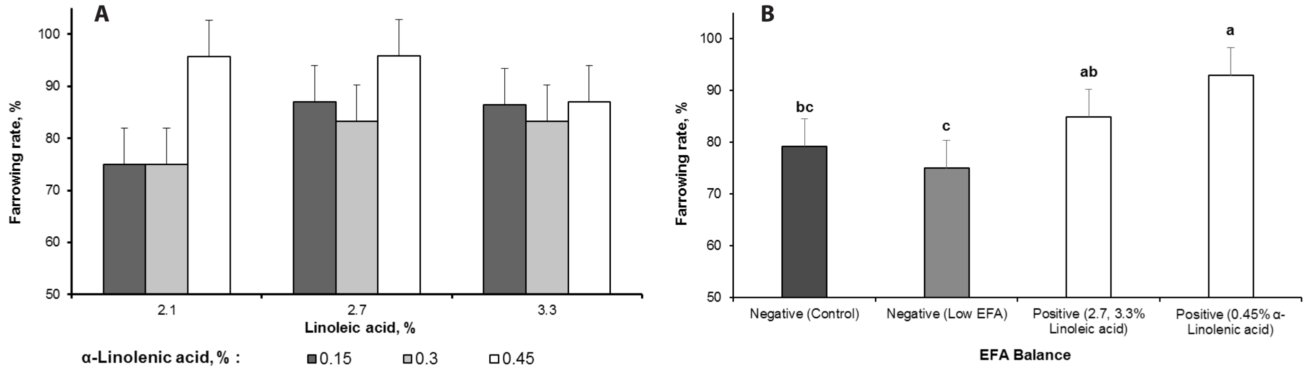


Figure 3. Effects of supplemental EFA during lactation on the subsequent farrowing rate (percentage of sows that farrowed in the subsequent cycle) of mature sows (P3+). (A) Supplemental linoleic by α-linolenic acid interaction effect. Supplemental α-linolenic acid (linear, $P = 0.079$) tended to improve the subsequent farrowing rate. Bars represent least squares means ± SEM (n = 23-25 sows). (B) Subsequent farrowing rate of sows that had a negative (control diet and diets containing < 2.7% linoleic acid and < 0.45% α-linolenic acid) or positive (≥ 2.7% linoleic acid or < 0.45% α-linolenic acid) EFA balance during lactation. Means represented by bars without a common letter are different ($P \leq 0.10$).

the number of pigs born in the subsequent cycle by 1.2 pigs. Similarly, observations from our research suggested that addition of lipids to lactation diets positively impact the subsequent reproduction of sows. The most intriguing finding of our research was that lactating sows fed diets without supplemental lipids had poor subsequent reproduction (farrowing rate < 72%), but this was remarkably improved by the inclusion of only 2% supplemental lipid to lactation diets (Figure 1b). It was hypothesized that the benefits observed on subsequent reproduction of sows were due to the supplementation of EFA (especially linoleic acid) from addition of lipids to diets.

Essential Fatty Acid Nutrition During Lactation

The studies conducted by Rosero et al. (2012a,b) caused one to consider the fact that lipids bring specific fatty acids that are known to be essential to performance. The essentiality of linoleic acid and α-linolenic acid in animals is due to the absence of desaturase enzymes that are able to introduce double bounds distal from carbon 10 of octadecenoic acids. These fatty acids, provided in high amounts in sow milk, play critical roles in the development of young animals (Innis, 2007). Given the essentiality of linoleic and α-linolenic acids for the development of the neonatal pig, our rationale is that the lactating female attempts to maximize the secretion of EFA in milk, even if this results in mobilization from body reserves.

To further investigate this hypothesis, we conducted a subsequent study and computed the estimated balance (apparently available intake minus secretion in milk) of EFA during lactation when EFA were provided (or not) in diets (Rosero et al., 2015). A total of 50 lactating sows were assigned randomly to a 2 x 2 factorial arrangement

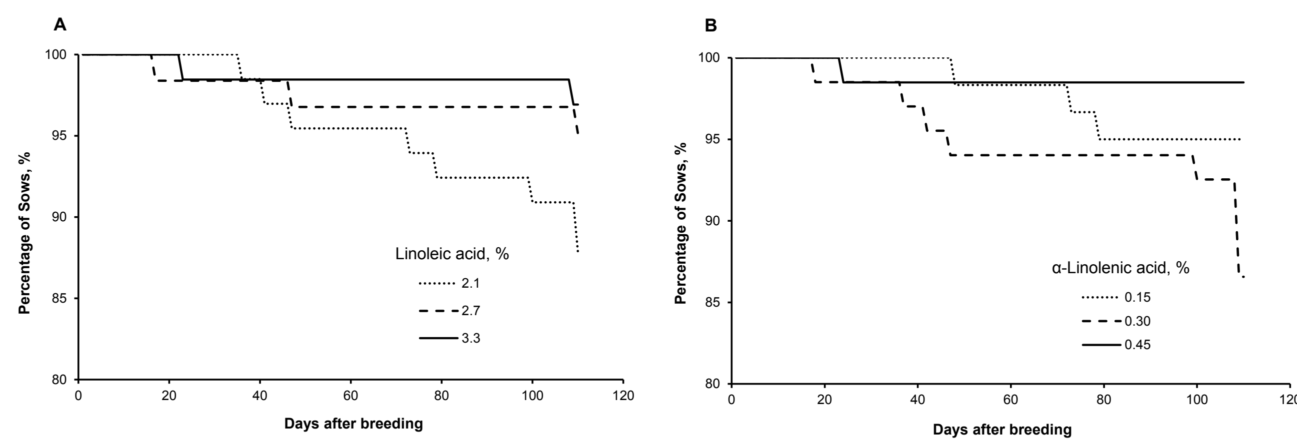


Figure 4. Effects of supplemental (A) linoleic and (B) α-linolenic acid during lactation on the capacity of mature sows (P3+) to maintain pregnancy in the subsequent cycle. Lines represent the percentage of pregnant sows after breeding (n = 60-67 bred sows).

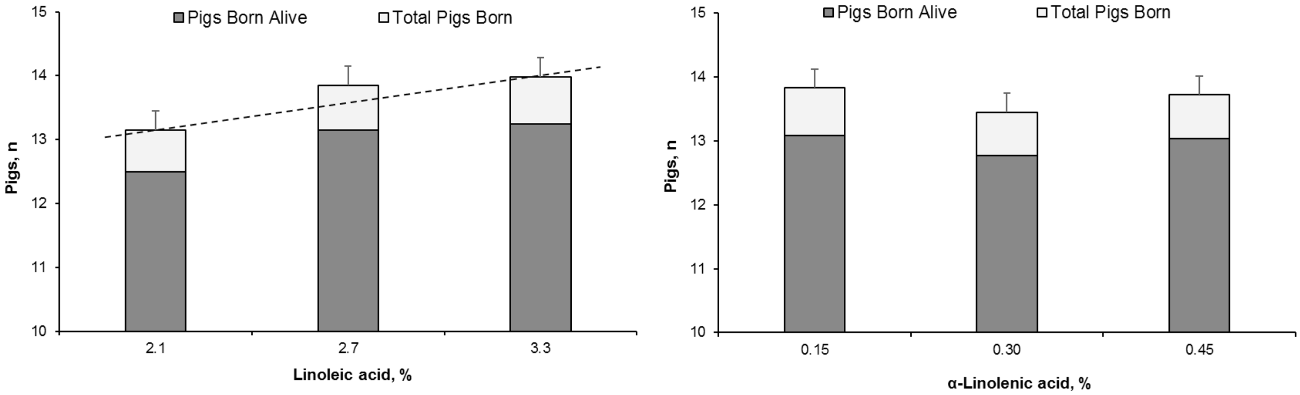
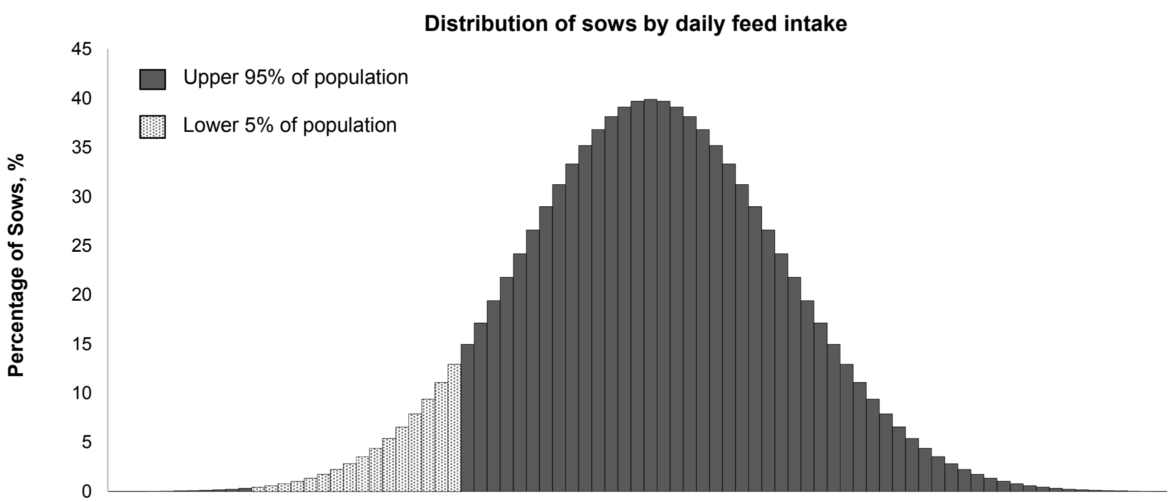


Figure 5. Effects of supplemental (A) linoleic and (B) α-linolenic acid during lactation on the number of pigs born alive and total pigs born in the subsequent cycle. Supplemental linoleic acid (linear, $P = 0.07$), but not α-linolenic acid ($P = 0.706$), tended to increase the number of total pigs born in the subsequent cycle. Bars represent least squares means ± SEM (n = 141-143 litters).

of diets plus a control diet without added lipid. Factors included linoleic (2.1 and 3.3%) and α-linolenic acid (0.15 and 0.45%), obtained by adding 4% of mixtures of canola, corn, and flaxseed oils to diets. We observed, for sows consuming a diet without added EFA, the amount of EFA secreted in milk (90 g/d of linoleic and 4 g/d of α-linolenic acid) were greater than the amount consumed. This resulted in a pronounced negative balance of linoleic (-11.6 g/d; Figure 2a) and marginal balance of α-linolenic acid (0.3 g/d; Figure 2b). This estimation highlights the potential nutritional deficiency of EFA during lactation and suggests mobilization from body reserves had occurred. The net effect of supplemental EFA (> 2.1% linoleic acid, > 0.15% α- linolenic acid) was to create a positive balance during lactation, which seemed to be beneficial for the subsequent reproduction of sows.

Despite the essentiality of EFA during lactation, current dietary recommendations for sows specify a low requirement for linoleic acid (0.1% of the diet or 6 g/d, assuming a feed intake of 6.28 kg/d; NRC, 2012) and no requirement minimum or maximum estimate for α-linolenic acid is specified. Compared with the least amount of linoleic acid secreted in milk (90 g/d, discussed above), the current recommendation estimate



Percentage of sows, %	0.0	0.0	0.3	4.4	21.8	39.7	26.6	6.6	0.6	0.0	0.0
Daily Feed Intake, kg/d	0	1	2	3	4	5	6	7	8	9	10
Linoleic acid intake, g/d											
Diets containing 2.1%	0	21	42	63	84	105	126	147	168	189	210
Diets containing 2.7%	0	27	54	81	108	135	162	189	216	243	270
Diets containing 3.3%	0	33	66	99	132	165	198	231	264	297	330

Figure 6. Estimated linoleic acid intake (g/d) of a normally distributed population of sows consuming an average of 5.1 ± 1.0 kg/d of feed during lactation.

of 6 g/d is logically too low. Based on the minimum amount of fatty acids secreted in milk, we suggest that provision of at least 100 g/d of linoleic will ensure adequate consumption and prevent any potential negative balance during lactation.

Essential Fatty Acid Nutrition and Subsequent Reproduction of Sows

Although supplemental EFA were demonstrated to benefit the subsequent reproduction of the dairy cow (discussed in the next section), little evidence exists for the modern lactating sow (NRC, 2012). Research in this area has been limited because it is commonly thought that diets, based on commonly used cereal grains and protein supplements, provide sufficient amounts of linoleic acid to lactating sows. This rationale is supported by older research (Kruse et al., 1977). However, litter-size born and weaned presently is almost twice that studied almost 4 decades ago. We expected that this may not hold true for the modern sow, especially for lactating sows under heat stress.

A following study was conducted to determine the adequate levels of EFA required by the prolific and high producing sow for optimal subsequent reproduction. A total of 480 lactating sows (equally balanced by parity 1, and 3 to 5, P3+) were assigned randomly to a 3 x 3 factorial arrangement plus a control diet without added lipid (linoleic acid = 1.3% and α-linolenic acid = 0.07%; from ingredients). Factors included linoleic (2.1, 2.7 and 3.3%) and α-linolenic acid (0.15, 0.30 and 0.45%), obtained by adding 4% of mixtures of canola, corn, and flaxseed oils to diets. Supplementation of EFA did not affect lactating sow performance but it improved the subsequent reproductive performance of sows depending on parity (Table 1). For young sows (parity 1), supplemental linoleic acid positively impacted the percentage of sows that farrowed in the subsequent cycle (93, 77.1, 93.2% for 2.1, 2.7, and 3.3% linoleic acid, respectively). This improvement with 3.3% linoleic acid (over 2.7%, but not 2.1% linoleic acid) was related with the high percentage of sows bred after weaning (97%). For mature sows (P3+), supplemental α-linolenic acid tended to improve the percentage of sows that farrowed in the subsequent cycle (linear, P = 0.079; 82.8, 80.5, and 92.8% for 0.15, 0.30, and 0.4% α-linolenic acid, respectively; Figure 3a).

Noticeably, sows that were fed lactation diets containing low levels of EFA (< 2.7% linoleic acid, < 0.45% α-linolenic acid) had a reduced subsequent farrowing rate (75%) and elevated culling rate (25%). It is possible that these sows were under a negative EFA balance during lactation. Under these conditions, supplementation of ≥ 2.7% linoleic or 0.45% α-linolenic acid improved the

Table 1. Effects of supplemental linoleic and α-linolenic acid on the performance of lactating sows and the subsequent reproductive cycle[1].

Item	Control	2.1			2.7			3.3			SEM
Linoleic Acid, %:		**2.1**			**2.7**			**3.3**			
α-Linolenic Acid, %:		**0.15**	**0.30**	**0.45**	**0.15**	**0.30**	**0.45**	**0.15**	**0.30**	**0.45**	
No.	**47**	**48**	**48**	**47**	**46**	**48**	**47**	**47**	**48**	**47**	
Lactating sow performance[2]											
Feed intake, kg/d	5.07	4.94	5.13	5.24	5.20	5.12	5.11	5.08	4.95	5.19	0.13
Sow body weight change, kg	-0.52	-2.76	-3.26	-0.42	-2.83	-0.97	-2.73	-1.23	-2.57	-1.94	1.74
Pigs after cross-fostering, no.	12.02	12.06	12.04	12.06	12.02	12.08	11.96	12.02	12.00	12.06	0.03
Pig survival, %	91.28	92.61	93.61	92.80	94.03	92.24	93.03	92.85	92.59	92.55	1.20
Litter gain, kg/d	2.44	2.51	2.54	2.56	2.59	2.43	2.59	2.55	2.52	2.54	0.05
Subsequent reproduction											
Parity 1											
Sows weaned	23	24	24	24	23	24	23	25	24	24	
Sows bred:weaned, %	91.3	95.8	95.8	87.5	91.3	87.5	78.3	96.0	100.0	95.8	4.9
Sows farrow:weaned,[3] %	91.3	95.8	95.8	87.5	78.3	79.2	73.9	92.0	95.8	91.7	6.2
Culling rate, %	8.7	4.2	4.2	4.2	17.4	13.0	18.2	8.0	4.2	8.3	5.0
Parity 3+											
Sows weaned	24	24	24	23	23	24	24	22	24	23	
Sows bred:weaned, %	91.7	87.5	95.8	95.7	87.0	87.5	100.0	86.4	95.8	87.0	5.2
Sows farrow:weaned,[4] %	79.2	75.0	75.0	95.7	87.0	83.3	95.8	86.4	83.3	87.0	6.9
Culling rate,[5] %	16.7	25.0	25.0	4.3	13.0	16.7	4.2	13.6	4.3	13.0	6.0

1 Dietary treatments were supplemented with 4% lipids that corresponded to 1 of 4 lipids obtained by blending canola, corn and flaxseed oils.
2 Supplemental linoleic × α-linolenic acid and linoleic or α-linolenic acids × parity interactions were not detected for any of the variables (P > 0.05).
3 Supplemental linoleic acid effect (linear, P = 0.909; lack of fit, P = 0.001).
4 Supplemental α-linolenic acid effect (linear, P = 0.079; lack of fit, P = 0.10).
5 Supplemental linoleic acid effect when α-linolenic acid < 0.45% (linear, P = 0.054; lack of fit, P = 0.955).

subsequent farrowing rate and reduced the culling rate (Figure 3b). We noted that conception rate was high at all levels of EFA, however, the level of EFA determined the extent to which the pregnancy was maintained. Sows fed adequate amounts of linoleic acid (> 2.1%; Figure 4a) or α-linolenic acid (0.45%; Figure 4b) were able to maintain pregnancy. In addition, supplemental linoleic acid (linear, $P = 0.07$; Figure 5a), but not α-linolenic acid ($P = 0.706$; Figure 5b), increased the subsequent litter size of parity 1 and P3+ sows.

Results of this study demonstrated that EFA supplementation during lactation directly affects subsequent reproduction and that this phenomenon is increasingly important with advancing sow age. Another significant finding was the fact that α-linolenic acid compensated for a deficiency of linoleic acid.

Essential Fatty Acid Nutrition and Possible Mechanism in Cattle

For many years, researchers suggested that the use of supplemental EFA is an effective nutritional strategy to improve the fertility of cattle. In an extensive review, Staples et al. (1998) concluded that supplemental lipids improved reproduction function and fertility in cattle, and suggested that positive responses were the result of providing supplemental EFA. The possible mechanisms that have been proposed included: nutraceutical regulation post-partum, modulation of follicle development, improved embryonic quality, increased concentrations of hormones important in reproduction (e.g. prostaglandins, progesterone), and pregnancy recognition and maintenance via cell signaling (Thatcher et al., 2010).

Linoleic acid is a precursor of prostaglandin F2α, which is synthesized by the endometrium, and plays an important role in diverse stages of reproduction, such as ovulation, luteal regression, implantation, uterine involution, and post-partum physiology (Weems et al., 2006). Feeding a protected lipid (rich in linoleic acid) pre-partum reduced the severity and incidence of uterine disease postpartum (e.g., retained placenta, metritis) and this was related with enhanced uterine secretion of prostaglandin F2α (Cullens et al., 2004; Santos et al., 2008). In 4 experiments (using 435 to 910 cows in each experiment), Lopes et al. (2009) demonstrated that supplementation of rumen-protected lipid (40% linoleic and 3% α-linolenic acid) to diets of lactating cows improved pregnancy rates at d 28 post insemination by more than 12% compared with cows fed diets with no added lipid. Rumen protection of EFA is necessary because microbes would change these fatty acids to forms that can severely decrease milk fat production.

