17th Annual Midwest Swine Nutrition Conference Proceedings

Indianapolis, Indiana—September 7, 2017

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Midwest Swine Nutrition Conference

Schedule of Presentations

8:15 a.m.	Registration
9:00	Welcome and Introductions *Merlin Lindemann, University of Kentucky*
9:05	Academic/Industry Partnerships: Personnel and Research for the Future Swine Industry *Robert A. Easter, President Emeritus, University of Illinois*
9:50	Of Fiber, Carbohydrases, and Pigs *Hans H. Stein, University of Illinois*
10:25	Break
11:00	Effect of Nutrition on Sow Behavior *Brian Richert, Purdue University*
11:30	Is There Antioxidant Protection for Sows and Nursery Pigs with Additional Vitamins A, D, and E? *Gretchen Myers Hill, Michigan State University*
12:00	Lunch
1:00	The 2018 Farm Bill: Its Potential Impact on Animal Agriculture *Lowell W. Randel, The Randel Group, Alexandria, VA*
1:35	Modern Plant Breeding and the Improvement of Corn Hybrids and Soybean Varieties *Sara Larsson and Charlie Zila, Dupont Pioneer*
2:10	Break
2:40	Mycotoxins: When, Where, and Why *Charles Woloshuk, Purdue University*
3:15	Inflammation: Costs and Control *Kirk C. Klasing, University of California, Davis*

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Academic/Industry Partnerships: Personnel and Research for the Future Swine Industry

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Summary

There is a rich history of a strong and productive relationship between the research and educational programs in the various disciplines of swine science housed in colleges of agriculture and the producers and industries associated with pork production. Both the swine industry and the academic enterprise have evolved greatly over many decades and change continues to occur. Continued progress in the quest to efficiently and sustainably meet the animal protein needs of the human population will depend very substantially on innovation and that in turn on the availability of individuals with necessary competencies to do the relevant research, development, and implementation of technologies.

In an era of changing priorities and seemingly ever-diminishing public support for agricultural research, especially applied research, it is reasonable to ask where future swine industry research will be done and, directly related to that, where the next generation of agricultural scientists will be trained. It is unlikely that academic colleges of agriculture will have the human capacity or the necessary facilities to do this work alone. Consequently, it is likely that the effort will increasingly be mounted through collaborative model involving both industry and the academic community.

First, Some Background

The Morrill Act of 1862 lead to the establishment of a Land-Grant University in every state with a mandate to do both research and education in agriculture. That community of scholars was expanded to include historically black colleges and universities by the second Morrill Act of 1890 and was further to include institutions serving Native American communities by the Improving America's Schools Act of 1994.

The Hatch Act of 1887 authorized the appropriation federal funds in support of agricultural research to be allocated by formula to agricultural experiment stations operated by the each state's Land-Grant University. That funding has been reauthorized continuously since 1887 and other specific authorizations have been added as well. It is reasonable to say that support, along with matching and other funds from state governments provided the majority of support for swine research for the first three-fourths of the 20th Century. It was that research that provided the basis not only for new discoveries but was at the same time the vehicle for training generations of swine scientists.

It was during the Second World War that the nation discovered the immense capacity of universities to contribute to the research needs of the country. As that conflict drew to a close and a national dialogue about the most appropriate strategy for implementing the research necessary for the so-called "Cold-War" began to unfold.

Dr. Vannevar Bush, a key figure in the national research effort during World War II, was tasked to lead the development of a national strategy. The resulting report spoke to the role of universities in this way. *"These institutions are uniquely qualified by tradition and by their special characteristics to carry on basic research"* (Bush, 1945). The transfer of discoveries into application was to be primarily the responsibility of industry. This became the national paradigm with the formation of the National Science Foundation to fund basic research in universities. Agencies created subsequently, e.g., the National Institutes of Health, have generally followed the same model.

Without doubt this approach has served the nation well and, arguably, much of the progress made in production agriculture in recent decades is grounded in technologies based on fundamental discoveries made through basic research and the development of products by industry from the new knowledge.

Historically, faculty in agricultural colleges not only did basic science but also focused significantly on trans-

lation of new understandings of fundamental phenomena to technologies directly relevant to the needs of farmers and associated industries. Funding for university work of that nature has not grown significantly in recent decades. The Department of Agriculture (**USDA**) is the primary vehicle for this support and the data in Table 1 reflect the reality that a very small amount (just over 4%) of the U.S. government's investment in universities is in agricultural research.

It is the case that research funded by other agencies, e.g., National Institutes of Health, which employees the pig as a model species for biomedical research and knowledge derived from that work does contribute significantly to the understanding fundamental aspects of pig biology.

The USDA funding allocated for university research is managed by the National Institute for Food and Agriculture (**NIFA**). The major research programs are shown in Table 2.

The Agriculture and Food Research Initiative (**AFRI**) is a competitive grants program for agricultural sciences that includes both research, education, and extension elements. The Hatch Act directs funds by formula to agricultural experiment stations in the 50 states and the District of Columbia and insular areas. The Evans-Allen Program provides research funding to the 1890 (historically black) land grant colleges. The other titles are self-explanatory. Funding for each has remained relatively constant with inflation over the last decade with the exception of AFRI which has grown somewhat more.

Deans of agricultural colleges and department heads make programmatic decisions based on many factors including student interest (i.e., enrollment), availability of research funding, availability and overhead cost of operating facilities for specific research, and to the extent possible, needs of the state's agricultural industries.

Historically, the cost of hiring faculty and operating laboratories was almost completely borne by state appropriations. To a greater or lesser extent at each Land-Grant university these costs are increasingly being shifted to student tuition. Thus, an administrator is compelled to grow programs with significant enrollment and remove support from those programs that are revenue negative. Across the country student enrollments in swine-related programs have been in decline for decades.

As a consequence of these considerations there has been a decline nationwide in programs directed at swine research directly applicable to the needs of the industry. This change is not unique to the pork sector.

Historically, much of agricultural research was done in the public sector, primarily by state agricultural research stations and the USDA laboratories. That relationship began to change in the early 2000's with a gradual decline in public funding and a rapid increase in work done within industry laboratories. In 2010 the contributions were roughly equivalent and the private sector investment continued to grow in the following years while the public sector trended downward at an increasing rate (data from Clancy et. al., 2016).

The public-private segmentation varies by industry. King et al. (2012) reported that the private sector investment in crop research exceeded the public investment while the public investment in animal research is greater.

Some Alternative Scenarios

Given the factors discussed above it seems unlikely that the swine industry's reliance on public sector research and workforce preparation will be sufficient in the years ahead. Around the world others have faced similar challenges and there are several models of formal public-private enterprises that are useful to consider.

Prairie Swine Centre

The research unit was originally established by the University of Saskatchewan in 1980. A review of the operation involving industry representatives was conducted seven years later and a decision was made to shift to a greater involvement with industry and other government agencies. The Centre supports research in nutrition, ethology, and engineering (facilities) and provides

Table 1. Federal Science and Engineering Support to Universities and Colleges FY 2014[a]

Federal entity	Total Dollars (thousands)
Department of Defense	3,696,131
Department of Energy	1,503,607
National Institutes of Health	17,100,186
National Science Foundation	4,982,327
Department of Agriculture	1,300,375
Total Federal Funding	30,762,640

[a] NSF 2014

Table 2. FY2016 Consolidated Appropriations for Selected Titles in NIFA.[a]

Program Areas	Total Dollars (thousands)
Agriculture and Food Research Initiative (AFRI)	$350,000
Hatch Act	$243,701
McIntire-Stennis Cooperative Forestry	$33,961
Evans-Allen Program	$54,185
Animal Health and Disease Section 1433	$4,000
Minor Crop Pest Management	$11,913
Sustainable Agriculture Research and Education Program	$24,667

[a] USDA (2016)

educational programs to the industry as well as providing significant graduate student training opportunities through a close relationship with the University of Saskatchewan and other universities. The research mission is described in the following statement:

> *"The research program seeks to fill a niche identified by the pork industry, to conduct near market research that can be applied within a one to seven year time frame. Because of those close linkages with the commercial pork industry, technology transfer is emphasized as a central part of the Centre's operation"* (Prairie Swine Center, 2017).