Conclusions

Understanding the requirements of the prolific and high-producing lactating sow is important to design nutritional programs oriented to maximize the biological potential of growth of the nursing litters and to maximize the long-term productivity of the sow. The experiments, described in this paper, demonstrated that the nutritional value of lipids is not limited to energy, because lipids are also important sources of essential fatty acids. It was demonstrated that adequate consumption of EFA during lactation, when negative EFA balance is likely, was important for improved subsequent reproduction. Conversely, we showed that the intake of EFA can be made low enough to result in disturbing outcomes. We recommend the provision of at least 100 g/d of linoleic acid to lactating sows. Alternatively, provision of 10 g/d of α-linolenic acid seems to compensate for a deficiency of linoleic acid. Feeding programs should be designed to provide the suggested amount of linoleic and α-linolenic acid to > 95% of sows, accounting for the high variability in feed intake during lactation (5.1 ± 1.0 kg/d; Figure 6). Finally, we conclude that adequate EFA nutrition is an effective heat abatement strategy to ameliorate heat stress effects on the subsequent reproduction of sows.

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Can Diet Affect Swine Behavior?

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Summary

Pigs are social animals. From an evolutionary perspective, being social conveys a number of benefits, but potentially some disadvantages, especially for certain individuals within the group. For example, living in a social group can improve successful foraging in a natural setting, but competition within the group can reduce access to resources for some individuals; even in a controlled indoor setting, this can include access to food. In order to better understand the consequences of the feeding systems which are used in commercial production, it is crucial to acknowledge the pig's origins, and feeding and social behavior in a natural setting. The way we feed pigs, and what we feed them, can have a direct effect on their behavior and on the amount of aggression seen within any given system. The majority of research effort has been directed towards systems-type research—i.e., the way we feed them rather than the potential effects of ingredients found within the diet. Where the feeding system encourages competition to access food, aggression will be relatively high. As the evidence of dietary ingredients affecting behavior increases, it opens up the possibility of designing diets as a behavioral management tool with the hope that welfare and productivity can be improved hand-in-hand.

Introduction

Food is extremely important to both the producer and the pig. From the producer's viewpoint, food is provided to maximize output for minimum input. For the pig, food is the most important daily resource, providing not only nutrition, but also stimulation. However, food can also present challenges. Because it is so important, it can become a focus of attention and a source of conflict. The way in which food is made available and the content of the food itself can ameliorate or exacerbate the conflict. The scope of this paper is to concentrate on food composition rather than the feeding system design, but in order to better understand the consequences of food in commercial production, it is crucial to acknowledge the pig's origins, and feeding and social behavior in a natural setting and the contrast with production settings and the systems in current use.

Social Oganization and Feeding Behavior in Natural Settings

The natural social organization of pigs centers on a core group or 'sounder' of 2 to 4 related sows plus their associated offspring of different sizes and ages (Graves, 1984). Group size will be influenced by habitat and resource availability (especially food), as will the size of the home range, which can be as large as 6000 hectares. Within sounders, aggression is very rare. Aggression does occur during competition for resources, especially food, but most often, subordinate animals actively avoid conflict with dominant animals (Jensen and Wood-Gush, 1984). Food will be scattered but available ad libitum in their complex environment as long as the pigs forage. Diet is variable—pigs are omnivorous—and may include birds, small mammals, amphibians, reptiles, insects, nuts/seeds, fungi, and plants (Schley and Roper, 2003). However, 80 to 90% of the diet is plant-based which is high in fiber and low in crude protein and metabolizable energy and it varies greatly according to season. Naturally, pigs tend to synchronize feeding and actively forage for many hours during the day, with peaks in activity around dawn and dusk. As much as 75% of their activity may be foraging-related.

Social Organization and Feeding Behavior in Production Settings

In contrast, pigs housed in commercial systems may be housed individually (but in close proximity to others) or in groups ranging from small (4 to 5) to large (200+). Regardless of group size, there will be relatively limited space and a relatively simple environment. Access to food may be ad libitum or restricted. Unsurprisingly, aggression will be much more prevalent under commercial conditions than under natural conditions and this may be influenced by the method of feeding, and the food itself. In production settings, pigs will have access to high quality feed which can meet their nutritional requirements quickly, and it may only be available for an extremely limited period of time each day. Whereas the grow/finish herd may have ad libitum access with restricted number of feeding spaces, the breeding herd usually has access to a single food drop once a day, with food present for about 15 to 20 minutes every 24 h. In many 'intensive' production systems, pigs do not have access to any alternative foraging substrate such as straw; thus, access to food becomes an important resource, and one that may play a major role in determining the amount of aggression being displayed within a system. For sows, feeding systems that promote competition for access can have relatively high levels of aggression. Feeding systems that reduce competition can have relatively low aggression.

Feeding System Design for Sows

For sows, the major welfare challenges arise from both the quantity of food and how that food is delivered. The quantity and content of food will affect the sow in terms of hunger and, potentially, stereotypic behavior regardless of housing system. The way the food is delivered will affect the sow in terms of the amount of aggression she encounters, and this is specific to group-housing systems (Csermely and Wood-Gush, 1986). Given her state of hunger, food is the most important resource in her environment and she will use aggression to gain access to, or protect, food. Naturally, sows would feed simultaneously, rather than sequentially. From a management perspective, superimposed upon this is the option of individual or group control of feed intake. These two factors give rise to a variety of feeding systems and each will vary in the degree of aggression associated with it. Floor feeding may be cheap and 'low tech' in terms of equipment, but it is highly competitive with dominant sows able to monopolize the feed if it is not widely distributed. Trough feeding is another method of feeding a group simultaneously, but without any partitions, dominant animals can again monopolize large lengths of trough space, displacing subordinate sows, especially if food distribution along the trough is uneven. Use of trickle feeders for delivery can help to keep sows 'tied' to a single feeding space and reduce displacements. Other feeding options for sows include individual feeding stalls into which the sows can be shut either manually or under their own control (free-access stalls) and thereby eat at their own rate without threat of displacement. Electronic Sow Feeder systems have the big advantage of allowing each sow to eat an individual, stockperson-controlled allowance without fear of displacement, but sows have to feed sequentially. The entrance to the feeder can become a focal point of activity for large parts of the day and hence, a focal point for aggression (Marchant et al., 1995), with low ranking sows especially being subject to more aggression and subsequent injuries than high-ranking sows.

Feeding System Design for Grow/Finish Pigs

For the growing/finishing pig, feed is usually available ad libitum. Although feeding behavior and actual feed intake is stimulated by allowing pigs to feed simultaneously, there is still the need to have allocated individual feeding spaces incorporated into the feeder design to keep aggression as low as possible (O'Connell et al., 2002). There is also the question of how many feeding spaces are made available for the number of pigs in the pen, whether these should be in the form of one 'multi-space' feeder or several 'single-space' feeders and where the feeder or feeders should be placed in the pen. The term 'social workload' has been used to describe the effort required and aggression encountered in negotiating a route through pen-mates to a feeder and displacing pigs which are either feeding or obstructing the feeder.

Food Composition and Behavior

The system used in commercial production can greatly influence behavior within the system, and especially aggression. Physical system design, however, is only part of the overall feeding system. If we take the definition of system to be "a set of interacting or interdependent components forming an integrated whole", it is clear that feeding system comprises the food itself, and not just the method by which it is made available. The food itself has attracted a great deal of research in terms of the delivery of nutrition to enable that maximal output for minimal input, but there has been less attention directed at how food might affect behavior, especially non-feeding-related behavior. For the remainder of this paper, aspects related to the composition of food, such as physical form, flavor, and ingredients, and how these may impact swine behavior will be examined.

Physical form

Food can be delivered in liquid form with variable viscosity, as pellets with varying diameter or as meal with varying particle size. For piglets, the time around weaning is the transition from liquid to solid feed, which under natural conditions is gradual. Under commercial conditions, it is usually abrupt and the change in diet, combined with social changes, results in a growth check. Not surprisingly, the form of the diet around the time of weaning has been investigated and liquid feeding post-weaning can result in higher feed intake and less investigation directed at pen-mates. This effect is also seen in finishing pigs. Pre-weaning, piglets seem attracted to larger diameter pellets (10 mm or 12 mm) versus small diameter pellets (2 mm) with greater solid feed intake. Also, time spent suckling reduces over lactation in piglets with access to large diameter creep feed as opposed to staying the same in piglets with access to the smaller diameter creep feed. This is more like natural lactation behavior and may give post-weaning advantages. Post-weaning, comparisons between meal and pelleted food have shown that meal takes longer to eat and thus, the number of pigs per feeding space should be reduced with meal feeding to prevent competition and limited access to feed for certain individuals within the pen. For sows, aggression can be reduced by using wet feed compared with dry feed, in a trough-based system and the reduction in displacements is thought to be related to the fact that eating speed of sows shows less individual variation when fed liquid (Andersen et al., 1999).

Flavor

The research focus on this area has been on the piglet around the time of weaning and attempts to make solid food more attractive and thus, improve post-weaning intake. Offering flavored creep feed pre-weaning may stimulate exploratory behavior, increase pre-weaning feed intake and post-weaning growth. A more detailed approach has been to add flavor to sow diets—when given during lactation this may increase sow feed intake, giving milk production and piglet growth a boost. When given during gestation as well, there is the potential impact of 'prenatal learning.' There is evidence that piglets from sows given aniseed-flavored diets show subsequent preference for aniseed flavored diets themselves, increasing time spent exploring and ingesting the food and improving piglet health at weaning. For growing pigs, certain flavors may also stimulate intake and increase feed intake speed.

Ingredients

The much larger body of work in relation to food composition and behavior concerns dietary ingredients. Much of the early work in this area was related to restricted feeding of the sow and the impact that the resulting hunger may have on her behavior, both in terms of incidence of repetitive stereotypic behavior, and more recently on aggression. The latter has become increasingly important as the industry looks to move away from individual housing to group housing, and deal with the effects that group formation and feed delivery system may have on sow social behavior.

Fiber and behavior

Many different types of fiber have been studied, including sugar beet pulp, dried citrus pulp, lignocellulose, pectin, oat hulls, soybean hulls, inulin, guar gum, konjac flour, retrograded tapioca starch, native potato starch, and other resistant or pregelatinized starches (da Silva et al., 2013). Many of these have been shown to change indicators of satiety, such as reducing feeder-directed behavior and reducing feed motivation measured in tests. Fermentable fibers and bulking fibers in particular appear to be most satiating. Other behavioral effects of high fiber diets include decreases in oral stereotypic behaviors, such as sham chewing and bar biting, decreases in overall activity, and decreases in aggression. However, many high fiber diets may also lengthen meal duration and thus in systems where there are multiple animals per feeding space, this may need to be adjusted to make sure uncontested access to food for all pigs does not become an issue.

Beta agonists and behavior

The only beta-agonist currently available for use in swine is ractopamine hydrochloride (**RAC**). This is available as Paylean™ (Elanco Animal Health—FDA approval 1999) and Engain™ (Zoetis—FDA approval 2013). Not long after RAC use started within the U.S., there were anecdotal reports that the behavior of pigs fed RAC was altered, with pigs exhibiting hyperactivity in the home pen and being harder to handle. Although an early study found little evidence of behavioral differences except for a decrease in investigatory behavior and an increase in nose-to-nose contact in RAC-fed pigs, these data were collected 5 to 6 weeks after the start of RAC feeding—i.e., during the period when actual effectiveness of the drug has diminished due to down-regulation of the ß-adrenergic receptors. The first study to examine behavior in detail found that pigs fed RAC at 10 ppm spent more time active and alert and less time lying laterally in the first 2 weeks on RAC, but that these differences disappeared during the second 2 weeks (Marchant-Forde et al., 2003). The increases in activity and alertness in RAC-fed pigs were also observed using a 2-week 5 ppm, 2-week 10 ppm "step-up" RAC feeding program. Other changes in home pen behavior include a decrease in play behavior and an increase in nosing other pigs observed in pigs fed 5 ppm RAC compared with control feed, with pigs fed RAC at 10 ppm showing intermediate levels of both behaviors. Stereotypic behaviors such as sham chewing and bar biting have also been shown to be increased with the "step-up" RAC feeding program.

In terms of handling, RAC-fed pigs became harder to handle during weekly weighing. RAC-fed pigs were more reluctant to exit the home pen, took longer to remove from the home pen, took longer to weigh, and required more pats, slaps, and pushes from the handler to weigh and return to the home pen. These differences did remain for the 4-week duration of the trial. A similar study examining R-salbutamol, another ß-adrenergic agonist, found no negative behavioral effects. A 3-factor study examining effects of genotype, castration method, and RAC feeding on transportation stress found that RAC-fed pigs required greater physical contact to drive along the alley to the truck ramp.

The other major area of behavior that has been subject to investigation is the effect of RAC on aggression (Poletto et al., 2010a). The behavioral studies mentioned above used scan sampling methods to examine home pen behavior. This method is useful for gathering information about relatively long-lasting behavioral states, but less useful for recording relatively short-lasting behavioral events, such as aggressive interactions. Two studies examined spontaneous aggression in the home pen and induced aggression in a resident-intruder (**RI**) test. In both cases, aggression was highest in RAC-fed gilts compared with RAC-fed barrows and control-fed gilts and barrows. In the home pen, although the number of aggressive interactions decreased over time, RAC-fed gilts showed more biting, more pursuits, and more total component actions per interaction than the other 3 treatments—i.e., their aggressive interactions were of higher intensity. During the RI test, RAC-fed gilts performed more attacks during the first 30 seconds of testing than the other 3 treatments. In a study of male pigs in lairage after a short-duration transport, fighting was much more prevalent in RAC-fed immunocastrated males than RAC-fed surgically-castrated males, with control-fed males being intermediate.

Tryptophan and behavior

Tryptophan (**Trp**), an essential amino acid only acquired through diet, is the precursor for serotonin (5-HT). Because Trp can cross the blood-brain-barrier, dietary elevations of Trp have been applied in an attempt to reduce stress in group housed pigs. A number of studies have shown that increasing Trp in the diet can decrease measures of aggression in piglets at weaning and mixing, and in nursery, grow-finish pigs (Poletto et al., 2010b) and sows at mixing. Some other studies have found no effect of increased Trp on aggression, but there is great variation in the concentrations of Trp fed and the duration of feeding before observations are carried out.

Other ingredients and behavior

In a similar approach to Trp, there have been other compounds with potential neurochemical links added to diets. The addition of gamma-aminobutyric acid, an inhibitory neurotransmitter, to weaner-age pigs reduces aggression. Another study which examined the levels and ratios of linoleic acid (**LA**) to α-linoleic acid (**ALA**) found that low LA and low LA:ALA ratio increased exploration and decreased anxiety-like behavior in growing pigs. These essential fatty acids are precursors of arachidonic acid and docosahexaenoic acid, respectively, both of which have central nervous system structural function. Finally, a magnesium-rich supplement added to the diet of growing pigs reducing mounting behavior and potentially harmful behavior such as tail-in-mouth, ear-chewing and belly-nosing (O'Driscoll et al., 2013).

Conclusions

The way we feed pigs, and what we feed them, can have a direct effect on their behavior within any given system. The majority of research effort has been directed towards systems-type research—i.e., the way we feed them—rather than the potential effects of ingredients found within the diet. As the evidence of dietary ingredients affecting behavior increases, it opens up the possibility of designing diets as a behavioral management tool, with the hope that welfare and productivity can be improved hand-in-hand.

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Effects of Pelleting Growing-Finishing Swine Diets on Growth, Carcass, and Bacon Characteristics

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Summary

A total of 192 barrows and gilts were allotted to two blocks based on age at the date of allocation. Pens of pigs were assigned to one of four dietary treatments: 1) meal form with 0% DDGS, 2) meal form with 30% DDGS, 3) pelleted form with 0% DDGS, or 4) pelleted form with 30% DDGS. Pigs were fed for 91 d and subsequently slaughtered at the University of Illinois Meat Science Laboratory. Over the 91-d feeding period, pigs fed the pelleted diet grew 3.1% faster and were at least 4% more efficient than pigs fed the meal diets. Pigs fed the pelleted diet had less full gastrointestinal weight as percentage of live weight when compared with pigs fed the meal diet. Emptied intestinal weights were not different between the two treatment groups. Pigs fed the pelleted diet had lesser gut fill (full gastrointestinal weight—emptied intestinal mass) than pigs fed the meal diet. Pigs fed the pelleted diet had greater ulceration scores compared with pigs fed the meal diet, but both treatments had stomachs that would be considered generally healthy. Neither feeding program would result in stomachs that would negatively affect pig drop value (value of the non-carcass components). Iodine values of belly fat from pellet fed pigs were 4.3% greater than meal fed pigs, but the increase in iodine value did not decrease commercial bacon slicing yields. Bellies from pellet fed pigs yielded 1.16 slices per kg less bacon than bellies from meal fed pigs. Producers can take advantage of the growth performance benefits of feeding a pelleted diet without reducing total drop value or commercial bacon slicing yield.

Introduction

Pelleting swine diets is a technology used by the feed milling industry where a meal diet is subjected to heat and (or) moisture, then pressed through a die to agglomerate smaller particles into a larger composite. In doing so, feed handling issues such as flowability and bridging of finely ground diets in bulk bins and delivery systems are ameliorated. Pelleting also reduces segregation of feedstuffs, increases bulk density, and reduces dustiness of the diet. In addition to these benefits, feeding a pelleted diet improves growth performance and feed efficiency of growing-finishing pigs. Feeding a pelleted diet for 81 d resulted in a 3% increase ($P = 0.03$) in growth rate and a 6% increase ($P < 0.01$) in feed efficiency when compared with pigs fed a meal diet (Nemechek et al., 2013). Wondra et al. (1995) reported that feed efficiency was increased and feed intake was reduced by feeding a pelleted diet, with a greater reduction in feed intake as particle size was reduced in pelleted diets than in meal diets. These improvements can be attributed to the compounding effects of reduced particle size and pelleting on nutrient digestibility. Digestible and metabolizable energy increased linearly ($P < 0.05$) as corn particle size decreased from 865 µm to 339 µm (Rojas and Stein, 2015). In another report, reducing dietary particle size from 1000 µm to 400 µm increased nutrient digestibility and in turn increased feed efficiency of meal fed pigs by 7% (Wondra et al., 1995). The challenge with reducing dietary particle size is the accompanied increase in stomach lesions and esophagogastric ulcers (Mahan et al., 1966). Additionally, feeding a pelleted diet increased the occurrence of stomach health issues of growing-finishing pigs (De Jong et al., 2015).

Feeding pelleted diets increased linoleic acid by 10.2% and linolenic by 7.8% (Nemechek et al., 2013). At the same time, palmitic acid was decreased by 2.6% and stearic acid by 2.2% (Nemechek et al., 2013). These changes resulted in 4.5% increase in calculated iodine value of belly fat from pigs fed a pelleted diet compared with pigs fed a meal diet (Matthews et al., 2014). Iodine value is considered an indication of fat quality. However, iodine value is poorly correlated with commercial bacon slicing yields (r = -0.15, $P < 0.05$; Kyle et al., 2014). It is not known if the observed increase in iodine value of fat from pellet fed pigs will have detrimental effects on commercial bacon slicing yields. Therefore, the objective of this experiment was to determine if the increased iodine value of belly fat of pigs fed a pelleted diet results in decreased commercial bacon slicing yields.

Table 1. Ingredient composition of experimental diets, as-fed basis.

	Phase 1: d 0 - d 35				Phase 2: d 36 - d 70				Phase 3: d 71 - 91			
	Meal		Pellet		Meal		Pellet		Meal		Pellets	
Ingredient, %	0%	30%	0%	30%	0%	30%	0%	30%	0%	30%	0%	30%
Corn	72.0	47.0	72.0	47.0	78.0	55.0	78.0	55.0	81.0	59.0	81.0	59.0
SBM, 48%	22.0	17.3	22.0	17.3	18.2	12.0	18.2	12.0	16.0	8.0	16.0	8.0
DDGS	0.0	30.0	0.0	30.0	0.0	30.0	0.0	30.0	0.0	30.0	0.0	30.0
C.W. Grease	2.0	2.0	2.0	2.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Limestone	0.85	1.15	0.85	1.15	0.80	1.10	0.80	1.10	0.70	1.05	0.70	1.05
Dicalcium P	1.1	0.6	1.1	0.6	0.8	0.35	0.8	0.35	0.7	0.2	0.7	0.2
Lys HCl	0.34	0.35	0.34	0.35	0.21	0.27	0.21	0.27	0.13	0.25	0.13	0.25
DL-Met	0.04	-	0.04	-	-	-	-	-	-	-	-	-
Thr	0.09	-	0.09	-	0.03	-	0.03	-	-	-	-	-
Salt	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Swine TM[1]	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Vit. ADEK[1]	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Tylan	1.0	1.0	1.0	1.0	-	-	-	-	-	-	-	-

[1] Provided the following quantities of vitamins and micro-minerals per kilogram of complete diet: Vitamin A as retinyl acetate, 11,136 IU; dimethylprimidinol bisulfite, 1.42 mg; thiamin as thiamine mononitrate, 0.24 mg; riboflavin, 6.59 mg; pyridoxine as pyridoxine hydrochloride,0.24 mg; vitamin B12, 0.03 mg; D-pantothenic acid as D-calcium pantothenate, 23.5 mg; niacin, 44.1 mg; folic acid, 1.59 mg; biotin, 0.44 mg; Cu, 20 mg as copper sulfate and copper chloride; Fe, 126 mg as ferrous sulfate; I, 1.26 mg as ethylenediamine dihydriodide; Mn, 60.2 mg as manganese sulfate; Se, 0.3 mg as sodium selenite and selenium yeast; and Zn, 125.1 mg as zinc sulfate.

Experimental Procedures

Experimental Design and Dietary Treatments

A total of 192 barrows and gilts (initial BW = 25.75 kg) were used in 2 blocks based on age. Each block consisted of 6 replications per treatment. Each replication included 4 pens with each pen housing 2 barrows and 2 gilts for a total of 24 pens per block (48 pens total). Pens of pigs were assigned to 1 of 4 dietary treatments: 1) meal form with 0% DDGS, 2) meal form with 30% DDGS, 3) pelleted form with 0% DDGS, or 4) pelleted form with 30% DDGS. All diets were formulated to meet current estimates for nutrient requirements for growing-finishing pigs (NRC, 2012).

A 3-phase, 91-d feeding program (Tables 1 & 2) was used with grower diets fed from d 0 to 35, early finisher diets fed from d 36 to 70, and late finisher diets fed from d 71 to 91. All diets were formulated based on values for the standardized total tract digestibility of P, standardized ileal digestibility (**SID**) of amino acids (**AA**), and net energy (NRC, 2012). Pigs were weighed at the beginning of the experiment and again at the end of each of the 3 feeding phases (d 35, 70, 91). Daily feed allotments were recorded,

Table 2. Calculated nutritional composition of experimental diets, as-fed basis.

	Phase 1: d 0 - d 35				Phase 2: d 36 - d 70				Phase 3: d 71 - 91			
Calculated	Meal		Pellet		Meal		Pellet		Meal		Pellets	
analysis	0%	30%	0%	30%	0%	30%	0%	30%	0%	30%	0%	30%
NE, kcal/kg	2,490	2,427	2,490	2,427	2,528	2,468	2,528	2,468	2,548	2,497	2,548	2,497
CP, %	16.43	20.34	16.43	20.34	15.06	18.44	15.06	18.44	14.3	16.88	14.3	16.88
Ca, %	0.67	0.66	0.67	0.66	0.56	0.56	0.56	0.56	0.50	0.49	0.50	0.49
P[1], %	0.31	0.31	0.31	0.31	0.25	0.26	0.25	0.26	0.23	0.23	0.23	0.23
Amino acids[2], %												
Arg	0.95	1.01	0.95	1.01	0.84	0.86	0.84	0.86	0.78	0.75	0.78	0.75
His	0.40	0.47	0.40	0.47	0.36	0.42	0.36	0.42	0.35	0.38	0.35	0.38
Ile	0.58	0.68	0.58	0.68	0.52	0.6	0.52	0.6	0.49	0.53	0.49	0.53
Leu	1.30	1.76	1.30	1.76	1.23	1.66	1.23	1.66	1.19	1.57	1.19	1.57
Lys	0.98	0.98	0.98	0.98	0.79	0.79	0.79	0.79	0.67	0.68	0.67	0.68
Met	0.28	0.31	0.28	0.31	0.23	0.29	0.23	0.29	0.22	0.28	0.22	0.28
Met + Cys	0.55	0.60	0.55	0.60	0.49	0.57	0.49	0.57	0.47	0.53	0.47	0.53
Phe	0.70	0.85	0.70	0.85	0.64	0.77	0.64	0.77	0.61	0.70	0.61	0.70
Thr	0.59	0.59	0.59	0.59	0.49	0.52	0.49	0.52	0.43	0.46	0.43	0.46
Trp	0.17	0.17	0.17	0.17	0.15	0.14	0.15	0.14	0.13	0.12	0.13	0.12
Val	0.65	0.79	0.65	0.79	0.6	0.72	0.6	0.72	0.56	0.65	0.56	0.65

[1] Standadardized total tract digestible P.
[2] Amino acids are indicated as standardized ileal digestible AA.

Table 3. Effects of pelleting and distillers dried grains with solubles (DDGS) on growth characteristics of barrows and gilts.

	Diet Form × DDGS Inclusion[1]					*P*-Values		
Item	Meal - 0% DDGS	Meal - 30% DDGS	Pelleted - 0% DDGS	Pelleted - 30% DDGS	SEM	Diet Form	DDGS	Diet Form × DDGS
Pen[1], n	12	12	12	12				
Phase 1 (Day 0-35)								
Beginning live weight (day 0), kg	25.79	25.78	25.68	25.73	0.66	0.07	0.68	0.41
Day 35 live weight, kg	57.66	56.60	58.61	56.72	0.97	0.28	< 0.01	0.41
ADG (0-35), kg/d	0.91	0.88	0.94	0.89	0.02	0.21	0.01	0.34
ADFI (0-35), kg/d	1.91	1.87	1.92	1.83	0.03	0.51	0.03	0.42
G:F (0-35)	0.474	0.472	0.491	0.485	0.007	< 0.01	0.44	0.68
Phase 2 (Day 36-70)								
Day 70 live weight, kg	91.53	91.19	94.13	91.39	1.31	0.12	0.09	0.18
ADG (70), kg/d	0.97	0.99	1.01	1.01	0.01	0.03	0.50	0.36
ADFI (70), kg/d	2.72[a]	2.86[b]	2.80[ab]	2.71[a]	0.05	0.40	0.45	< 0.01
G:F (70)	0.357[ab]	0.347[a]	0.363[bc]	0.374[c]	0.005	< 0.01	0.90	0.03
Phase 3 (Day 71 -91)								
Day 91 live weight, kg	111.19	111.60	115.31	113.38	1.37	< 0.01	0.37	0.17
ADG (91), kg/d	0.92	0.97	1.00	1.01	0.03	0.01	0.18	0.46
ADFI (91), kg/d	3.11[a]	3.37[b]	3.14[a]	3.15[a]	0.06	0.07	< 0.01	0.02
G:F (91)	0.297	0.288	0.318	0.321	0.007	< 0.0001	0.58	0.36
Overall (Day 0-91)								
Overall ADG, kg/d	0.94	0.94	0.98	0.96	0.01	< 0.01	0.46	0.11
Overall ADFI, kg/d	2.58[a]	2.70[b]	2.62[ab]	2.56[a]	0.04	0.11	0.25	< 0.01
Overall G:F	0.370[b]	0.360[a]	0.383[c]	0.386[c]	0.005	< 0.0001	0.27	0.03

1 Each pen of pigs housed 2 barrows and 2 gilts.

and data were summarized to calculate ADG, ADFI, and G: F for each pen during each phase of the feeding period. The heaviest barrow and gilt in each pen were harvested on d 92 and the remaining barrows and gilts were slaughtered 2 d later to determine hot carcass weight (**HCW**), carcass yield, carcass characteristics, meat quality, and fat quality. Mass of the gastrointestinal (**GI**) tract was determined using the heaviest barrow and gilt from each pen.

Slaughter Procedures and Evisceration

Pigs were transported to the University of Illinois Meat Science Laboratory (Urbana, IL) and held for approximately 16 h in lairage prior to slaughter. Pigs were weighed immediately prior to slaughter to determine ending live weight. Pigs were immobilized via head-to-heart electrical stunning followed by exsanguination. Full GI tract and GI tract component weights were recorded immediately following evisceration for the heaviest barrow and gilt from each pen. Each section of the GI tract was rinsed with water to remove all digestive and fecal material. Mesenteric tissue surrounding the GI tract was removed and weighed separately. Gut fill was calculated as the difference between the full GI tract and the cleaned, separated components. GI tract mass was calculated in terms of absolute mass and as a percentage of ending live weight. The stomach from the heaviest barrow and heaviest gilt in each pen were identified, frozen, and stored for later ulcer evaluation.

Table 4. Effects of pelleting and distillers dried grains with solubles (DDGS) on carcass characteristics of barrows and gilts.

	Diet Form			DDGS			*P*-Values		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet Form	DDGS	Diet × DDGS
Pen[1], n	24	24		24	24				
Final farm wt, kg	111.40	114.34	1.24	113.25	112.49	1.24	0.002	0.37	0.17
Ending live wt, kg	110.50	113.06	1.30	112.65	110.91	1.30	< 0.01	0.06	0.11
HCW, kg	86.34	88.84	1.12	88.65	86.54	1.12	0.01	0.01	0.17
Carcass yield, %	78.11	78.56	0.14	78.66	78.00	0.14	0.02	< 0.001	0.78
Loin eye area, cm^2	49.49	49.65	0.75	50.41	48.73	0.75	0.84	0.04	0.71
Fat depth (10th rib), cm	1.63	1.80	0.04	1.74	1.70	0.04	0.01	0.40	0.08
Estimated carcass lean[2], %	56.70	54.91	0.59	56.25	55.36	0.59	0.04	0.30	0.10

1 Each pen of pigs housed 2 barrows and 2 gilts.
2 Estimated carcass lean = [(8.588 + (0.465 * HCW, lb) - (21.896 * 10th rib fat depth, in) + (3.005 * 10th rib LEA, in^2))/ HCW] * 100.

Table 5. Effects of pelleting and distillers dried grains with solubles (DDGS) on visceral weights and percentage of ending live weight of barrows and gilts.

	Diet Form			DDGS			*P*-Values		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet Form	DDGS	Diet Form × DDGS
Pen[1], n	24	24		24	24				
Full GI tract, kg	7.65	7.42	0.11	7.37	7.70	0.11	0.14	0.03	0.08
Full GI tract, %	6.79	6.46	0.11	6.41	6.84	0.11	0.03	< 0.01	0.18
Esophagus, kg	0.07	0.08	0.002	0.07	0.08	0.002	0.02	0.23	0.01
Esophagus, %	0.06	0.07	0.002	0.06	0.07	0.002	0.08	0.05	0.02
Stomach, kg	0.63	0.61	0.01	0.61	0.62	0.01	0.25	0.36	0.66
Stomach, %	0.55	0.53	0.01	0.53	0.55	0.01	0.07	0.10	0.51
Small intestine, kg	1.50	1.53	0.03	1.51	1.52	0.03	0.57	0.86	0.37
Small intestine, %	1.34	1.33	0.03	1.32	1.35	0.03	0.87	0.39	0.27
Large intestine, kg	1.73	1.72	0.03	1.64	1.80	0.03	0.81	< 0.01	0.17
Large intestine, %	1.54	1.49	0.03	1.43	1.60	0.03	0.31	< 0.01	0.27
Intestinal mass[2], kg	3.24	3.25	0.05	3.17	3.33	0.06	0.94	0.02	0.42
Intestinal mass, %	2.88	2.83	0.04	2.76	2.95	0.04	0.41	< 0.01	0.62
Mesenteric fat, kg	1.68	1.83	0.05	1.77	1.74	0.05	0.02	0.75	0.06
Mesenteric fat, %	1.49	1.59	0.04	1.53	1.55	0.04	0.07	0.86	0.08
Gut fill[3], kg	2.07	1.66	0.07	1.75	1.98	0.07	< 0.01	0.02	0.19
Gut fill, %	1.84	1.45	0.07	1.53	1.77	0.07	< 0.01	0.01	0.24
Ulceration score[4]	1.27	1.79	0.12	1.40	1.67	0.12	< 0.01	0.10	0.44

1 Each pen of pigs housed 2 barrows and 2 gilts. Represents the mean of the heaviest barrow and heaviest gilt from each pen.
2 Intestinal mass = esophagus + stomach + small intestine + large intestine.
3 Gut fill = full GI tract - (esophagus + stomach + small intestine + large intestine + mesenteric fat).
4 Ulceration scores were rated on a 10 point scale where 0 represents a normal stomach with no evidence of ulceration and 10 represented a bleeding ulcer that might later cause the pig's death.

Stomach Morphology Evaluation

Stomachs were allowed to thaw at 4°C for 72 h prior to evaluation. Evaluation of ulceration and parakeratosis in the pars oesophagea region of the stomach was conducted by 3 trained panelists, using a 10-point scale, according to the protocol described by Nielsen and Ingvartsen (2000). Zero represented a normal stomach with no evidence of ulceration and 10 represented a bleeding ulcer that might later cause the pig's death. Scores were averaged across the 3 evaluators for each pig. The average score was reported as the ulceration score.

Carcass Characteristics and Fresh Loin Quality

Carcasses were weighed immediately prior to entering the cooler to determine HCW. Carcass yield was calculated as the ratio of HCW and ending live weight. Carcasses were chilled at 4°C for approximately 24 h. Carcass characteristics and fresh loin quality were determined on the left side of each carcass. Carcasses were cut between the 10th and 11th rib interface to expose the longissimus muscle (**LM**). Tenth rib backfat was measured at ¾ the distance of the LM from the dorsal process of the vertebral column. Loin eye area (**LEA**) was measured by tracing the surface of the LM on double matted acetate paper. Longissimus muscle tracings were measured in duplicate using a digitizer tablet (Wacom, Vancouver, WA) and Adobe Photoshop CS6 and the average of the 2 measurements were reported. Water-holding capacity, proximate composition, and Warner-Bratzler shear force were determined on an excised portion of the longissimus muscle cut posterior to the 10th rib. Color, marbling, firmness, and ultimate pH were determined on the cut surface anterior to the 10th rib after a 20-min bloom period by trained individuals.

Belly Characteristics

Bellies were fabricated to meet the specifications of an Institutional Meat Purchase Specifications (**IMPS**) #408 belly and then skinned to the meet the specifications of an IMPS #409 belly. Bellies were transported to a commercial bacon processing facility and were processed at the facility in the same manner as described by Tavárez et al. (2014). Bellies were processed using standard operating protocols of the commercial bacon processing facility. In short, bellies were pumped using a cure solution that delivered a target of 1.50% sodium chloride at a 13% pump uptake. Bellies were then cooked and smoked using a step-up cooking cycle for approximately 4 h with bellies reaching an internal temperature of 53°C. Bellies were frozen to –6°C, pressed, and sliced. Unusable ends and incomplete slices were sorted and removed by trained plant personnel. Sliced bellies were boxed individually maintaining anatomical

Table 6. Effects of pelleting and distillers dried grains with solubles (DDGS) on meat quality of barrows and gilts.

	Diet Form			DDGS			*P*-Values		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet Form	DDGS	Diet Form × DDGS
Pen[1], n	24	24		24	24				
Subjective evaluations[2]									
Color	1.93	1.80	0.05	1.87	1.86	0.05	0.07	0.89	0.48
Marbling	1.32	1.28	0.06	1.31	1.30	0.06	0.70	0.90	0.64
Firmness	1.46	1.55	0.08	1.51	1.49	0.08	0.40	0.83	0.89
Objective color[3]									
L*	50.66	51.32	0.40	51.34	50.63	0.40	0.19	0.16	0.79
a*	8.59	8.34	0.16	8.55	8.38	0.16	0.23	0.38	0.31
b*	4.13	4.16	0.19	4.32	3.97	0.19	0.92	0.15	0.64
Ultimate pH	5.57	5.58	0.01	5.58	5.58	0.01	0.38	0.85	0.61
Drip loss, %	5.67	5.47	0.26	5.63	5.51	0.26	0.55	0.70	0.90
Cook loss, %	24.90	24.51	0.45	24.45	24.96	0.45	0.47	0.35	0.57
Shear force[4], kg	3.21	3.10	0.07	3.13	3.18	0.07	0.27	0.62	0.57

1 Each pen of pigs housed 2 barrows and 2 gilts.
2 L* = lightness; a* = redness; b* = yellowness.
3 Subjective evaluations based on standards provided by the National Pork Producers Council (Des Moines, IA).
4 Warner-Bratzler shear force.

orientation (blade to flank end) and transported back to the Meat Science Laboratory at the University of Illinois for further evaluation. Sliced weights of each processed belly were collected to determine a bacon slicing yield. Slices were counted to determine the number of saleable slices. Processed bellies were then separated into 5 equal portions based on anatomical orientation (zones A, B, C, D, and E) with zone A representing the anterior (blade) end and zone E representing the posterior (flank) end. Moisture and lipid content was determined as the pooled average of 2 slices from the approximate center of each zone. Image analysis on 1 slice from the approximate center of zones A, C, and E was used to determine lean-to-fat ratios of each processed belly.

Statistical Analyses

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC, USA) as a 2 x 2 factorial arrangement of treatments in a randomized complete block design. Pen (n = 48) was the experimental unit for all dependent variables. Fixed effects were diet form (meal or pellet), DDGS inclusion (0% or 30%), and the interaction between diet form and DDGS. Block and replication nested within block were random variables.