The Centre is overseen by a Board of Directors that includes both industry and academic representatives and is managed by a Chief Executive Officer. The 2015-16 report lists the following as major financial supporters: Agricultural Development Fund (ADF) Alberta Pork Producers Development Corporation Manitoba Pork Council Saskatchewan Pork Development Board Ontario Pork Producers' Marketing Board.

PorkCRC

A different model was PorkCRC established in Australia in 2011. It is a quasi-independent entity with a 10-person board having both academic and private sector/industry members. PorkCRC was established under the Australian Government Department of Industry, Innovation and Science Cooperative Research Centres Program. It should be noted that New Zealand is participant in the organization and one board member is from that country. Executive leadership is provided by Dr. Roger Campbell, a globally recognized leader in swine science who has both significant academic and industry experience (PorkCRC, 2017).

The mission of PorkCRC is broad: *"To differentiate Australian pork as a 'high integrity' meat that is welfare-optimal, premium quality, nutritious, in high demand nationally and internationally, and which is produced while conserving energy and water, minimizing greenhouse gas emissions and maintaining efficiency and cost of production at levels which encourage investment, growth and sustainability"* (PorkCRC, 2016). And, it appears to draw on virtually every discipline of swine science.

Revenue for PorkCRC in 2016 was $18,891,594 (Australian dollars) and included funds from both government sources as well as private sector contracts. The enterprise supports research as well as sustaining necessary facilities and the capacity to do the research. Some of the work is done by universities while other projects are executed by consultants and private sector organizations. There is a means for commercialization of products that emerge from projects. The website provides an impressive summary of accomplishments.

Danish Pig Research Centre

This enterprise is also known as SEGES Pig Research Centre. The staff conduct research on swine production topics and disseminates knowledge derived from the work. According to the 2015 annual report funding was in the amount of 130 million (roughly 20 million U.S. dollars) or 60 cents per pig. Funds are collected somewhat similar to the U.S. pork checkoff. The enterprise is governed by a board of 12 farmers who are elected by the Danish Agricultural and Food Council (Pig Research Centre, 2017).

Both the reports and the detailed information on the website confirm that the effort is comprehensive including effort in maintenance of industry statistical data and work in genetics, nutrition, environment, housing, welfare, health, and production management. The research is largely carried out by staff using commercial swine operations as experimental sites. In addition to research and education the organization has responsibility for promotion of the industry and engaging with government on behalf of the farmers. The productivity and efficiency of the Danish industry testifies to the effectiveness of the model.

There are two Danish universities with animal science programs but the faculty there do very little applied research. If there is a student interested in doing applied work, they will conduction the research in collaboration with the Pig Research Centre (Hans H. Stein, personal communication).

CREA (Consorcios Regionales de Experimentacion Agricola)

This model is based in Argentina and grew out of the inconsistent capacity of national agencies under different governments to meet the needs of agriculture (CREA, 2017). It is a somewhat different model being composed of small groups of farmers within regions which are connected through a national organization (AACREA). Typically a group will employ an agronomist (crop or livestock specialist) as an advisor. Data and experience within the group are shared and forms the basis for self-improvement. (Maria B. Villamil, personal communication). In some respects CREA is analogous to the local advisor system that existed in the U.S. prior to the establishment of the Cooperative Extension System.

Summary

Declining public support for applied swine research coupled with decreasing student interest in pork production and the over-arching national strategy directing universities to give focus to discovery research point to a continued reduction in the capacity of academic programs to fully address the research needs of the swine industry nationally. This in turn affects the availability of a qualified workforce because of the linkage of research programs to the preparation of the next generation of professionals in the key disciplines such as reproduction, nutrition, meat science and muscle biology, economics, housing, etc.