Results and Discussion

Over the 91-d feeding period, pigs fed the pelleted diet (0.97 kg/d) grew 3.1% faster ($P < 0.01$) than pigs fed the meal diet (0.94 kg/d; Table 3). There were no differences in ADFI between pellet fed pigs fed either 0 or 30% DDGS. However, the meal fed pigs fed 30% DDGS consumed 0.12 kg/d more feed than the meal fed pigs fed 0% DDGS. This resulted in pellet fed pigs, regardless of DDGS inclusion, being 4% more efficient ($P < 0.0001$) than the meal fed pigs fed 0% DDGS and 6.7% more efficient than the meal fed pigs fed 30% DDGS. Pigs fed the meal diet with 0% DDGS also were 2.7% more efficient ($P = 0.02$) than pigs fed the meal diet with 30% DDGS.

Table 7. Effects of pelleting and distillers dried grains with solubles (DDGS) on fresh belly characteristics of barrows and gilts.

	Diet Form			DDGS			*P*-Values		
Item	Meal	Pellet	SEM	0%	30%	SEM	Diet Form	DDGS	Diet Form × DDGS
Pen[1], n	24	24		24	24				
Belly wt (IMPS # 408), kg	6.39	6.73	0.13	6.62	6.49	0.13	< 0.001	0.13	0.99
Belly wt, % chilled side wt	15.09	15.21	0.18	15.31	14.98	0.18	0.55	0.11	0.68
Length, cm	64.55	64.96	0.36	64.93	64.58	0.36	0.26	0.33	0.46
Width, cm	28.06	28.45	0.26	28.19	28.42	0.26	0.11	0.17	0.72
Average thickness[2], cm	3.58	3.66	0.05	3.78	3.46	0.05	0.12	< 0.0001	0.48
Flop distance, cm	11.64	10.85	0.77	13.73	8.76	0.77	0.44	< 0.0001	0.76
Thaw loss, %	1.63	1.57	0.07	1.61	1.59	0.07	0.55	0.80	0.13

1 Each pen of pigs housed 2 barrows and 2 gilts.
2 Average thickness was calculated as the average of 8 locations (1 to 4 were from anterior to posterior position of dorsal edge of the belly; locations 5 to 8 were from the anterior to posterior position of the ventral edge of the belly).

Table 8. Effects of pelleting and distillers dried grains with solubles (DDGS) on fatty acid profiles of belly fat from barrows and gilts.

Item	Diet Form			DDGS			P-Values		
	Meal	Pellet	SEM	0%	30%	SEM	Diet Form	DDGS	Diet Form × DDGS
Pen[1], n	24	24		24	24				
C16:0, %	22.66	21.99	0.13	23.07	21.58	0.13	< 0.01	< 0.0001	0.76
C16:1, %	2.66	2.30	0.03	2.73	2.24	0.03	< 0.0001	< 0.0001	0.09
C18:0, %	9.66	9.67	0.09	10.09	9.24	0.09	0.94	< 0.0001	0.64
C18:1, %	43.55	41.92	0.16	44.41	41.05	0.16	< 0.0001	< 0.0001	0.99
C18:2n6, %	16.13	18.86	0.24	14.55	20.44	0.24	< 0.0001	< 0.0001	0.86
C18:3n6, %	0.03	0.02	0.003	0.02	0.03	0.003	0.09	< 0.01	0.98
C18:3n3, %	0.55	0.59	0.01	0.53	0.61	0.01	< 0.01	< 0.0001	0.13
C20:1n9, %	0.77	0.76	0.01	0.77	0.75	0.01	0.75	0.09	0.07
Iodine value[2]	70.03	73.11	0.35	68.02	75.11	0.35	< 0.0001	< 0.0001	0.67

[1] Each pen of pigs housed 2 barrows and 2 gilts.
[2] Iodine value = C16:1 (0.95) + C18:1 (0.86) + C18:2 (1.732) + C18:3 (2.616) + C20:1 (0.785) + C22:1 (0.723), AOCS (1998).

There were no interactions ($P > 0.05$) between diet form and DDGS inclusion for carcass characteristics (Table 4). In general, there are few differences in carcass characteristics between meal and pellet fed pigs in the literature (Wondra et al., 1995; Myers et al., 2012, Nemechek et al., 2013). Unlike previous reports, pellet fed pigs in this experiment were 2.3% heavier ($P < 0.01$) at slaughter, and produced carcasses that were 2.9% heavier ($P = 0.01$), 9.9% fatter ($P = 0.01$) at the 10th rib, and had 1.79 percentage unit less carcass lean than meal fed pigs. There were no differences ($P = 0.84$) in LEA between meal and pellet fed pigs. These observations indicate that protein deposition was not influenced by dietary treatment, but pigs fed the pelleted diets likely were able to absorb more energy, which resulted in the increased deposition of fat and reduced lean percentage.

There were no differences ($P \geq 0.25$) in stomach weight, small intestine weight, large intestine weight, or calculated intestinal mass between pelleted and meal fed pigs (Table 5). There were also no differences ($P = 0.41$) in the proportion of intestinal mass relative to ending live weight between pelleted and meal fed pigs. Similar to 10th rib fat thickness, pellet fed pigs had 0.15 kg more ($P = 0.02$) mesenteric fat than meal fed pigs, which further indicate that pellet fed pigs absorbed more energy than meal fed pigs. Pellet fed pigs also had 0.41 kg less ($P < 0.01$) gut fill than meal fed pigs, which is likely a result of increased dry matter and energy digestibility in the pellet fed pigs. The greater ($P = 0.02$) carcass yield of pellet fed pigs compared with meal fed pigs was likely due to the combination of less gut fill and increased fatness. As expected, stomach ulceration score was greater ($P < 0.01$) in pellet fed pigs (1.79) compared with meal fed pigs (1.27), but the magnitude of difference was small and the average score of each treatment group was less than 2 and therefore considered healthy.

Fresh loin quality did not differ ($P \geq 0.23$) between pellet and meal fed pigs (Table 6). However, subjective color tended ($P = 0.07$) to be less (lighter) in pellet fed

Table 9. Effects of pelleting and distillers dried grains with solubles (DDGS) on belly processing characteristics of barrows and gilts.

Item	Diet Form			DDGS			P-Values		
	Meal	Pellet	SEM	0%	30%	SEM	Diet Form	DDGS	Diet Form × DDGS
Pen[1], n	24	24		24	24				
Green weight (IMPS #409), kg	5.29	5.64	0.11	5.54	5.38	0.11	< 0.0001	0.04	0.87
Pumped wt, kg	6.15	6.54	0.13	6.40	6.28	0.13	<0.01	0.19	0.54
Pump uptake, %	16.15	16.08	0.12	15.47	16.76	0.12	0.67	< 0.0001	< 0.01
Cooked and pressed wt, kg	5.54	5.95	0.12	5.80	5.70	0.12	< 0.0001	0.25	0.76
Cooked yield, %	104.61	105.63	0.18	104.48	105.77	0.18	< 0.01	< 0.0001	0.40
Sliced weight, kg	4.93	5.31	0.10	5.17	5.06	0.10	< 0.0001	0.14	0.54
Slicing yield (green wt), %	93.14	94.28	0.56	93.38	94.04	0.56	0.16	0.41	0.26
Sliced yield (cooked weight), %	89.02	89.26	0.51	89.37	88.90	0.51	0.75	0.52	0.16
Number of slices	183.76	191.97	2.85	191.71	184.02	2.85	< 0.01	< 0.01	0.42
Slice wt, g	26.82	27.67	0.25	26.97	27.52	0.25	< 0.01	< 0.09	0.10
Slices per kg	37.36	36.20	0.33	37.15	36.41	0.33	< 0.01	< 0.08	0.06

[1] Each pen of pigs housed 2 barrows and 2 gilts.

pigs compared with meal fed pigs, but there were no differences in L^*, a^*, or b^* ($P \geq 0.19$). Bellies from pellet fed pigs (6.73 kg) were 0.34 kg heavier ($P < 0.001$) than bellies from meal fed pigs (6.39 kg), but when calculated as a percentage of ending live weight, were not different ($P = 0.55$, Table 7). Furthermore, no other fresh belly characteristic differed ($P \geq 0.11$) between pellet and meal fed pigs.

Palmitic acid (C 16:0) was 0.67 percentage units greater ($P < 0.01$) in meal fed pigs compared with pellet fed pigs (Table 8). Both essential fatty acids (C 18:2 and C 18:3) were greater ($P \leq 0.01$) in pellet fed pigs compared with meal fed pigs. This increase in essential fatty acid percentages led to a 4.3% increase in calculated iodine value of pellet fed pigs (73.11) compared with meal fed pigs (70.03).

An increased iodine value is often associated with poor fat quality because it results in bellies that are soft and potentially more difficult to slice (Stein and Shurson, 2009). However, bacon processing techniques (chilling, pressing, and trim specifications) used today are in some cases able to compensate for soft bellies and still manufacture bacon slices that meet the criteria of a #1 bacon slice. A bacon slice regarded as a #1 slice must have secondary lean (m. cutaneous trunci) that is greater than 50% of the length of the slice and the slice must not be less than 1.9 cm thick at its thinnest point (Person et al., 2005). Iodine value is poorly correlated with commercial bacon slicing yields (r = -0.15, $P < 0.05$; Kyle et al., 2014). For example, Tavárez et al. (2014) reported an 8.48 iodine value unit difference between barrows fed 0% and 30% DDGS, but no difference ($P > 0.05$) in commercial bacon slicing yields. At the same time, Kyle et al., 2014 reported a 3.03 iodine value unit difference between barrows and boars, which resulted in a 3.8% difference ($P < 0.05$) in commercial slicing yield. In the current experiment, initial green weight differences persisted throughout processing, but there were no differences ($P = 0.75$) in commercial bacon slicing yields between bacon from pellet fed pigs and meal fed pigs (Table 9). However, processed bellies from pellet fed pigs produced 1.16 fewer ($P < 0.01$) slices of bacon per kg of sliced belly weight than processed bellies from meal fed pigs.

Some bacon slicers rely on a push-feed mechanism where constant pressure against the blade from subsequent bellies is necessary to produce slices with uniform slice thicknesses. In this type of belly slicing system, it is possible that the softer fat associated with an increased iodine value may influence the integrity of the slice thickness even though it meets the criteria for #1 bacon slice. The reduction in slices/kg may not be a cause for concern when producing bacon for retail service where producers are paid on weight, but may be potentially detrimental to processors manufacturing bacon for food-service applications where bacon is sold by the slice.

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The Future of the Midwest Poultry Consortium Center of Excellence: What Have We Learned in 19 Years?

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Summary

The demise of poultry departments throughout the Midwest universities and colleges in the late 1980s and early 1990s created a unique scenario where the relationship between the commercial poultry industry and academic repositories were being disrupted. The foresight of a small group of industry people and poultry academicians decided to embark on a truly unique endeavor to educate students in the area of poultry. While I do not believe the Midwest swine industry will face this scenario, the changing demographics in Animal Science programs across the U.S., may require the facilitation of Center of Excellence programs being developed in other species to ensure the continuity of business in the future.

Introduction

The Midwest poultry departments in the late 1980s and early 1990s were consolidated into the animal science departments within Midwest universities and colleges. As a result, the attrition of academic poultry positions occurred as individuals retired and those positions were no longer replaced (Graves, 1998). The commercial poultry industry may not have fully understood why this was happening or the long-term ramifications and impacts. Fortunately, a group of individuals decided to take action to abate the loss of academic knowledge throughout the Midwest. As a result, the Midwest Poultry Consortium was formed in 1993 bringing together members and organization funding from the broiler, egg, turkey, allied industries, and several members and supporters with poultry academic interests (Graves, 1998). The initial membership of the Midwest Poultry Consortium consisted of 13 states (Figure 1). In 2006, Florida was admitted to the Consortium at the same time that Colorado was no longer affiliated.

Center of Excellence

History

The establishment of the Consortium in 1993 decided it was best to begin the process of trying to reverse the declining enrollment of poultry science students around academic institutions in the Midwest. Over the course of the next three years, the favorable relationship between the Consortium and academic community agreed that there would be three courses in poultry science offered over two consecutive summers for a total of six classes. Those faculty that were interested in any of the 13 states had the opportunity to help in planning all aspects of the classes to be taught. These classes would be taught at a single university location over a six-week period essentially requiring a course to be covered in a two-week period. The initial curriculum covered Incubation & Hatchery Management, Avian Physiology, Poultry Business Management the first year and Avian Health, Advanced Poultry Nutrition, and Poultry Product Technology the second year. The Consortium, prior to recruiting students, put together the benefits of attending this type of program: 1) Unique opportunity to go to a different campus and interact with faculty from around the Midwest, 2) internship experience, and 3) major expenses covered by a scholarship (Graves, 1998). The inaugural Center of Excellence (**COE**) class had 21 students from nine schools in eight states participating.

Nineteen Years Later

The COE program continues to offer the two six-week summer sessions that provide students with a total of 18 credits. Each academic institution handles the credits differently related to how they may count for the students' undergraduate degree at their home institution. The same six classes that were initially outlined are still taught though the order and content are dra-

Figure 1. Original Midwest Poultry Consortium States in 1993.

matically different today. The course material is taught through interactive lectures, discussion groups, industry field trips, and laboratory curriculum to apply concepts taught in class. The continued effort and support of faculty from around the Midwest contribute time to instruct the students and ensure the COE is a success. In an effort to expose students to various aspects of the industry, the Wednesday Night Forums were created around 2007 and have become very popular. Individuals from sponsoring companies can meet with the students and talk about their company, job, and offer words of wisdom. Students are given opportunity to ask numerous questions. Another change that has occurred over the years is the requirement that all students must complete an internship. The Midwest Poultry Consortium coordinates the internships with the students and companies by dealing with the logistics of different timetables across the academic institutions and the COE classes. Typically, this will translate into a 4 to 8- week internship during the summer. The commercial and allied industry continues to support the COE program with over 100 Midwest Poultry Consortium members (Midwest Poultry Consortium, 2015). These companies contribute to the program by sponsoring scholarships to the students covering the housing and tuition. Sponsors meeting specific criteria are able to have employees participate in courses.

Program Statistics

The following information was pulled from the 2015 COE Program Statistics and Information provided by the Midwest Poultry Consortium (written communication). The Midwest Poultry Consortium has sponsored 387 students in the past 19 years through the COE program. Fifty-one percent (200 students) have completed all six classes earning a "COE: Poultry Diploma" at the annual awards banquet. In 2015, 36 faculty members were present across the six classes instructing the 32 students in the various course materials. Twenty-four internships were coordinated for the attending students with five students securing full time jobs in the industry prior to their graduation. Surveying the students, 87% indicated the COE helped prepare them for future careers; 70% plan on or were employed in the poultry industry; and 95% agree or strongly agree that their internship was a positive experience.

Relative to Pork?

What can a program like this mean to the pork industry? Currently, the U.S. Pork Center of Excellence (**USPCE**) exists and functions somewhat similarly to the COE. The Swine Science Online curriculum appears to allow students to progress at their own pace on their own time. It also provides swine curriculum to students at universities where such curriculum is no longer available. However, I would question whether students experience quality interactions and friendships that are made with more in-class time together. The COE is a way to gather those interested students in poultry to a common location and provide the interaction and experience of working with poultry faculty. Attending the COE as a student, I made life-long friends that are now in various aspects of the poultry industry affording connections to companies and other people that I may not have made on my own.

How does the USPCE train the future workforce? I do not see in my crystal ball the diminishing of swine programs and faculty at academic institutions as what has happened with poultry. However, I think the issue all of animal agriculture will face is the changing interests in the undergraduates in animal science. Looking at poultry, most of the Midwest universities offer a class or two related to poultry and have used them as a springboard to get the students interested in the COE program. I am unclear on how that may work with pork, but could see a similar benefit allowing for more in-depth training of students beyond what is offered at their home institution.

Finally, the COE is viewed as a worthwhile investment for the future of the poultry industry. The commercial and allied industry have made many investments, including monetary, to cover the COE expenses. I am unclear on how the USPCE is structured, but without industry support relying on grant dollars will make it challenging for the program to exist.

Conclusion

The Midwest Poultry Consortium Center of Excellence program has been extremely beneficial to the commercial industry over the past 19 years. The training of over 375 students in poultry classes begin to capture the dedication and importance of having commercial and allied industry along with academics vested in the future of the poultry industry in the Midwest. While this program worked effectively in the past, the same success may not exist with other animal science programming. The COE continues to evolve to better meet the needs of the students and ensure they have the basic poultry knowledge making them a commodity to the commercial and allied poultry industry.

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Effects of Decreasing Dietary Crude Protein with Amino Acid Supplementation on Performance, Carcass, and Nutrient Excretion of Pigs

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Summary

Two nursery studies, two grow-finish studies and one nutrient balance study have been conducted in an attempt to define the practical limits for replacement of intact proteins in swine diets with feed grade amino acids (FGAA) without impacting growth performance or carcass composition. These studies are part of a USDA/NIFA grant to evaluate reduced nitrogen content in the feed with FGAA to meet nutrient requirements coupled with ractopamine supplementation in the final finishing stage as a potential means of mitigation of carbon footprint in swine production systems. These studies evaluating the effects of lowering crude protein (CP) in nursery and grow-finish diets and adding FGAA indicate that nursery diet formulations can be based on a His Set Point without impacting performance as long as the SID AA:Lys ratio requirements are met. However, in grow-finish studies, ADG, ADFI, G:F, and carcass composition improved or remained similar with lower inclusion levels of FGAA in reduced CP, net energy-based diets, but live pig performance and carcass composition declined in pigs fed the reduced CP diet with the highest inclusion of FGAA (His Set Point). Nitrogen balance studies conducted at Purdue University using similar reduced CP nursery and grow-finish diets observed a 36.5% linear reduction in nitrogen excretion with sequential CP reduction.

Introduction

The overall goal of this research is to experimentally evaluate reductions of crude protein (**CP**) in swine diets as a part of evaluation of several mitigation technologies to support development of a robust and accurate process-based Life Cycle Analysis (**LCA**) model of greenhouse gas (**GHG**) emission from swine production systems. The University of Arkansas has been working with the National Pork Board to create a detailed LCA model for live swine production which serves as the foundation for the modeling work proposed. Nitrogen (**N**) compounds from manure and urine are oxidized/reduced by soil and air, with some N being released into the atmosphere as nitrous oxide (**N_2O**). The greenhouse effect of N_2O is about 298 times that of carbon dioxide (**CO_2**); therefore, N_2O has the next largest impact on global warming after CO_2 and methane. Our hypothesis is that reducing dietary CP while maintaining amino acids (**AA**) at equivalent ideal protein ratios will reduce N excretion and GHG emissions without impacting swine performance or carcass yield.

Maximizing feed grade AA use and reducing dietary CP in swine diets has been shown to reduce N excretion in both nursery and growing/finishing swine (Kerr and Easter, 1995; Kendall, 2000; Figueroa et al., 2002, Hinson, et al., 2009). However, there was variability in growth performance and carcass characteristics when reduced CP diets were fed (Dourmad et al., 1993; Kerr et al., 1995; Figueroa et al., 2002). The situation with Paylean® is further complicated by FDA regulations requiring the feeding of a 16% CP diet with Paylean (Feed Additive Compendium, 2010), even though preliminary studies indicate that lower CP diets with appropriate added AA could potentially be fed to Paylean-fed pigs without compromising performance or carcass composition (DeCamp et al., 2001, Gaines et al., 2004) and may actually improve the yield reduction associated with increased dietary soybean meal needed to meet the minimum CP required (Gaines et al., 2004 and 2007). These studies suggest that the maximum level of CP reduction, in conjunction with the optimum AA inclusion rate, has not been sufficiently determined for widespread acceptance by the swine industry. Therefore, we propose to utilize wean-to-finish facilities at the University of Arkansas to develop a 3-phase nursery and a 5-phase grow/finish feeding program with Paylean fed during the final 3-week phase to develop diets that maximize use of feed grade AA and minimize CP without negatively impacting gain and carcass composition or quality, along with collecting digestibility data of these diets at Purdue University.

Specific Objectives for these studies

- Determine the impact of sequential increases in feed grade AA in reduced CP diets on growth performance in phases 1 to 3 of the nursery stages of production.
- Determine the impact of sequential increases in feed grade AA in reduced CP diets on growth performance in phases 1 to 5 of grow-finish stages of production.
- Perform experimental validation of the effectiveness of reduced dietary N as a mitigation technology to support development of a robust and accurate process-based Life Cycle Analysis model of GHG emission from swine production systems.
- Provide data which will allow coupling this model with Life Cycle Cost Analysis and development of an animal model capable of predicting swine performance and nutrient excretion.

Procedures

Nursery Studies

Experiment 1

Weaned pigs (n = 320) were blocked within gender by initial body weight (**BW**; 6.51 ± 0.37 kg) and allotted to gender-balanced pens in a wean-to-finish facility (8 pigs/pen) to evaluate maximum replacement of CP with feed grade AA (**FGAA**). Within blocks, pens were randomly assigned to 1 of 5 dietary treatments during nursery phases 1 (10 d), 2 (14 d) and 3 (14 d). Diets were formulated to maintain constant metabolizable energy (**ME**) and standardized ileal digestible (**SID**) lysine (**Lys**) across treatments with SID Lys set at 95% of the requirement (PIC, 2011). Diets were formulated to meet the SID AA ratio recommendations for other indispensable AA (SID) for nursery pigs through the 6th limiting AA (PIC, 2011). For each phase, control diets were devoid of FGAA, whereas Lys HCl was added in equal increments (Table 1) at the expense of CP by reducing soybean meal (**SBM**), fish meal (**FM**), and poultry meal (**PM**) in phase 1, FM and PM in phase 2, and SBM in phase 3. This formulation procedure resulted in diets that were below the His and Phe+Tyr SID requirement for the highest level of CP reduction. Analyzed CP and Lys inclusion levels for the nursery study are listed in Table 1. Also, example diets for each nursery phase are presented in Table 3. Complete diet formulations as well as calculated and analyzed AA levels for all growth studies are posted on http://directory.uark.edu/people/cmaxwell.

Experiment 2

A second 3-phase nursery study (8 d, 13 d, and 18 d for phases 1 to 3, respectively) was conducted with pigs weaned at 21 d to further evaluate limits of CP reduction in nursery diets and compare performance in pigs fed diets based on formulation on an ME vs. net energy (**NE**) basis. The study involved 7 pigs/pen and 7 replicates/treatment. Dietary ingredients were similar to those used in experiment 1, except soy protein concentrate was used to replace FM. Dietary treatments were: 1), Control diet formulated on an ME basis and with FGAA used to meet the "Tryptophan (**Trp**) Set Point" without adding feed grade Trp in phase 1 and 2 and 0.02 % added Trp in phase 3; 2) Diet formulated on an ME basis and to meet the "His Set Point" without added feed grade His; 3) As 2 with diets formulated on a NE basis.

Grow-Finish Studies

Each experiment was conducted following a 5-phase grow-finish protocol. During phases 1 (23 to 41 kg), 2 (41 kg to 59 kg), 3 (59 to 82 kg), 4 (82 to 104 kg), and 5 (104 to 127 or 134), pigs were fed 1 of 4 or 5 diets and 10 ppm of Paylean was fed during the final 3-week finishing phase or phase 5. During phase 1 through 5, individual pig BW, and pen feed disappearance were measured over each phase to allow calculation of ADG, ADFI and G:F by phase. Tenth rib, ¾ midline backfat measurements and loin muscle area were estimated at study initiation and at the end of each phase via ultrasound to allow estimation of carcass lean gain. When the average of all blocks was 129-134 kg, all pigs were individually weighed, tattooed, transported to a commercial pork packing plant, and harvested according to industry accepted procedures. Longissimus muscle (**LM**) and fat depths at the 10th rib were measured on-line with a Fat-O-Meater probe and individual hot carcass weight was recorded.

Experiment 1

A total of 420 pigs (PIC C-29 females x PIC 380 sires) were blocked by initial BW within gender into 7 weight blocks and randomly allotted to pens with 6 pigs/pen; within blocks, pens of pigs were randomly assigned to 1 of 5 dietary treatments when pigs averaged 21.7 kg BW. There were 35 pens representing a total of 210 pigs within each gender (7 reps/treatment for each gender).

Diets were formulated by incrementally increasing levels of Lys with corresponding reductions in CP (**RCP**). Pigs were randomly allotted to the following diets: 1) Control: Corn-SBM-DDGS diets devoid of FGAA, 2) RCP 1, 3) RCP 2, 4) RCP3, and 5) RCP 4. The

RCP 4 reduction in CP was balanced on the requirement of the 7th limiting AA, His (PIC, 2011) which was considered the practical limit of the highest level of RCP because of availability constraints. RCP 1 to 4 were then formulated to have stepwise and equally spaced increased Lys with corresponding reductions in CP between RCP 1 and 4. Diets 2, 3, and 4 were supplemented with FGAA as needed to meet AA needs based on AA minimum ratios.

Analyzed dietary CP and Lys inclusion levels for the first grow-finish study are listed in Table 2 with composition of control and RCP 4 diets for each phase presented in Table 4 as example diets used in all grow-finish studies.

Diets were formulated to 95% of the average SID Lys requirement for barrows and gilts (PIC, 2011), and exceeded the SID AA:Lys ratio recommendations for other indispensable AA by 2 percentage points. Distillers dried grains with solubles (**DDGS**) were included in all diets at the 20% level, with the exception of phase-5 finishing diets which was devoid of DDGS.

Experiment 2

In experiment 1, diets were formulated on an ME basis and as soybean meal was reduced in diets, the calculated Lys:NE decreased which may explain some of the increase in fat deposition in pigs fed ME-based diets formulated by decreasing SBM and including high levels of FGAA. Therefore, experiment 2 was conducted to establish the efficacy of using a "Set Point SID requirement" of sequentially reducing CP by adding FGAA to meet the SID AA:Lys ratio as a means of establishing the practical limits of CP reduction and AA replacement without impacting growth performance and carcass composition or quality in growing and finishing pigs fed NE-based RCP diets. Diets were formulated starting with a control diet that approximates acceptable inclusion levels of FGAA currently used in industry, followed by sequentially formulating 3 additional dietary treatments, each based on the next limiting AA. Diets in this study were formulated on a constant NE basis within phase. DDGS was included in all diets. The SID His requirement in the highest RCP diet was met in each phase without added feed grade His.

There was a total of 9 reps/treatment with 6 pigs/pen. Sex within pen was balanced such that each pen was represented by equal numbers of each sex within pen. Diets were formulated as in experiment 1 which were: **Treatment 1**, Control: Conventional phase 1 through 5 diets that approximates acceptable levels of FGAA currently used in industry. The assumption is that most in the industry are comfortable utilizing feed grade threonine (**Thr**) and methionine (**Met**) to meet the suggested SID Thr:Lys and SID Met:Lys ratios in diets formulated to meet the SID Trp:Lys requirement without added feed grade Trp. This is referred to as the Trp Set Point. **Treatment 2**, RCP 1: Diets were formulated to meet the next limiting AA. In phase 1 and 5, the next limiting AA was valine (**Val**) while isoleucine (**Ile**) was next limiting in phases 2, 3 and 4. This is referred to as the "Val or Ile Set Point". Neither feed grade Val nor Ile were added in any phase. **Treatment 3**, RCP 2: Diets were formulated to meet the next limiting AA. In phase 1 and 5, the next limiting AA was Ile while Val was next limiting in phases 2, 3 and 4. This is referred to as the "Val and Ile Set Point". Feed grade Val but not Ile was added in phases 1 and 5, and Ile but not Val was added in phase 2, 3, and 4. **Treatment 4**, RCP 3: Diets were formulated to meet the next (7th) limiting AA, histidine (**His**). This is referred to as the "His Set Point". All diets were supplemented with FGAA to meet indispensable AA recommended levels. Feed grade His was not added to any diet.

Table 1. Analyzed crude protein and added Lys in diets fed in each nursery phase.

Treatment	Control	RCP1	RCP2	RCP3	RCP4
CP, analyzed %					
Phase 1	26.21	24.26	22.42	20.64	18.86
Phase 2	27.65	25.30	23.05	20.89	18.75
Phase 3	27.18	24.41	21.77	19.31	16.78
Lys·HCl increment, %					
Phase 1	0.00	0.19	0.37	0.56	0.74
Phase 2	0.00	0.22	0.44	0.67	0.89
Phase 3	0.00	0.25	0.50	0.75	1.00

Table 2. Crude protein and added Lys in diets fed in each grow-finish phase.

Item, %	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
CP, analyzed					
Treatment 1	23.67	21.53	18.97	17.66	20.24
Treatment 2	21.59	19.46	17.34	16.30	18.60
Treatment 3	19.56	17.44	15.74	14.96	17.01
Treatment 4	17.59	15.49	14.16	13.64	15.44
Treatment 5	15.74	13.61	12.68	12.31	13.93
SID Lys, calculated	1.01	0.86	0.74	0.65	0.90
Added Lys·HCl					
Treatment 1	0.00	0.00	0.00	0.00	0.00
Treatment 2	0.19	0.18	0.15	0.12	0.15
Treatment 3	0.38	0.36	0.30	0.24	0.30
Treatment 4	0.56	0.54	0.44	0.36	0.45
Treatment 5	0.75	0.72	0.59	0.48	0.60

Nitrogen Balance Study

In the N balance experiment, 32 barrows (initial BW 8.66 ±0.136 kg) were used to evaluate the effect of feeding reduced CP, AA supplemented diets, on nutrient and volatile fatty acid (**VFA**) excretion. Pigs were randomly allotted to the following diets: 1) Control: Corn-SBM-DDGS diets with no FGAA, 2) 1X reduction in CP, 3) 2X reduction in CP, and 4) 3X reduction in CP. Diet 4, the 3X reduction in CP, was balanced on the 7th limiting AA in each phase. Diets 2 and 3 were then formulated to have stepwise and equally spaced reductions in CP between diets 1 and 4. Diets 2, 3, and 4 were supplemented with FGAA as needed to meet AA needs based on NRC 2012 AA minimum ratios. There were 4 nursery phases (d 0-7, d 7-14, d 14-28, d 28-42) and 5 grow-finish phases (21 d phases). Pigs were housed in stainless-steel metabolism pens equipped with a nipple waterer and stainless steel feeder. Collections started with nursery phase 3 and during nursery phases pigs were allowed an 8-d adjustment period to the diets followed by a 3-d total collection of feces, urine, and orts. During the grow-finish phases, pigs were acclimated to diets for the first 10 d of each phase, and then feces, urine, and orts were collected for 3 d.

Table 3. Composition (as-fed basis) of control and RCP 4 diets in nursery experiment 1[1].

	Phase 1 (6.5 to 7.9 kg)		Phase 2 (7.9 to 14.0 kg)		Phase 3 (14.0 to 22.9 kg)	
	C	RCP4	C	RCP4	C	RCP4
CP, %:	**25.8**	**18.3**	**27.3**	**18.3**	**26.8**	**16.4**
Ingredient, %						
Corn	32.18	47.11	32.45	52.22	35.76	64.00
SBM, 48%	19.33	9.50	28.55	14.00	38.55	7.45
DDGS[2]	10.00	10.00	15.00	15.00	20.00	20.00
Poultry meal	3.00	-	3.00	-	-	-
Poultry fat	2.50	2.75	2.50	2.50	2.50	2.23
Dicalcium phosphate	0.00	1.33	0.00	0.68	0.22	0.43
Limestone	0.29	0.81	0.03	0.94	0.93	1.06
Salt	0.30	0.30	0.31	0.40	0.50	0.50
Potassium sulfate	-	-	-	-	-	0.55
Lys·HCl	-	0.75	-	0.90	-	1.00
Met	0.06	0.30	0.02	0.31	-	0.27
Thr	-	0.26	-	0.32	-	0.34
Trp	-	0.10	-	0.11	-	0.13
Val	-	0.23	-	0.26	-	0.26
Ile	-	0.22	-	0.21	-	0.25
Copper sulfate	-	-	-	-	0.10	0.10
Dried whey	20.00	20.00	10.40	10.40	-	-
Dried plasma	4.00	4.00	-	-	-	-
Fish meal, Menhaden	6.00	-	6.00	-	-	-
Lactose	0.60	0.60	-	-	-	-
Zinc oxide	0.30	0.30	0.30	0.30	-	-
Other[3]	1.45	1.45	1.45	1.45	1.45	1.45
Calculated composition, %						
SID Lys	1.39	1.39	1.35	1.35	1.22	1.22
SID EAA:Lys ratio						
SID Met:Lys	33	38	35	42	33	42
SID Met+Cys:Lys	60	60	60	60	63	60
SID Thr:Lys	66	62	66	62	70	62
SID Trp:Lys	19	19	20	19	22	19
SID Ile:Lys	66	57	73	57	81	57
SID Val:Lys	78	67	82	67	90	67
SID Leu:Lys	144	105	153	106	173	111
SID His:Lys	44	28	47	28	52	27
SID Arg:Lys	96	54	111	58	129	53
SID Phe:Lys	76	50	82	50	96	49
SID Tyr:Lys	56	37	61	36	72	35
SID Phe+Tyr:Lys	132	87	144	86	168	85
Available P	0.53	0.53	0.44	0.32	0.22	0.22
Total Ca	0.84	0.84	0.70	0.70	0.60	0.60
ME, Mcal/kg	3.42	3.42	3.42	3.42	3.42	3.42

1 C = control diet formulated to meet 95% of the SID Lys requirement; PCR1 = reduced CP diet with added 0.19, 0.22, and 0.25% (phase 1, 2, and 3, respectively) of Lys + Thr, Met, and Trp; RCP2 = reduced CP diet with added 0.37, 0.44, and 0.50% (phase 1, 2, and 3, respectively) of Lys + Thr, Met, Trp, Val, and Ile; RCP3 = reduced CP diet with added 0.56, 0.67, and 0.75% (phase 1, 2, and 3, respectively) Lys + Thr, Met, Trp, Val, and Ile; and RCP4 = reduced CP diet with added 0.75, 0.90, and 1.00% (phase 1, 2, and 3, respectively) of Lys + Thr, Met, Trp, Val, and Ile.

2 Corn distiller dried grains with solubles.

3 Included vitamin premix, mineral premix, phytase (Ronozyme), antioxidant (Ethoxiquin), and antibiotic (Neo-Terramycin).

Results

Nursery Studies

Experiment 1

Pigs fed RCP 1, RCP 2, and RCP 3 diets in phase 1, 2 and 3, and for the overall study had similar ADG and BW but growth performance declined for pigs fed RCP 4 diets (Table 5; quadratic effect, $P < 0.01$). A similar response was observed in ADFI in all time periods except phase 1 where ADFI was similar among treatments. In phase 1, G:F ratio followed a similar response (quadratic effect, $P < 0.01$), but G:F ratio decreased linearly in phase 2 ($P < 0.08$), in phase 3, and overall ($P < 0.01$). It should be noted that the RCP 4 diet was below the requirement for SID His:Lys and phenylalanine (**Phe**)+tyrosine (**Tyr**):Lys which might explain the decrease in perfor-

Table 4. Composition (as-fed basis) of control and RCP 4 grow- finish diets in experiment 1[1].

	Phase 1 (23 to 41 kg)		Phase 2 (41 to 59 kg)		Phase 3 (59 to 82 kg)		Phase 4 (82 to 104 kg)		Phase 5 (104-127 kg)	
	C	RCP4	C	RCP4	C	RCP4	C	RCP4	C	RCP4
CP, %:	**23.7**	**15.72**	**21.5**	**13.61**	**19**	**12.68**	**17.7**	**12.37**	**20.2**	**13.93**
Ingredient, %										
Corn	47.4	68.62	53.1	73.82	59.4	75.55	63	76.24	69.1	86.23
Soybean meal	30.1	6.73	24.6	1.5	18.4	0.25	15	0	28.7	9.6
DDGS[2]	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	---	---
Limestone	0.95	1.06	0.99	1.09	1.16	1.24	0.94	1.00	0.60	0.69
Restaurant grease	0.55	0.50	0.50	0.58	0.31	0.47	0.33	0.58	0.45	0.49
Dical. phosphate	0.16	0.31	0.09	0.24	0.01	0.13	0	0.10	0.36	0.49
Potassium sulfate	0	0.50	0	0.65	0	0.60	0	0.60	0	0.50
Lys·HCl	0	0.75	0	0.72	0	0.59	0	0.48	0	0.60
Thr	0	0.22	0	0.20	0	0.16	0	0.11	0	0.23
Met	0	0.11	0	0.07	0	0.01	0	0	0	0.10
Ile	0	0.14	0	0.16	0	0.10	0	0.06	0	0.11
Val	0	0.11	0	0.12	0	0.05	0	0	0	0.10
Trp	0	0.09	0	0.09	0	0.07	0	0.06	0	0.07
Other[3]	0.88	0.88	0.78	0.78	0.78	0.78	0.78	0.78	0.81	0.81
Calculated composition, %										
SID Lys	1.01	1.01	0.86	0.86	0.74	0.74	0.65	0.65	0.90	0.90
SID EAA:Lys ratio										
SID Met:Lys	34.3	33.9	37.6	33.1	39.9	30.0	42.7	31.9	35.0	37.3
SID Met+Cys:Lys	68.8	57.1	74.0	57.4	79.1	57.1	84.7	62.4	67.0	60.0
SID Thr:Lys	74.0	63.0	78.8	64.0	77.9	65.1	81.0	66.0	74.0	70.1
SID Trp:Lys	22.7	19.0	23.2	19.0	22.6	19.1	22.8	19.1	22.5	19.1
SID Ile:Lys	83.7	58.0	80.7	58.1	86.0	58.0	88.6	58.1	79.7	58.1
SID Val:Lys	95.4	67.0	94.8	67.0	102	67.0	107	68.2	89.8	67.1
SID Leu:Lys	192	136	206	143	218	158	235	178.6	184	136
SID His:Lys	55.1	32.4	58.5	33.0	60.1	35.9	63.0	40.4	51.9	32.0
SID Arg:Lys	132	62.8	139	61.2	136	63.2	139	70.6	134	71.0
SID Phe:Lys	101	59.5	108	59.8	108	63.4	113	71.4	98.6	62.0
SID Tyr:Lys	75.4	42.2	79.4	40.9	80.7	45.4	83.9	50.9	69.2	38.8
SID Phe+Tyr:Lys	177	102	187	101	189	109	197	123	168	101
Available P	0.31	0.31	0.29	0.29	0.26	0.26	0.26	0.26	0.25	0.25
Total Ca	0.55	0.55	0.53	0.53	0.56	0.56	0.46	0.46	0.45	0.45
ME, Mcal/kg	3.37	3.37	3.38	3.38	3.37	3.37	3.38	3.38	3.38	3.38

1 C = control diet formulated to meet 95% of the SID Lys; RCP1 = reduced CP diet with added Lys; RCP2 = reduced CP diet with added Lys, Thr, and Trp; RCP3 = low CP diet with added Ly, Thr, Met, Trp, Ile, and Val; and RCP4 = lowest CP diet with added Lys, Thr, Met, Trp, Ile, and Val.
2 Corn distiller dried grains with solubles
3 Includes mineral and vitamin premixes and other common protein sources.

mance. The results of this study establishes that a high inclusion of feed grade Lys at the expense of intact proteins can be fed without decreasing ADG and ADFI except at the highest level of FGAA where the requirement for all indispensable AA was not met. However, G:F was generally reduced at the higher inclusion rates of FGAA, particularly in phase 3.