This research and educational challenge is not unique to the United States and is being addressed in variety of ways as described in the preceding section. With the exception of PorkCRC the other models have been in operation for multiple decades. That would seem to indicating that a real need is being met.

One can only speculate about the nature of an entity or a system of entities that might serve the U.S. swine industry but, it seems at least some characteristics can be defined. It is likely that the majority of funding would come from swine and related industries and the governance structure would reflect that. The focus would be on research directed at clearly defined problems of importance to the industry. And, there would be a significant partnerships with relevant academic units to both facilitate preparation of individuals to meet workforce needs including graduate training and, importantly, to insure access to concepts and technologies emerging from university laboratories.

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Of Fiber, Carbohydrases, and Pigs

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Summary

Fiber in cereal grains and cereal grain co-products typically used for pigs include cellulose, arabionoxylans, betaglucans and xyloglucans and fibers in the oilseed meals include cellulose, rhamnogalacturonans, arabinogalactans, arabinans, xyloglucans, and galactomannans. Arabinoxylans and some of the fibers in oilseeds may be esterified to lignin, which reduces the likelyhood of fermentation. Because the microbes in the hindgut of pigs are relatively ineffective in fermenting most of the dietary fibers, exogenous enzymes are often included in the diets. However, because all fiber components require more than one enzyme for hydrolysis, inclusion of single enzymes has often been unsuccessful in improving fiber fermentation. It is possible that by including mixtures of carbohydrases that target the same fiber component, fermentability can be increased and the energy obtained from fiber in diets fed to pigs may be improved.

Introduction

The major carbohydrate in cereal grains is starch and in most cereal grains, the nonstarch polysaccharide (**NSP**) fraction is less than 15%. In contrast, most co-products from cereal grains have only small concentrations of starch whereas NSP is the greatest proportion of the carbohydrates. The primary NSP in cereal grains and cereal grain co-products are cellulose, arabinoxylan, and mixed-linked β-glucans, and smaller quantities of xyloglucans may also be present (Figures 1 and 2). However, concentrations of the different fiber fractions may vary among cereal grains in terms of structure, proportions, and crosslinkages to other compounds (Theander et al., 1989; Bach Knudsen, 1997; Bach Knudsen, 2011).

In legumes and oilseeds, there is also a considerable amount of cellulose in the NSP fraction, but unlike cereal grains, arabinoxylans and mixed linked beta-glucans are not present in these ingredients (Table 1). Instead, the non-cellulosic NSP fraction in oilseeds primarily consists of pectic polysaccharides such as rhamnogallactans, arabinogalactans, arabinans, and galactomannans (Selvendran et al., 1988; de Vries et al., 2012). Many of the NSP in cereal grains as well as in oilseed meals are esterified to lignin, which reduces their water solubility.

Figure 1. Percentages of mixed linked betaglucans (MBM) and arabinoxylans (AX) in cereal grains (from Navarro, 2015, unpublished).