Experiment 2

No differences were observed in ADG, ADFI, or G:F (Table 6) in any phase or overall in pigs fed diets formulated on an aggressive FGAA inclusion (His Set Point) based on ME (Treatment 2) or NE (Treatment 3) compared to pigs fed AA inclusion levels currently used in the swine industry (Treatment 1). These results indicate that in nursery pigs, one should be able to use a His Set Point in formulating AA based diets without concern for pig performance.

The previous nursery experiment (Experiment 1; Bass et al., 2013) conducted to evaluate feeding reduced CP diet with the highest levels of FGAA to nursery pigs resulted in poor growth performance, especially G:F ratio in phase 3 and the overall nursery period. In the previous study, experimental diets were formulated to meet 95% of the SID Lys requirement for nursery pigs. Also, RCP 4, which was formulated with the highest level of FGAA, did not meet the His and Phe requirement based on Lys:NE.

In conclusion, unlike the previous study, growth performance of nursery pigs was not affected by the higher level of FGAA and lower dietary CP. This may be due to different SID His:Lys and SID Phe+Tyr:Lys ratios used

Table 5. Main effects of reduced CP diets on live pig performance, nursery experiment 1, LS means.

	Treatments[1]						*P*-Value		
								Lys Level	
Item	C	RCP1	RCP2	RCP3	RCP4	SEM	Diet	Linear	Quadratic
BW, kg									
d 0	6.49	6.51	6.52	6.53	6.50	0.37	0.4050		
d 10	7.74	8.10	8.10	7.90	7.83	0.35	0.0198	0.9220	0.003
d 24	13.46	14.61	14.35	14.08	13.28	0.55	0.0007	0.2105	<0.0001
d 38	22.39	24.11	23.92	23.02	21.20	0.82	<0.0001	0.0017	<0.0001
ADG, kg									
d 0-10	0.125	0.160	0.158	0.137	0.133	0.016	0.0269	0.8058	0.0056
d 10-24	0.407	0.465	0.446	0.442	0.389	0.017	0.0010	0.1488	0.0002
d 24-38	0.638	0.679	0.684	0.633	0.566	0.029	<0.0001	0.0003	<0.0001
d 0-38	0.418	0.463	0.458	0.434	0.387	0.015	<0.0001	0.0014	<0.0001
ADFI, kg									
d 0-10	0.193	0.214	0.217	0.207	0.218	0.012	0.3726	0.1877	0.3642
d 10-24	0.477	0.566	0.565	0.527	0.509	0.024	0.0108	0.6868	0.0015
d 24-38	0.940	1.034	1.090	1.039	0.993	0.045	0.0454	0.3022	0.0046
d 0-38	0.570	0.646	0.666	0.629	0.610	0.023	0.0042	0.2415	0.0004
G:F									
d 0-10	0.645	0.736	0.725	0.658	0.611	0.047	0.0008	0.0374	0.0003
d 10-24	0.852	0.827	0.792	0.844	0.766	0.028	0.1510	0.0756	0.8604
d 24-38	0.684	0.657	0.630	0.612	0.577	0.029	0.0058	0.0002	0.9338
d 0-38	0.732	0.717	0.689	0.686	0.637	0.019	0.0009	<0.0001	0.4377

[1] C = control diet formulated to meet 95% of the SID Lys requirement; RCP1 = reduced CP diet with added 0.19, 0.22, and 0.25% (phase 1, 2, and 3, respectively) of Lys + Thr, Met, and Trp; RCP2 = reduced CP diet with added 0.37, 0.44, and 0.50% (phase 1, 2, and 3, respectively) of Lys + Thr, Met, Trp, Val, and Ile; RCP3 = reduced CP diet with added 0.56, 0.67, and 0.75% (phase 1, 2, and 3, respectively) of Lys + Thr, Met, Trp, Val, and Ile; and RCP4 = reduced CP diet with added 0.75, 0.90, and 1.00% (phase 1, 2, and 3, respectively) of Lys + Thr, Met, Trp, Val, and Ile.

in diet formulation or different protein sources used in each study. In the second nursery study, all diets were formulated based on 100 % or excess of SID Lys requirement for nursery pigs, and were formulated to meet the His and Phe+Tyr requirement. In addition, soy protein concentrate (**SPC**) was used in the second study during phase 1 and 2, replacing menhaden fish meal used in nursery study one.

Grow-Finish Studies

Experiment 1

Body weights of pigs decreased linearly with decreasing dietary CP during phase 1, 2, and 3 ($P < 0.01$; Table 7). Additionally, BW increased and then decreased quadratically during phase 3 ($P = 0.09$), 4 ($P < 0.04$), and 5 ($P < 0.01$) with BW decreasing significantly in pigs fed RCP 4. When Paylean was included in the Phase 5 diets, barrows fed the control diet had greater ADG than control-fed gilts, but RCP 1-, RCP 2-, and RCP 3-fed gilts had greater ADG than their castrated male counterparts (Quadratic gender × reduced CP diet, $P = 0.08$; Figure 1A) Both ADG and G:F decreased linearly ($P \leq 0.06$) during phase 1 and 2. Furthermore, gain efficiency increased 4.6 % in gilts between control and RCP 2 before decreasing to similar G:F values between control and RCP 4; however, G:F remained relatively unchanged in barrows across the 5 dietary treatments (Quadratic gender × reduced CP diet, $P = 0.04$; Figure 1B).

Over the entire feeding trial, ADG increased only 2 % between control and RCP3, but dropped 6 % between RCP3 and RCP4 (Quadratic, $P < 0.01$). On the other hand, ADFI tended to decreased linearly ($P = 0.09$) as CP was reduced in swine diets. Gain efficiency increased 4.6 % in gilts between control and RCP2 before decreasing to similar values between control and RCP4; however, G:F remained relatively unchanged in barrows across the 5 dietary treatments (Quadratic gender × reduced CP diet, $P = 0.04$; Figure 1C).

Reducing dietary CP and optimizing the use of FGAA had limited ($P \geq 0.21$) effects on HCW, dressing percentage, or LM depth; however, 10th rib fat depth increased linearly ($P < 0.01$), and fat-free lean percentage at study termination decreased linearly as CP was reduced in swine diets ($P < 0.02$; Figure 1D).

Experiment 2

Effects of dietary treatment indicated that ADG decreased linearly with increasing dietary FGAA in phase 3 (Table 8, $P < 0.05$), 4 ($P < 0.10$), 5 ($P < 0.01$) and overall ($P < 0.01$). Similarly, ADFI decreased linearly in phase 4 ($P < 0.05$), 5 ($P < 0.01$) and overall ($P < 0.01$) with increasing FGAA. Compared to pigs fed the control diet (Treatment 1), G:F in phase 1 increased in pigs fed in-

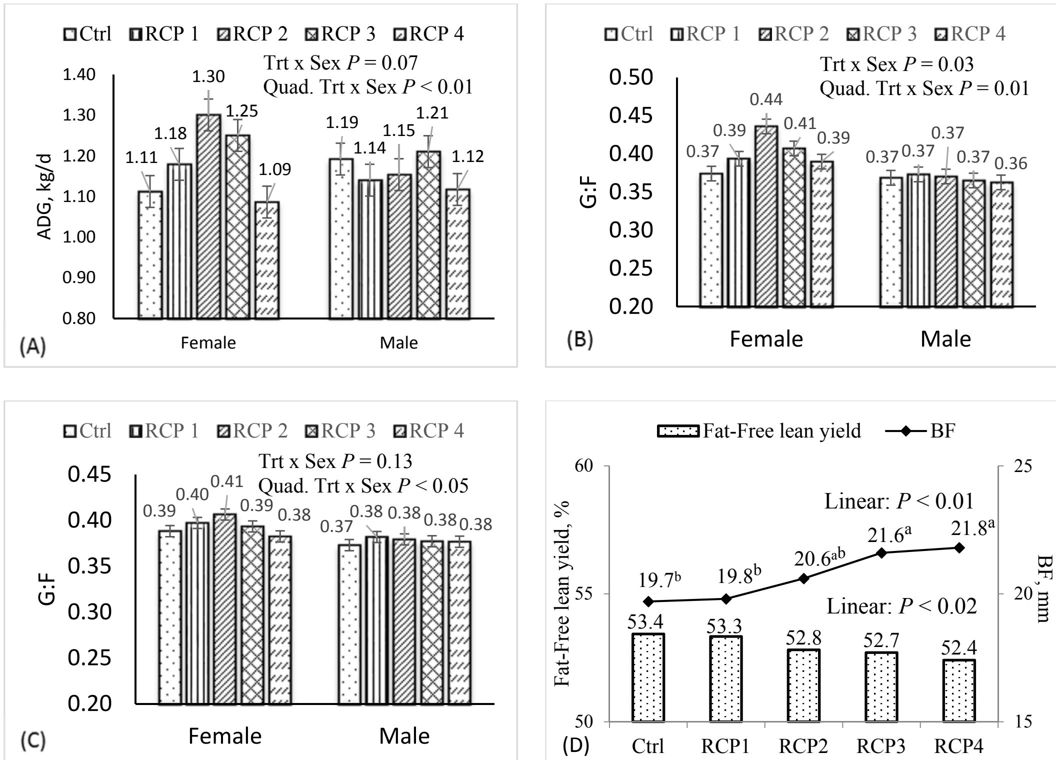

Figure 1. (A) Effect of gender and reduced CP diet on ADG in phase 5, (B) Effect of gender and reduced CP diet on G:F in phase 5,(C) Effect of gender and reduced CP diet on overall G:F, and (D) Effect of decreasing CP on BF and the percentage of fat-free lean yield.

creasing levels of FGAA at the lower inclusion rates (Treatments 2 and 3) before decreasing to the control level at the highest level of inclusion (Treatment 4, quadratic effect, $P < 0.05$). During phase 3, a small, but significant, decrease in G:F was observed with increasing levels of FGAA (linear effect, $P < 0.05$). For the overall study, however, a trend for increased G:F was observed (linear effect, $P < 0.06$). BW increased at the end of phase 2 with increasing level of FGAA (quadratic effect, $P < 0.06$). However, consistent with ADG, BW decreased with increasing dietary FGAA at the end of phase 3, 4 and 5 (linear effect, $P < 0.05$, $P < 0.01$ and $P < 0.01$, respectively).

As might be expected based on BW, hot carcass weight decreased with increasing inclusion of dietary FGAA (linear effect, $P < 0.01$). Tenth rib backfat was lower in pigs fed diets formulated to the Val or Ile Set Point (Treatment 2) or the His Set Point (Treatment 4) when compared to those fed diets formulated to the Val and Ile Set Point (Treatment 3).

Nitrogen Balance Study

Overall, from d 14 to d 147 post-weaning ADFI was linearly increased as dietary CP was reduced, but no effect of dietary CP concentration on ADG or G:F (Table 9) was observed. Fecal dry matter (**DM**) excretion tended to

Table 6. Main effects of reduced CP diets on live pig performance, nursery experiment 2, LS means.

	Treatment[1]				Diet
Item	Control	RCP-ME	RCP-NE	SEM	*P*-Value
ADG, kg					
d 0-8	0.142	0.149	0.152	0.009	0.7393
d 8-21	0.426	0.428	0.449	0.024	0.6736
d 21-39	0.631	0.590	0.614	0.022	0.2954
d 0-39	0.461	0.445	0.468	0.016	0.4035
ADFI, kg					
d 0-8	0.188	0.181	0.193	0.008	0.5432
d 8-21	0.578	0.578	0.596	0.030	0.8775
d 21-39	1.071	1.012	1.047	0.035	0.4538
d 0-39	0.726	0.697	0.721	0.025	0.6511
Gain:Feed					
d 0-8	0.754	0.821	0.798	0.040	0.4925
d 8-21	0.736	0.740	0.754	0.016	0.6847
d 21-39	0.593	0.583	0.588	0.020	0.9268
d 0-39	0.637	0.639	0.650	0.015	0.7655
BW, kg					
d 0	6.43	6.41	6.44	0.47	0.8077
d 8	7.57	7.60	7.65	0.44	0.5785
d 21	13.13	13.16	13.49	0.69	0.6133
d 39	24.45	23.80	24.66	0.99	0.4039

[1] Control: The diet was supplied with Lys, Met, and Thr in Phases 1 and 2, and with Lys, Met, Thr, and Trp in Phase 3; RCP-ME: Reduced CP ME based diet formulated to meet the His requirement without added feed-grade His; and RCP-NE: Reduced CP NE based diet formulated to meet the His requirement without added feed-grade His.

Table 7. Main effects of reduced CP diets on live pig performance and carcass composition, grow-finish experiment 1, LS means.

	Treatment[1]						*P*-Value[2]				
	C	RCP 1	RCP 2	RCP 3	RCP 4	SEM	Trt	TrtxSex	Lin.	Quad.	Cubic
ADG, kg/d											
Phase 1	0.77	0.78	0.77	0.75	0.72	0.1	0.06	0.95	0.01	0.11	0.91
Phase 2	0.93[a]	0.88[bc]	0.91[ab]	0.90[abc]	0.86[c]	0.3	0.05	0.34	0.05	0.74	0.02
Phase 3	1.02	1.05	1.03	1.00	0.99	0.2	0.19	0.55	0.06	0.23	0.31
Phase 4	0.92	0.95	0.94	0.96	0.95	0.2	0.47	0.88	0.18	0.34	0.98
Phase 5	1.15[bc]	1.16[bc]	1.23[ab]	1.23[ab]	1.10[c]	0.3	0.01	0.07	0.73	< 0.01	0.04
Overall	0.96[a]	0.97[a]	0.98[a]	0.98[a]	0.92[b]	0.2	0.00	0.32	0.05	< 0.01	0.08
ADFI, kg/d											
Phase 1	1.46	1.46	1.53	1.52	1.48	0.1	0.17	0.17	0.24	0.10	0.21
Phase 2	2.16	2.07	2.12	2.07	2.10	0.1	0.27	0.76	0.27	0.29	0.69
Phase 3	2.65	2.58	2.57	2.56	2.48	0.1	0.26	0.28	0.03	0.92	0.43
Phase 4	3.04	3.1	2.99	3.07	2.99	0.1	0.58	0.97	0.50	0.67	0.94
Phase 5	3.09[ab]	3.02[bc]	3.05[bc]	3.21[a]	2.93[c]	0.1	0.02	0.57	0.47	0.20	0.00
Overall	2.51	2.47	2.48	2.48	2.42	0.1	0.29	0.78	0.08	0.63	0.19
G:F											
Phase 1	0.53[ab]	0.53[a]	0.51[bc]	0.50[c]	0.49[c]	0.01	< 0.01	0.40	< 0.01	0.69	0.29
Phase 2	0.43[a]	0.43[a]	0.43[a]	0.43[a]	0.41[b]	0.01	0.01	0.65	0.03	0.11	0.02
Phase 3	0.39	0.41	0.40	0.39	0.40	0.01	0.20	0.82	0.99	0.43	0.02
Phase 4	0.30	0.31	0.32	0.32	0.32	0.01	0.17	0.75	0.02	0.42	0.90
Phase 5	0.37[b]	0.38[b]	0.40[a]	0.39[ab]	0.38[b]	0.01	0.02	0.03	0.59	< 0.01	0.96
Overall	0.38[b]	0.39[a]	0.39[a]	0.39[ab]	0.38[b]	0.01	0.01	0.13	0.48	< 0.01	0.40
BW, kg											
Initial	21.7	21.7	21.7	21.7	21.7	1.4	0.96	0.99	0.78	0.98	0.49
End of phase 1	37.9[a]	38.1[a]	37.9[a]	37.5[ab]	36.8[b]	1.9	0.05	0.95	0.01	0.11	0.89
End of phase 2	57.5[a]	56.7[a]	57.2[a]	56.6[a]	55.1[b]	2.4	0.02	0.45	0.01	0.22	0.17
End of phase 3	79.0[a]	78.7[a]	79.0[a]	77.8[ab]	75.9[b]	2.7	0.01	0.28	< 0.01	0.08	0.55
End of phase 4	104.7	105.5	105.3	104.9	102.5	2.7	0.08	0.20	0.06	0.03	0.71
End of phase 5	129.1[a]	129.9[a]	131.1[a]	131.1[a]	124.9[b]	2.8	< 0.01	0.31	0.05	< 0.01	0.07
Real time ultrasound scan[3]											
Lean, kg	48.0[a]	48.6[a]	48.6[a]	48.3[a]	45.3[b]	1.0	< 0.01	0.21	< 0.01	< 0.01	0.14
Carcass composition											
HCW, kg	93.8	94.7	95.3	96.2	93.2	1.6	0.69	0.90	0.95	0.21	0.48
Dressing, %	72.6	72.7	72.5	72.7	73.1	0.3	0.66	0.46	0.28	0.30	0.71
FFL[4], %	53.4	53.3	52.8	52.7	52.4	0.3	0.19	0.42	0.02	0.97	0.82
LD[4],mm	64.3	64.5	63.4	64.6	62.3	1.4	0.76	0.68	0.38	0.60	0.61
BF[4], mm	19.7	19.8	20.6	21.6	21.8	0.5	0.02	0.50	< 0.01	0.88	0.41

[a.b.c.] Means within row lacking a common superscripts differ (P < 0.05).
[1] C = control diet formulated to meet 95% of the SID Lys requirement; RCP1 = reduced CP diet with added Lys; RCP2 = reduced CP diet with added Lys, Thr, and Trp; RCP3 = low CP diet with added Lys, Thr, Met, Trp, Ile, and Val; and RCP4 = lowest CP diet with added Lys, Thr, Met, Trp, Ile, and Val.
[2] Dietary feed grade Lys inclusion rate was used in PROC IML to generate coefficient for polynomial contrasts.
[3] 10th rib fat depth and longissimus area were scanned from individual pig at the end of study to calculate lean tissue weight. Lean muscle weight = 2.2 × (-0.534 + (0.291 × BW, lbs) – (16.498 × 10th rib fat depth, in) + (5.425 × LM area, in2) + (0.833 × gender)), where 1 = barrow and 2 = gilt.
[4] FOM was equipped to measure loin depth (LD) and 10th rib fat depth (BF), which together with HCW, was used to calculate fat free lean (FFL).

respond in a quadratic ($P = 0.08$) fashion with decreasing fecal DM excretion up to 2X reduction in CP, but then increasing in 3X fed pigs. Both DE and ME (kcal/kg) were linearly ($P < 0.01$) reduced as dietary CP was reduced. The linear ($P < 0.01$) decrease in N intake for pigs fed reduced CP diets was accompanied by linear ($P < 0.01$) decreases in both urinary and total N excreted. Nitrogen digestibility (%) linearly decreased ($P < 0.01$) and N retention (%) linearly increased ($P < 0.01$) with reductions in dietary CP. Overall, there was a linear ($P < 0.03$) reduction in fecal ammonium as dietary CP was reduced. Total carbon (**C**) intake and total fecal C excreted tended ($P = 0.06$) to respond quadratically with an increase in both C intake and C excretion up to the 1X reduced CP diets, followed by a decrease in C intake and increasing C excretion to the 3X diet creating a linear ($P < 0.05$) decrease in C digestibility as dietary CP was reduced.

Implications from these studies suggest that CP can be replaced with FGAA to meet the requirement of the first 7 limiting AA in nursery diets without affecting growth performance and the first 6 limiting AA (Val and Ile set point) in grow-finish diets without impact-

Table 8. Main effects of reduced CP NE based diets on live pig performance and carcass composition, grow-finish experiment 2, LS means.

	Treatment[1]					P-Value[2]			
	C	RCP 1	RCP 2	RCP 3	SEM	Trt	Lin.	Quad.	Cubic
ADG, kg/d									
Phase 1	0.93	0.94	0.94	0.92	0.02	0.39	0.56	0.12	0.67
Phase 2	1.02	1.01	1.04	0.97	0.03	0.22	0.22	0.22	0.22
Phase 3	1.16[x]	1.16[x]	1.13[xy]	1.10[y]	0.02	0.09	0.02	0.36	0.41
Phase 4	0.96	0.95	0.95	0.90	0.02	0.28	0.10	0.30	0.96
Phase 5	1.09[a]	1.07[a]	1.08[a]	0.99[b]	0.03	0.04	0.01	0.29	0.72
Overall	1.03[a]	1.03[a]	1.03[a]	0.98[b]	0.01	< 0.01	< 0.01	0.09	0.79
ADFI, kg/d									
Phase 1	1.55	1.53	1.49	1.52	0.03	0.22	0.26	0.20	0.20
Phase 2	2.39	2.48	2.49	2.37	0.07	0.29	0.99	0.06	0.81
Phase 3	2.88	2.89	2.89	2.80	0.05	0.36	0.19	0.23	0.85
Phase 4	3.14[x]	3.15[x]	3.08[xy]	2.96[y]	0.05	0.07	0.02	0.16	0.57
Phase 5	3.22[a]	3.13[ab]	3.06[b]	2.84[c]	0.05	< 0.01	< 0.01	0.35	0.77
Overall	2.62[a]	2.61[a]	2.57[a]	2.47[b]	0.04	< 0.01	< 0.01	0.22	0.61
G:F									
Phase 1	0.60[a]	0.62[ab]	0.64[b]	0.61[a]	0.01	0.03	0.44	0.02	0.08
Phase 2	0.43	0.41	0.42	0.41	0.01	0.32	0.13	0.70	0.32
Phase 3	0.40	0.40	0.39	0.39	0.01	0.12	0.05	0.97	0.16
Phase 4	0.31	0.30	0.31	0.31	0.01	0.94	0.94	0.96	0.55
Phase 5	0.34	0.34	0.35	0.35	0.01	0.35	0.15	0.35	0.54
Overall	0.38	0.39	0.40	0.40	0.01	0.09	0.06	0.10	0.47
BW, kg									
Initial	20.7	20.7	20.7	20.7	0.7	0.89	NA	NA	NA
End of phase 1	46.8	47.0	47.2	46.5	1.1	0.38	0.60	0.11	0.62
End of phase 2	58.0[xy]	58.0[xy]	58.6[x]	57.2[y]	1.2	0.09	0.25	0.06	0.17
End of phase 3	85.9[a]	85.9[a]	85.8[a]	83.6[b]	1.5	0.05	0.02	0.08	0.78
End of phase 4	106.2[a]	105.9[a]	105.7[a]	102.6[b]	1.5	0.01	< 0.01	0.06	0.84
End of phase 5	134.5[a]	133.8[a]	133.6[a]	128.3[b]	1.9	0.01	< 0.01	0.09	0.78
Carcass composition									
HCW, kg	97.9[a]	98.5[a]	96.9[ab]	94.6[b]	1.0	0.01	0.01	0.13	0.31
Dressing, %	72.9	73.3	73.2	73.9	0.7	0.77	0.32	0.88	0.82
Fat free lean[3], %	53.1	53.1	52.6	53.3	0.3	0.31	0.61	0.17	0.24
LD[3], mm	63.7	63.4	63.4	62.7	0.8	0.83	0.37	0.82	0.93
BF[3], mm	19.5[ab]	19.3[a]	21.0[b]	19.0[a]	0.6	0.07	0.62	0.12	0.03

[a,b,c] Means with different superscript differ, P < 0.05
[x,y,z] Means with different superscript differ (P < 0.10)
[1] C. control diet, met Trp requirement without adding feed grade Trp; RCP1, met SID Val (Phase 1 & 5) or Ile (Phase 2, 3 & 4) requirement without adding feed grade Val or Ile; RCP2, met SID Val (Phase 2, 3 & 4) or ILE (Phase 1 & 5) requirement without adding feed grade Val and Ile; RCP3, met SID His requirement without adding feed grade His. Feed grad Lys, Met, Thr, Trp, Val, and ILE were supplemented. All diets were formulated to meet 100% SID Lys requirements.
[2] Proc IML was used to generate coefficient for orthogonal contrast by using Lys supplementation level from each treatment for each phase.
[3] FOM was equipped to measure loin depth (LD) and 10th rib fat depth (BF), which together with HCW, then used to calculate fat-free lean.

ing growth performance or carcass composition, but further reductions in CP in grow-finish diets to meet the set point of the 7th limiting AA (His) results in more variable performance and reduced energy and carbon digestibility. A third experiment has been initiated to determine if the reduced growth performance and carcass composition observed in the previous 2 studies at the higher FGAA inclusion could be corrected by supplementing diets to control levels of indispensable AA, dispensable AA, or correcting for differences in dietary electrolyte balance.

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Table 9. Effect of reduced CP-AA supplemented diets on overall (d14-147) pig performance, fecal and urinary excretion, composition, and nutrient digestibility[1].

	Treatment					Probability, *P*≤				
Diets[1]	**C**	**1X**	**2X**	**3X**	**SEM[2]**	**Phase**	**Diet**	**Linear**	**Quadratic**	**Phase x Diet**
Performance data										
ADG, kg	0.73	0.74	0.77	0.77	0.021	0.0001	0.4214	0.1271	0.8619	0.2871
ADFI, kg	1.64	1.67	1.70	1.70	0.016	0.0001	0.1205	0.0340	0.3041	0.1297
GF	0.45	0.44	0.45	0.46	0.013	0.0001	0.8648	0.5812	0.6344	0.3459
Collection data										
ADFI, g	1726.4	1776.1	1786.8	1787.0	23.36	0.0001	0.1258	0.0624	0.2688	0.0338
Feces, g/pig/d as-is	512.0	494.2	469.4	503.3	19.28	0.0001	0.4184	0.5569	0.1709	0.0261
Urine, mL/pig/d	3536.4	3378.6	3711.0	2876.4	270.65	0.0826	0.1297	0.1662	0.1925	0.6599
DM, % digestibility	86.5	85.7	86.6	85.2	0.47	0.0001	0.0902	0.1410	0.4931	0.0244
Energy,										
DE, kcal/kg	3603	3515	3522	3394	15.0	0.0001	0.0001	0.0001	0.1678	0.0001
ME, kcal/kg	3452	3362	3385	3293	17.3	0.0001	0.0001	0.0001	0.9024	0.0001
Nitrogen										
N, % digested	83.0	82.6	82.5	79.4	0.69	0.0001	0.0011	0.0007	0.0541	0.4844
N, % retained	45.3	48.8	53.4	59.6	1.09	0.0001	0.0001	0.0001	0.2356	0.0018
Total N excreted, g/pig/d	29.0	24.5	21.8	16.0	0.82	0.0001	0.0001	0.0001	0.4210	0.0015
Fecal AmmN, g/pig/d	1.5	1.4	1.3	1.3	0.07	0.0001	0.189	0.0319	0.9685	0.1816
Carbon										
Total C intake, g/pig/d	696.4	713.5	709.6	693.6	9.22	0.0001	0.3088	0.7644	0.0632	0.0008
Fecal C excreted, g/pig/d	93.3	94.2	91.3	105.3	3.49	0.0001	0.0222	0.0378	0.0571	0.0201
C, % digested	86.7	86.1	86.5	84.6	0.47	0.0001	0.0065	0.0054	0.1501	0.0278

[1] Control: Corn-SBM-DDGS diets with no FGAA, 2) 1X reduction in CP, 3) 2X reduction in CP, and 4) 3X reduction in CP. Diet 4, the 3X reduction in CP, was balanced on the 7th limiting AA in each dietary phase.

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Betaine for Boars and Sows During Heat Stress

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Summary

The swine industry faces major economic losses each year because the animals are raised in areas of the country where the temperatures during the warm seasons exceed their thermal neutral zone of comfort. The losses are hard to estimate because they are more than just increased mortality. Sows, boars, and market hogs all experience stress from the elevated temperatures reducing performance and growth as well as reproductive success and milk production. Therefore, there is a need to understand the mechanisms impacted by heat stress and identify methods to mitigate the production losses. Previously, betaine, a naturally occurring methylamine, was investigated as a feed additive for pigs and was found to provide benefit for litter size. The benefit to growing pigs has been equivocal. Recently, investigations into the benefits of betaine supplementation to sows and boars have been conducted to determine if it has any benefits in relation to improved reproductive efficiency during heat stress. The results of these studies suggest that betaine supplementation to both sows and boars can provide benefits during the summer months with improved piglets born alive dependent on age of the sow and improved semen production in boars.

Introduction

The current industry production goals are greatly challenged when fertility of the sow and boar is compromised during 25% of the year from elevated ambient temperatures. Random surveys of sow farms and boar studs have identified reductions in fertility and increases in ejaculate discard rates associated with the summer months (Knox et al., 2008, 2013) which is thought to cost the swine industry more than $350 million per year (St. Pierre et al., 2003) or more than double the economic impact of PRRS (Dr. Steve Pollmann, personal communication). Sows and boars are both susceptible to stress from elevated ambient temperatures and humidity outside of the animal's thermal neutral zone. Methods to reduce the negative impacts of seasonal infertility in swine are needed. The present paper will describe the use of dietary betaine supplementation to boar and sow diets during the summer months and the subsequent impacts on reproductive success.

Heat Stress and Reproduction

Environmental temperature may not have to greatly exceed the animal's thermal neutral zone in order to have detrimental effects on fertility, and the effects may vary within and between genetic lines of animals (Flowers, 1997). Stress from heat is more than just a fever and results in multiple physiological changes within the animal in attempts to dissipate the heat from its body. Pigs will increase their respiratory rates, decrease feed intake, increase water intake, and divert blood flow to the extremities to aid in heat dissipation. This results in a decrease of blood flow in the gastrointestinal (**GI**) tract, tissue hypoxia, and ATP depletion, ultimately increasing the permeability of tight junctions allowing bacteria and endotoxins to enter into the animal's blood stream (Hall et al., 1999). The overall impacts of heat stress on reproduction are decreased milk yield, increased body weight loss, increased wean-to-estrus intervals, and impairments in embryo development (Liao and Veum, 1994, Kojima et al., 1996).

Betaine Effects on Reproduction in Sows

Betaine is a naturally occurring methylamine present in plant and animal tissues and is also commercially available as a feed additive. Studies from swine and poultry have suggested multiple functions for this molecule as an osmoprotectant, osmolyte, and as a methyl donor to convert homocysteine into methionine (reviewed by Eklund et al., 2005). When evaluating metabolic changes associated with heat stress, it seems logical that the osmolytic capacity of betaine may spare tissue damage in the GI tract, therefore increasing nutrient digestibility. Additionally, Japanese quails demonstrated increased homocysteine concentrations as a result of heat stress (Sahin et al., 2003), suggesting a potential benefit from betaine's role as a methyl donor to convert homocysteine into methionine.

Table 1. Overall ejaculate characteristics for treatments and genetic lines of boars supplemented with betaine. (Volume and concentration are reported with a 1:1 dilution).

	Treatment				*P*-Value					
Ejaculate	**CON**	**BET 0.3%**	**BET 0.6%**	**SE**	**CON vs BET**	**BET Difference**	**Treatment**	**Genetic**	**Week**	**Genetic x Week**
No.	32	27	30							
Volume (ml)	446.4	423.6	471.7	26.1	0.964	0.159	0.368	0.007	0.001	0.041
Concentration (10^8/ml)	1.99	2.26	2.05	0.12	0.196	0.175	0.183	0.001	0.001	0.003
Total sperm (10^9)	80.4	85.2	90.8	4.22	0.093	0.336	0.143	0.005	0.001	0.318

CON = control boars fed 0% betaine.
BET 0.3% = boars fed betaine at 0.3% of the diet.
BET 0.6% = boars fed betaine at 0.6% of the diet.

Van Wettere and colleagues (2012, 2013) have evaluated betaine supplementation (7.6-9.0 g/d) to gestating sows and found increased litter sizes in older sows, being greatest during the summer months. Supplementation of betaine during lactation (1.92 g/kg of feed) increased litter weight gain, decreased wean-to-estrus interval, and increased the subsequent number of pigs born alive (Ramis et al., 2011; Greiner et al., 2014). Recent work at North Carolina State has suggested that age of the female may dictate when betaine can benefit reproductive outcomes (Mendoza et al., 2015). Feeding natural betaine (0.20%) from weaning until 35 days post-insemination to young sows (parity 1 and 2) decreased wean-to-estrus interval, and increased number of piglets born alive. The greatest impact of feeding betaine to both young and mature sows was observed for those fed betaine only during the lactation period (14.24 vs 13.46 total pigs born/litter for betaine supplemented and control, respectively)

Reproductive benefits from betaine supplementation during summer months to sows likely results, at least in part, from reducing homocysteine concentrations by donating methyl groups to convert homocysteine into methionine. Increased homocysteine in the blood has been correlated to reductions in conception rates in swine (Matte et al., 2006). Van Wettere and colleagues (2013) demonstrated a reduction in plasma homocysteine during early gestation in sows supplemented with betaine and a subsequent increased in number of pigs born alive. Work in rodents suggests that betaine is required in the pre-implantation blastocyst as a methyl donor to convert homocysteine into methionine for successful embryo development (Corbett et al., 2014), suggesting a mechanism by which reduced homocysteine from betaine supplementation can increase number born alive.

In addition, betaine may provide benefits to reproduction by controlling cell volume and integrity in the GI tract by acting as an osmolyte. A negative energy balance during lactation can decrease follicular development post-weaning and impair reproductive success (Quesnel et al., 2007). If betaine helps maintain intestinal integrity during times of stress, this could maintain the sow's energy metabolism and utilization, preventing the negative impacts of heat stress on wean-to-estrus interval and litter performance.

Betaine Effects on Boar Fertility

Reproductive responses in the male from supplemental betaine have not been well studied. Approximately 18% of men seeking medical treatment for infertility have a mutation in methylenetetrahydrofolate reductase, causing an increase in homocysteine concentrations (Bezold et al., 2001). Feeding supplemental betaine to rabbit bucks and mice during summer months has been shown to increase the concentration of sperm in the ejaculates, potentially via betaine acting as an antioxidant and reducing oxidative cell loss in the testes (Alirezaei et al., 2012). It also improves motility, either from its role as an osmolyte and sparing ATP (Johnson and Zeisel, 2010; Hassan et al., 2012), or from its role as a methyl donor in the metabolism of homocysteine into methionine, or ultimately creatine, which is important for sperm function (Lee et al., 1998).

We recently conducted a study in which we supplemented diets of mature boars (11-63 months of age) with either 0, 0.3, or 0.6% betaine during the summer months in Oklahoma and evaluated the effects on sperm production and estimates of semen quality. This study found that betaine supplementation at 0.3% in-

Table 2. Serum homocysteine concentrations (micromoles/liter) as affected by treatments on various days of blood sampling.

Day of Blood Sampling	Treatment				
	CON	**BET 0.3%**	**BET 0.6%**	**SE**	***P*-Value**
9 d	34.47	28.22	30.52	2.91	0.237
45 d	42.28	30.68	35.20	2.90	0.009
73 d	42.69	33.09	39.25	2.96	0.043

CON = control boars fed 0% betaine.
BET 0.3% = boars fed betaine at 0.3% of the diet.
BET 0.6% = boars fed betaine at 0.6% of the diet.

creased the concentration of spermatozoa in the ejaculate without impairing any other estimates of semen quality in two different genetic lines of boars (Table 1). An increase in motility was not observed in this study likely due to the fact that semen samples were extended at collection and shipped overnight from Oklahoma to Indiana, reducing overall motility estimates. Additionally, this study demonstrated blood homocysteine concentrations increased linearly in all boars during the summer months and betaine supplementation reduced blood homocysteine concentrations by 22.8 and 11.9% for the 0.3% and 0.6% supplementation, respectively (Table 2).

Sources of betaine in tissues and bodily fluids originate from the diet as well as derivation from choline within body tissues where the liver, kidney, and testes contain the greatest amounts in the male, likely regulated by osmotic stress (Slow et al., 2009). Testes betaine concentrations were not determined in our study; however, betaine supplementation to the diet resulted in an increased concentration of betaine in the seminal plasma (K. R. Stewart, unpublished data).

In summary, there is evidence that natural betaine supplementation to boars and sows can negate some of the negative impacts on reproduction from heat stress. The question of whether betaine will benefit sow reproduction when heat stress is not an issue is being addressed by a study that we have just completed. More detailed research needs to be conducted with boars under heat and disease stress.

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An Overview of the 2015 Digestive Physiology of Pigs Symposium

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Summary

The Digestive Physiology of Pigs meetings have been held triennially for 36 years. The meetings were organized in Europe initially as an information exchange between researchers working in swine physiology and nutrition. The meetings were held exclusively in Europe for many years but began to grow in their attendance. In 2003 they were held outside Europe for the first time when they went to Banff, Canada. They returned to Europe in 2006 and 2009 and then, in 2012, were held in the USA for the first time. These premier meetings have grown to an attendance of more than 400 people from more than 30 countries and serve as a venue for presentation of both basic and applied aspects of digestive physiology and nutrition. The information exchange and development of relationships among academic and industry scientists in the many disciplines related to the digestive tract of pigs is one of the most invigorating meetings currently held. Presentations from the meetings in 2006 and 2009 have been published as a special supplement to Livestock Science while those of the 2012 and 2015 meetings are published as a special supplement to the Journal of Animal Science.