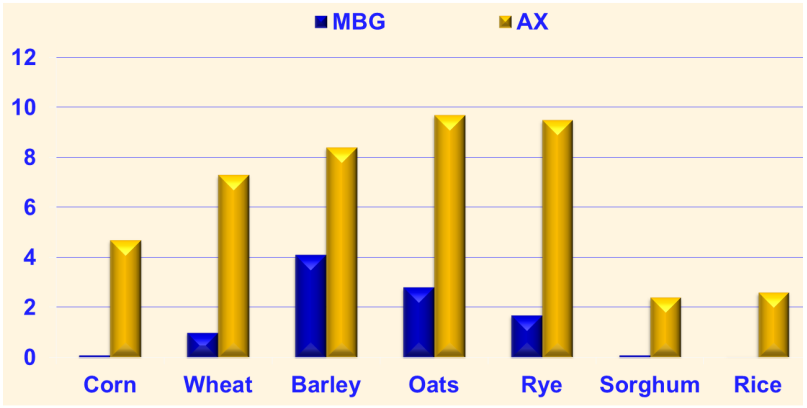
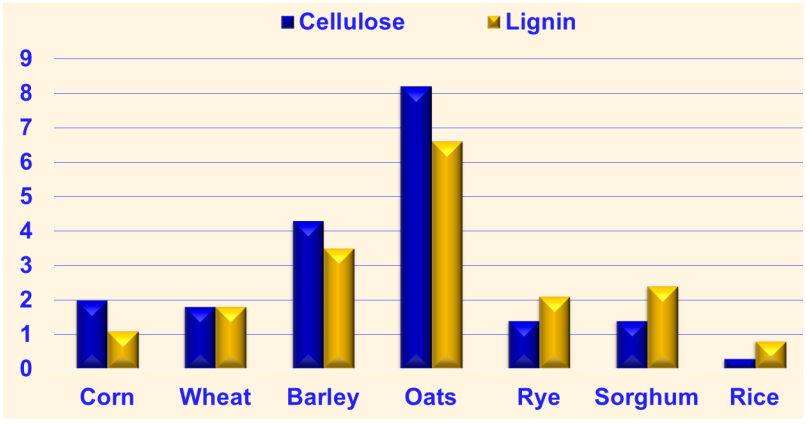


Figure 2. Percentages of cellulose and lignin in cereal grains (from Navarro, 2015, unpublished).



The combination of NSP and lignin is called fiber and by definition, fiber cannot be digested by enzymes that are expressed by animals. However, some of the fi-

Table 1. Types of nonstarch polysaccharides in cereal grains and oilseed meals (from Navarro, 2015, unpublished).

Cereal grains	Oilseed meals
Cellulose	Cellulose
Arabinoxylans	Homogalacturonans
Mixed linked beta-glucans	Xylogalacturonans
Xyloglucans	Rhamnogalaturonan I
(Lignin)	Rhamnogalacturonan II
	Arabinogalactan I
	Arabinogalactan II
	Arabinans
	Galactomannans
	(Lignin)

ber may be digested by enzymes expressed by microbes in the intestinal tract of pigs, but the degree to which this takes place depends on the fiber that is fed and the total number of microbes that reside in the intestinal tract, which is largely determined by the size of the intestinal tract. Thus, sows or older pigs have more microbes in the intestinal tract than younger pigs because they have larger intestinal tracts, and certain indigenous pigs have larger intestinal tract than domesticated pigs, which results in greater quantities of microbes in the intestinal tract. The number of microbes in the intestinal tract is directly related to the quantites of fiber digesting enzymes that are secreted and thus to the total amount of fiber that may be hydrolyzed in the intestinal tract. As a consequence, sows have greater hydrolysis of fiber than growing pigs (Le Goeff and Noblet, 2001), and indigenous pigs have greater hydrolysis than domestic pigs (Urriola and Stein, 2012).

The monosaccharides that are released from hydrolysis by microbial enzymes may be absorbed if the hydrolysis takes place in the small intestine. However, because the number of microbes in the small intestine of pigs is limited, the majority of hydrolysis of fiber takes place in the cecum and the colon (Jaworski and Stein, 2017), and there is no absorption of monosaccharides in this part of the intestinal tract. Instead, microbes will metabolize the monosaccharides and the coproducts from this metabolism are water, carbon dioxide, methane, and short chained fatty acids. Only methane and short chain fatty acids contain energy, but methane is release from the intestinal tract via the anus, whereas short chain fatty acids may be absorbed and metabolized by the animal. Thus, fermentation of fiber may contribute to the energy status of the animal and depending on the type of diet that is fed and the physiological state of the pig, energy obtained from metabolism of short chain fatty acids may satisfy more than 30% of the energy requirement of the pig. Thus, fiber fermentation may play a significnat role in the overall energy metabolism of pigs.

Table 2. Monosaccharides in fiber.