DPP–North America

The first symposium of Digestive Physiology of Pigs (**DPP**) was initiated by Dr. R. Braude and was held in Shinfield, Reading, United Kingdom in 1979 with 33 scientists in attendance. Subsequently there have been symposia held triennially in France, Denmark, Poland, The Netherlands, Germany, France, Sweden, Canada, Denmark, and Spain. The 12th International Symposium on the Digestive Physiology of Pigs, DPP–2012, was held in Keystone, Colorado on May 30 - June 1, 2012 and was by all accounts a very successful event. The setting was inspiring and the weather beautiful. There were 250 abstracts accepted for presentation at the meeting and a total of 403 attendees from 28 countries. The attendees represented academia, industry, and a few major swine production entities. The countries represented with the greatest attendance at the meetings were: USA–131, Canada–47, Denmark–25, Germany–23, Netherlands and Spain–22 each, France–11, South Korea–10, Mexico–9, Sweden–8, Ireland and Belgium–7 each, and Australia, China, and Italy–6 each. There were a total of 29 sponsors. An exciting Pre-Conference Symposium, sponsored by Lucta, Inc., was held during the afternoon of May 29th with the theme of gut chemosensing.

To facilitate the activities of the DPP–2012, a non-profit entity called DPP–North America (**NA**) was established in Illinois with assistance from FASS (Federation of Animal Science Societies) in 2010. The stated mission of DPP–NA was "in cooperation with European academic colleagues, to establish triennial venues that present the most current research and discovery information relative to digestive physiology of pigs." The current Board of Directors of DPP–NA is Merlin Lindemann, President, University of Kentucky; Layi Adeola, Purdue University; Kolapo Ajuwon, Purdue University; Thomas Burkey, Secretary, University of Nebraska; Nicholas Gabler, Treasurer, Iowa State University; Brian Kerr, USDA–ARS; John Patience, Iowa State University; Rob Payne, Evonik Degussa; Chad Risley, Berg+Schmidt America; Andrew Van Kessel, University of Saskatchewan; and Ruurd Zijlstra, University of Alberta.

The mission of DPP–NA continues and some of its most recent activities have been to sponsor three graduate student travel scholarships to the DPP–2015 meetings in Poland and to initiate a lectureship at the Midwest ASAS in Des Moines each year. This lecture-

Table 1. DPP - International Steering Committee 2015-2018.

Dr. D. Braña, Mexico	Dr. C.H. Malbert, France
Dr. T. Burkey, USA	Dr. J. Michiels, Belgium
Dr. J. Freire, Portugal	Dr. J. O'Doherty, Ireland
Dr. A. Jansman, The Netherlands	Prof. A. Piva, Italy
Dr. Y.Y. Kim, South Korea,	Dr. J. Pluske, Australia
Dr. K.E. Bach Knudsen, Denmark	Dr. D. Torrallaradona, Spain
Dr. C.F.M. De Lange, Canada	Dr. A. van Kessel, Canada
Dr. P. Leterme, Spain	Prof. R. Zabielski, Poland
Prof. J.E. Lindberg, Sweden	Prof. J. Zentek, Germany

ship was initiated in 2015 and takes place over lunch between the Gary Allee Symposium and the David H. Baker Symposium. The inaugural lecture was an expansive overview of the effects of zinc oxide on gut microbiota entitled "The physiological role of zinc in the pig—does it have a Janus head?" and was given by Dr. Jürgen Zentek of the Freie Universität in Berlin.

The overall guidance for the triennial DPP meetings is provided by an international steering committee (**ISC**) of scientists from many countries and several scientific disciplines (Table 1). When the ISC grants that the meetings return to North America, DPP–NA will again have the responsibility of establishing the conference venue, planning the program and inviting speakers, advertising, and soliciting sponsors for the meetings assigned to North America.

The Most Recent DPP–2015

The 13th Digestive Physiology of Pigs Symposium was convened at Kliczków Castle near Bolesławiec, Poland on May 19 - 21, 2015 (www.dpp2015.com) with over 400 participants (Figure 1) and more than 260 abstracts (Figure 2). A pre-conference symposium, sponsored by BASF, was conducted on May 18 focusing on "Feed additives and their interactions with the pig—state of the art and future developments". The official meetings began on May 19 with the DSM award ceremony and lecture and the opening Keynote Lecture given by Knud Eric Bach Knudsen (Carbohydrates in pig nutrition—recent advances). The remainder of the symposium was divided into five sections: 1) Functional ingredients and feed processing; 2) Digestion and absorption; 3) Gut microbial ecosystem; 4) Gut maturation; and 5) Pig as a model for humans. Invited lectures were given in each section along with selected abstracts. What follows herein are brief highlights and summaries of select lectures and abstracts presented at DPP–2015 to illustrate both basic and applied presentations that will have value for the feed industry and swine production industry in the future.

Pre-conference Symposium: Feed additives and their interactions with the pig—state of the art and future developments. The scope of the 2015 Pre-conference Symposium consisted of lectures focusing on new hypotheses related to feed additives, feed additive interaction with the host organism, methodological aspects, industry requirements, and regulatory aspects.

DSM Nutritional Sciences Award. Dr. Hans H. Stein (University of Illinois) was presented with the 2015 DSM Nutritional Sciences Award recognizing his impressive career in the field of sustainable swine nutrition and research and for nurturing future talent in animal nutrition.

Keynote Lecture: Carbohydrates in pig nutrition-recent advances (Knud Erik Bach Knudsen, Aarhus University, Denmark). Dr. Bach Knudsen provided an eloquent review of carbohydrate classification and terminology, properties of starch and dietary fiber, carbohydrate fermentation, and functional properties of carbohydrate derived metabolites. Obviously, carbohydrates are a key substrate for energy metabolism; however, carbohydrates also contribute to other effects throughout the gastrointestinal tract dependent on the specific properties of those carbohydrates. For example, the rates of starch digestion, the transport of lipid digestion products, the control of gastric emptying, and satiety may all be affected by various carbohydrates. In addition, a large focus of Dr. Bach Knudsen's lecture was placed on carbohydrate by microbiota interactions. Although it is quite clear that dietary carbohydrates and dietary fiber impact the composition of microbial communities within the gastrointestinal tract, what is not quite so clear is exactly what fiber types affect which microbial populations. For example, Dr. Bach Knudsen presented data demonstrat-

Table 2. Content and standardized ileal digestibility (SID) of crude protein and amino acids in pigs fed a soybean meal (SBM) diet, a processed SBM (pSBM) diet, a rapeseed meal (RSM) diet, or a processed RSM (pRSM) diet. Processed diets refers to over-processing via addition of lignosulfonate and subsequent toasting. EAA: Essential amino acids; NEAA: Non-essential amino acids.

	SBM Diet	pSBM Diet	RSM Diet	pRSM Diet	*P*-Value Processing
CP, g/kg DM	185	189	136	138	
Lys, g/100 g CP	6.0	4.3	7.7	6.3	
Arg, g/100 g CP	6.9	5.9	5.4	4.6	
SID CP	84	72	75	65	0.001
SID Lys	86	67	76	58	0.001
SID average other EAA	87	79	81	74	0.05
SID average NEAA	85	74	78	69	0.05

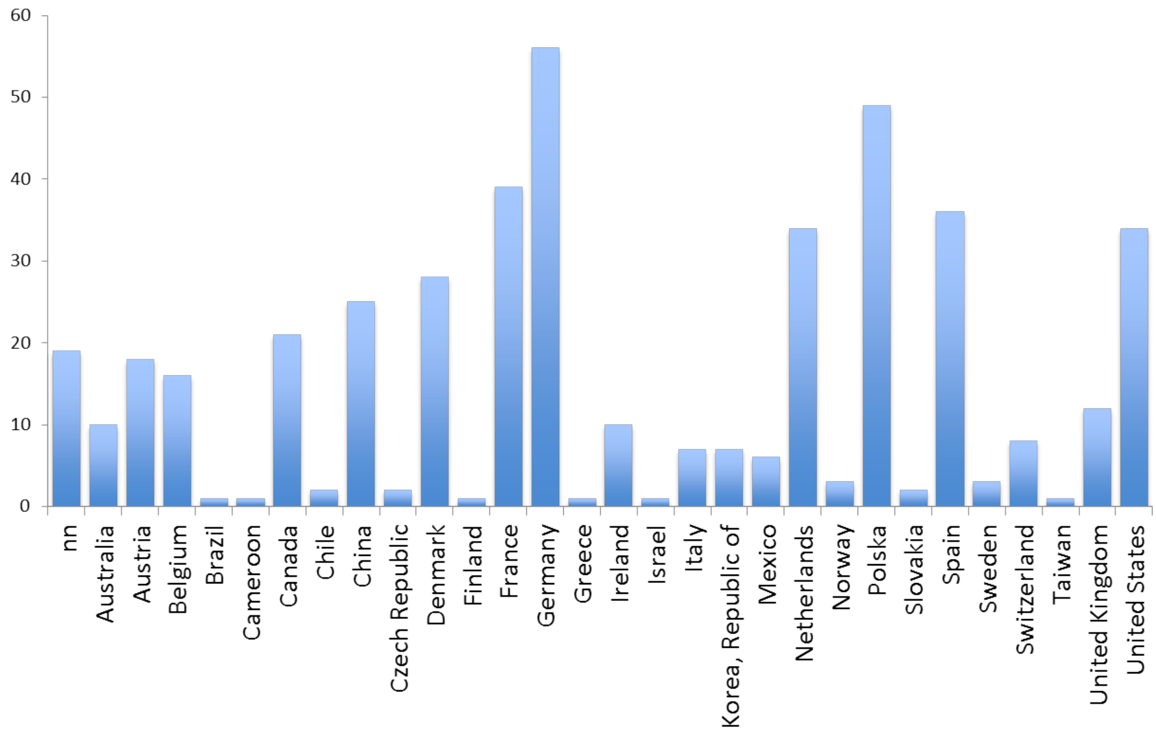

Figure 1. Country of origin of attendees of DPP-2015.

ing that diets high in dietary fiber (i.e., arabinoxylan or resistant starch) not only affect microbial community composition but also impact short chain fatty acid production (Figure 3). Dr. Bach Knudsen concluded his presentation with intriguing thoughts on the effects of resistant starches on gene expression and the functional properties of carbohydrate derived metabolites and their roles as signaling molecules. Clearly, there is a large area of opportunity in delineating the effects of specific fiber types in the gastrointestinal environment and defining how these effects impact metabolic pathways.

Section 1: Functional ingredients and feed processing. "Approximation of the amino acid composition and bio-functional properties of current and novel protein sources for pigs" was presented by S. Kar et al., Host-Microbe Interactomics, Wageningen University, The Netherlands. The objective of this work was to characterize and quantify individual proteins contained within various protein (traditional and novel) sources using mass-spectrometry (**MS**). Due to increased demand for pork and the increasing cost of protein sources needed to feed pigs, alternative protein sources are required which also creates a need to better define the physiological effects of these novel protein sources. This work was carried out to begin to characterize and to predict functionality of novel/alternative protein sources. Currently, protein analyses are somewhat limited to providing information about total protein and amino acid content with little information on the presence, abundance and functionality of individual peptides liberated by digestive processes. This work represents an initial step in using MS-based proteomic and peptidomic analyses combined with genomics and bioinformatics tools to provide a greater depth of knowledge of individual peptides and their bioactive potential in complex matrices. In this experiment, protein sources evaluated included casein, partially delactosed whey powder, spray-dried porcine plasma, soybean meal, wheat gluten meal, and yellow meal worm. In addition to providing detailed information on composition of complex protein sources, this work also may provide a means to predict bio-functional properties of protein sources. For example, the bioinformatics analysis revealed that select protein sources may be rich in angiotensin-converting enzyme inhibitors and antioxidants. The potential impacts of MS-based approaches for protein analysis include increased quality control, precise monitoring of effects of feed processing, and the potential for studying protein digestion kinetics.

Section 2: Digestion and absorption. "Over-processing negatively affects digestibility and post-absorptive utilization of protein in growing pigs" was a presentation by T. Hulshof et al., Animal Nutrition Group, Wageningen University, The Netherlands. The objective of this work was to determine the effect of over-processing, using a model of lignosulfonate addition and subsequent toasting (95°C for 30 min), on standardized ileal digestibility (**SID**)of protein and amino acids and post-absorptive utilization of protein from soybean meal and rapeseed meal. As expected, over-processing decreased crude protein and lysine SID (Table 2). In addition, over processing also decreased the post-absorptive utilization (i.e., the amount of nutrient retained/amount of nutrient absorbed) of crude protein and amino acids and these effects were dependent on protein source.

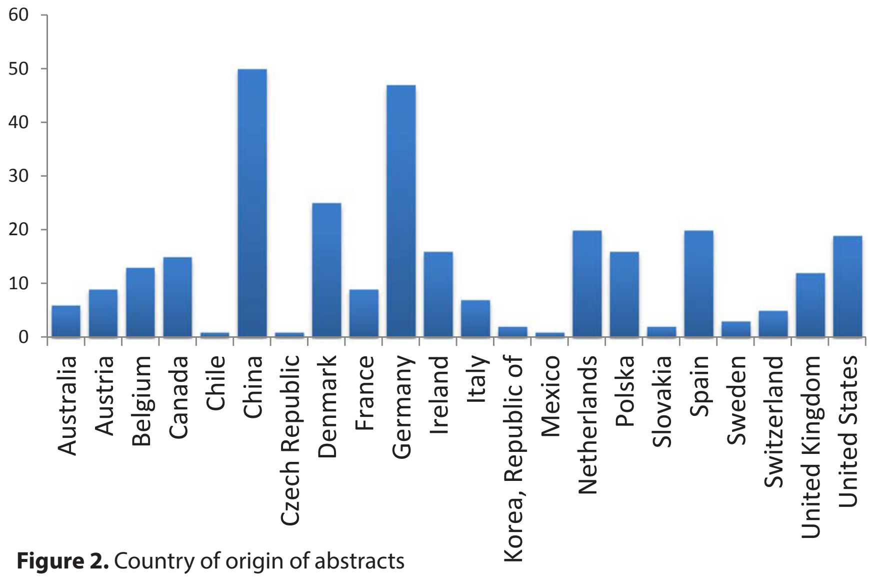

Figure 2. Country of origin of abstracts presented at DPP–2015.

Section 3. Gut microbial ecosystem. "Effects of dietary resistant starch content on nutrient digestibility and fecal metabolomics profile in growing pigs" was given by K.M. Ajuwon et al., Purdue University. Resistant starch (**RS**) resists enzymatic digestion in the small intestine but is fermented in the hindgut producing short chain fatty acids such as acetate, propionate, and butyrate. In this experiment, high-amylose corn (considered a rich source of RS) was utilized to determine the effects of dietary RS content on apparent ileal digestibility, apparent total tract digestibility, and hindgut fermentation, as well as on fecal metabolomics profile. As expected, RS decreases nutrient and energy digestibility accompanied by an increase in hind gut fermentation. A novel aspect of this work was to use metabolomics to identify biomarkers associated with pig metabolism in response to RS and to determine if fecal water is an adequate biofluid to identify those biomarkers. The non-targeted metabolomics analysis revealed differences, including 97 different metabolites, between low- and high-RS diets. For example, L-acetylcarnitine increased with the addition of RS which may have implications for energy metabolism. The use of metabolomics, particularly as we invest in knowing more about novel dietary ingredients, will certainly become more useful in revealing a more global view of outcomes associated with changes in diet.

Section 4. Gut maturation. "Porcine epidemic diarrhea virus negatively impacts the jejunum protein profile in pigs" was presented by N. Gabler et al., Iowa State University. The objective of this work was to evaluate the jejunum protein profile (using 2D-differential gel electrophoresis and electrospray mass spectrometry) of pigs challenged with porcine epidemic diarrhea virus (**PEDV**) to identify novel proteins that may help to explain how pigs perceive and adapt to the presence of the virus. The long-term goal of this work is to develop strategies to enhance intestinal resolution/restitution in pigs that have been exposed to PEDV. Proteins of interest that were identified, for example, included glucose regulated protein, calreticulin, prolyl-hydroxylase beta,

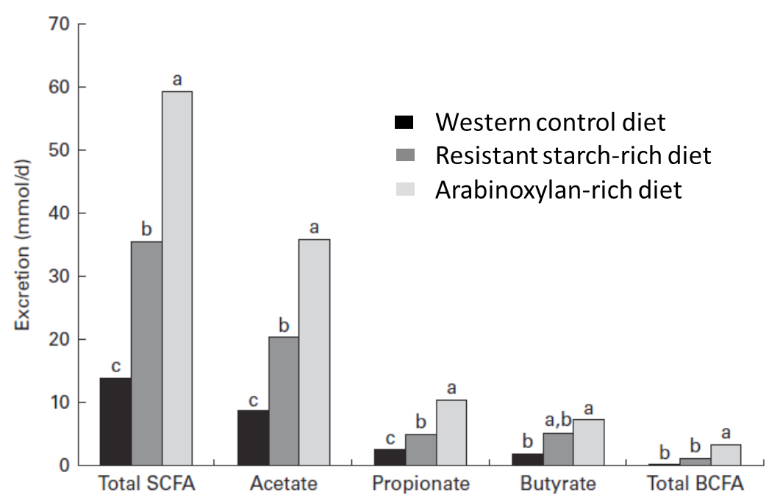

Figure 3. Daily fecal short chain fatty acid (SCFA) and branched chain fatty acids (BCFA) excretion (mmol/d) in pigs fed a western control diet, a resistant starch-rich diet, or an arabinoxylan-rich diet. [a,b,c] Mean values with unlike letters were significantly different ($P \leq 0.05$). Modified from Ingerslev et al. 2014. British Journal of Nutrition. 111: 1564-1576.

and heat shock protein 60 among others. Together, proteins identified using this approach indicate changes in immune response, cell proliferation/ differentiation, intestinal barrier function, and metabolism.

After concluding remarks by Drs. Romuald Zabielski and Jürgen Zentek (DPP–2015 Co-chairs for the official DPP–2015 meetings), the symposium was followed with a post-conference workshop of the European Cooperation in Science and Technology (**COST**) Action FA1401. COST Action 1401 is a European network (PiGutNet; www.pigutnet.eu) exploring the factors affecting the gastrointestinal microbial balance and the impact on the health status of pigs. The PiGutNet was initiated following the realization that the 'hoped for' reduction in antibiotic use by pork producers in the European Union had not materialized and that the wide use of antibiotics for control of enteric diseases is still a threat to consumer health via the potential spread of antibiotic resistance. Thus, the goal of the PiGutNet is to define environmental and host genetic factors affecting the gastrointestinal microbiota and the complex interactions between microbiota and gut maturation in order to maintain a healthy gut throughout life.

The next Symposium, the 14th Digestive Physiology of Pigs Symposium, will be conducted in August of 2018 in Brisbane, Australia. We hope to see you there!!

2014 Conference

Bobby Moser, Vice President and Dean Emeritus,
The Ohio State University, Keynote Speaker

Knud Erik Bach Knudsen, Aarhus University, Denmark,
International Speaker

John Patience, Iowa State University

Hans Stein, University of Illinois

Ryan Dilger, University of Illinois

Dale Rozeboom, Michigan State University

2014 Conference

Don Mahan, The Ohio State University

Brian Richert, Purdue University

Gretchen Hill, Michigan State University, Moderator

Jim Pettigrew, University of Illinois, Moderator

Roast pork loin lunch.

Midwest Swine Nutrition Conference

Company/Organization Years of Sponsorship

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