Group	Monosaccharide
Pentoses	Arabinose, xylose
Hexoses	Glucose, galactose, mannose, fructose
Deoxy-hexoses	Rhamnose, fucose
Acidic sugars	Glucuronic acid, galacturonic acid, mannuronic acid, aceric acid

Composition of Fiber in Feed Ingredients

Most fiber present in feed ingredients is composed of a common set of 12 monosaccharides (Table 2). Two of these are the pentoses arabinose and xylose, which are present in many of the non-cellulosic NSP. Four hexoses including glucose, galactose, mannose, and fructose are also present in many NSP with glucose being by far the most dominating of these hexoses. Three of the hexoses, glucose, galactose, and mannose, may be modified at the C-6 position, where an acidic group is attached instead of the CH_2OH group. This will yield the acidic hexoses glucuronic acid, galacturonic acid, and mannuronic acid. The branched chained sugar, aceric acid, which is synthesized from xylose, is also present in one of the pectic polysaccharides in oilseeds. If the hydroxyl group at the C-6 position of galactose and mannose is missing, the 2 deoxy sugars fucose and rhamnose are synthesized, which may also be used in the synthesis of specific fibers. Thus the 12 common monosaccharides provide the building blocks for most of the fibers that are present in feed ingredients fed to pigs.

Cellulose

Cellulose is composed of 7,000 to 15,000 glucose units that are linked by β-(1-4) glycosidic bonds and is insoluble in water, alkali, and dilute acids because of the linear arrangement of glucose units, which allow them to pack tightly (BeMiller, 2007; Cummings and Stephen, 2007; Bach Knudsen, 2011). Cellulose is composed of varying proportions of crystalline and amorphous regions. Crystalline regions have a more rigid structure compared with the amorphous region because of linkages between the linear glucose structures by hydrogen bonds, making crystalline cellulose less susceptible to fermentation. However, amorphous regions of cellulose have a less rigid structure because of fewer hydrogen linkages and are, therefore, more fermentable (Ciolacu et al., 2011). For complete fermentation of cellulose with a subsequnet liberation of glucose, the enzymes endoglucanase, cellodextrinase, and β-glucosidase are needed (Duan and Feng, 2010). All 3 enzymes are expressed by microbes, but because of the slow action of these enzymes, fermentation of cellulose in the hindgut of pigs is limited.

Arabinoxylans

Arabinoxylans are polysaccharides composed of a backbone of xylose units linked by β-(1-4) glycosidic bonds. The backbone of arabinoxylans is highly substituted by arabinose and some of these may be linked to ferulic or coumaric acids that may be esterified to lignin (de Vries, 2003). The xylose backbone may also be linked to xylose, glucuronic acid, galactose, and acetyl. Arabinoxylans may be water soluble or insoluble, which is determined by the ratio between arabinose and xylose (Ebringerová, 2005). Water soluble arabinoxylans, which have an arabinose:xylose ratio of 1:1 to 1:2, are highly viscous, have the ability to form gel, and do not interact with other cell wall components. In contrast, water insoluble arabinoxylans have an arabinose:xylose ratio of 1:3 to 1:5 and have strong water holding capacity and are difficult to isolate because they are connected to protein, lignin, and phenolic acids present in the cell wall (Ebringerová, 2005). Complete hydrolysis of arabinoxylans requires at least 9 enzymes: β-(1-4)-endoxylanases, β-(1-4)-xylosidases, β-(1-4)-galactosidases, α-arabinofuranosidases, arabinoxylan α-arabinofuranohydrolases, α-glucuronidases, acetyl xylan esterases, and ferulic or coumaric acid esterases (Dodd and Cann, 2009). The ferulic and coumaric esterases are likely the most important enzymes because they will result in delignification of arabinoxylans, which is a prerequisite for microbial fermentaion.

Mixed Linked β-glucans

Mixed-linked β-glucans are present in grasses and in the endosperm and subaleurone layer of cereal grains. Mixed-linked β-glucans are composed of a backbone of glucose units linked by β-(1-3) and β-(1-4) glycosidic bonds on a ratio of 1:2 to 1:3, preventing the glucose units from packing tightly, thereby making them water soluble (Ebringerová, 2005). Complete hydrolysis of mixed-linked β-glucans requires the enzymes β-(1-3)-glucanase and β-(1-4)-glucanase (Schwarz et al., 1987). Both enzymes are expressed by hindgut microbes and β-glucans are, therefore, easily fermented in the hindgut of pigs.

Xyloglucans

Xyloglucans are the main non-cellulosic NSP in the primary cell walls of dicotyledons, accounting for about 20% of the dry mass in the cell wall (O'Neill and York, 2003). Xyloglucans coat, cross-link, and form hydrogen bonds with the cellulose microfibrils in the primary cell wall of plants and serve as seed storage carbohydrates (Zhou et al., 2007). Xyloglucans are composed of a backbone of glucose units linked together by β-(1-4) glycosidic bond and side chains of xylose and galactose units. The xyloglucan backbone is composed of repeating units of 3 consecutive glucose units that have substituted side cahins followed by 1 unsubstituted glucose residue. The xylose side chain may be further substituted by arabinose, α-galactose, β-galactose, or fucose units that may be linket to O-acetyl. Complete hydrolysis of xyloglucans requires at least 8 enzymes including exo-β-(1-4) glucanases, endo-β-(1-4) glucanases, xylosidase, α -L-galactosidases, β-D-galactosidases, α-L-fucosidases, α-L-arabinofuranosidases, and xyloglucan acetylesterases (de Vries, 2003).

Pectic Polysaccharides

Pectins or pectic polysaccharides are polysaccharides composed of many different monosaccharides, and have the most complex structure among dietary fiber (Vincken et al., 2003; Wu and Mort, 2014). Pectins include unsubstituted homogalacturonan, rhamnogalacturonan II, xylogalacturonan, rhamnogalacturonan I, Arabino galactan I, and Arabino galactan II.

Homogalacturonans. Homogalacturonan is composed of a backbone of galacturonic acids linked by α-(1-4) glycosidic bonds that may be methyl-esterified or acetylated. More than 60% of pectins in the cell wall of plants is composed of homogalacturonans (Ridley et al., 2001). Homogalacturonan with low degree of esterification to methyl is referred to as pectic acid or pectate, whereas homogalacturonan that is highly esterified is called pectin. Complete hydrolysis of the homogalacturonans backbone requires pectin lyases, pectate lyases, endopolygalacturonases, exopolygalacturonases, and pectin methyl esterase (Gamauf et al., 2007; van den Brink and de Vries, 2011).

Xylogalacturonans. Xylogalacturonans are composed of a homogalacturonan backbone substituted either by a xylose unit or by a disaccharide composed of 2 xylose units, with degree of xylosylation between 25 and 75% (Vincken et al., 2003). Complete hydrolysis of xylogalacturonan requires the enzymes exopolygalacturonases, endoxylogalacturonases, and xylosidases (van den Brink and de Vries, 2011).

Rhamnogalacturonan II. Rhamnogalacturonan II comprises about 10% of the plant cell wall pectin in higher plants (Pabst et al., 2013) and is composed of 12 different monosaccharides, 21 different glycosidic bond, and the homogalacturonan backbone is substituted by complex side chains A and B and by simple side chains C, D, E, and F (Ndeh et al., 2017). Rhamnogalacturonan II structure is very complex, but highly conserved among plants (Pabst et al., 2013) and typically resist degrada-

tion by pectin enzymes (Vidal et al., 2000). Ndeh et al. (2017) recently described in great detail the structure of rhamnogalacturonan II and the enzymes needed for hydrolysis. Degradation of rhamnogalacturonan II starts with backbone depolymerization followed by side chain hydrolysis carried out by 20 distinct enzymes including polysaccharide lyase, rhamnosidases, glucuronidases, arabinofuranosidases, galacturonosidases, arabinopyranosidases, aceric acid hydrolases, inverting enzymes, endo-apiosidases, DHA-hydrolase, and pectin methylesterases (Ndeh et al., 2017).

Rhamnogalacturonan I. Rhamnogalacturonan I is composed of a backbone of alternating units of rhamnose and glacturonic acids linked by glycosidic bond α-(1-4) and side chains that are attached to either backbone units. Single units of galactose and/or arabinose as well as polymers of arabinan, galactan, and arabinogalactan may substitute rhamnose residues from 20 to 80%, whereas acetyl may substitute the galacturonic acid residues (Vincken et al., 2003). Enzymes needed for hydrolysis of rhamnogalacturonan I include α-arabinofuranosidases, endoarabinanases, exoarabinanases, β-1,4-endogalactanases, β-galactosidases, rhamnogalacturonan acetyl esterases, rhamnogalacturonan lyases, endorhamnogalacturonases, exorhamnogalacturonases, and feruloyl esterases (van den Brink and de Vries, 2011).

Arabinogalactan I. Arabinogalactan I is composed of a backbone of galactose units linked by β-(1-4) glycosidic bond and may be substituted by arabinose at the O-3 position of galactose residues in varying proportions (de Vries and Visser, 2001). Arabinogalactan I is present in different tissues of higher plants, but not in grasses and cereals (Clarke et al., 1979; Stephen, 1983; Van De Vis, 1994), and subdivided into linear homogalactans, branched homogalactans, galactans substituted with arabinose, and galactans substituted with uronic acid (Van De Vis, 1994).

Arabinogalactan II. Arabinogalactan II is composed of a backbone of galactose units that are linked by β-(1-3) glycosidic bond substituted by galactose units linked by β-(1-6) glycosidic bond. Arabinogalactan II is often co-extracted with proteins. The arabinogalactans may be completely hydrolyzed by endogalactanases, exogalactanases, arabinofuranosidases, and galactosidases (de Vries and Visser, 2001).

Arabinans. Arabinans are composed of a backbone of arabinose units linked by α-(1-5) glycosidic bonds and side chains of arabinose units at O-2 and/or O-3 position and in some cases by ferrulic acids. Pectins with side chain of arabinans are present in apple, sugar beets, rapeseed, apricots, tomatoes, carrots, cabbage, mung bean hypocotyl cell wall, horse bean roots, onions, and pears. Feruloylated arabinans are present in spinach. Arabinans are hydrolyzed by arabinofuranosidase and endoarabinases (Caffall and Mohnen, 2009).

Galactomannans. Galactomannans are composed of a backbone of mannose units linked by β-(1-4) glycosidic bonds and side chain of galactose units linked by β-(1-6) glycosidic bonds in varying amounts (Southgate and Spiller, 2001; BeMiller, 2007). Galactomannans are mainly present in the endosperm of all leguminous seeds, and are also present in coconut, coffee, and several palm species (Nishinari et al., 2007). Complete hydrolysis of galactomannans requires β-(1-4)-mannanase, β-(1-4)-mannosidase, and α-(1-6)-galactosidase (Kim et al., 2003).

Disappearance of Fiber in the GI Tract

The structure and physicochemical characteristics of NSP influence the disappearance of NSP along the intestinal tract (Bach Knudsen, 2001). Polysaccharide degradation is determined by the chemical structure, solubility, and degree of lignification (Bach Knudsen, 2011). Mixed-linked β-glucans, soluble arabinoxylans, and pectins are primarily degraded in the cecum and proximal colon, whereas the insoluble NSP such as cellulose and insoluble arabinoxylans take more time to ferment, thus, most degradation occurs at a more distal part of the colon (Bach Knudsen, 2011; Jaworski and Stein, 2017). Nevertheless, the overall fermentability of fiber in most feed ingredients is less than 50% (Urriola et al., 2010; Jaworski and Stein, 2017) and the ingested energy in fiber is, therefore, utilized less efficiently than the energy of other nutrients such as protein, fat and non-fiber carbohydrates. However, due to the increased utilization of high-fiber co-products in diets for pigs, there is an increased interest in increasing the fermentability of fiber by pigs. To aid in this, exogenous enzymes and direct fed microbials (**DFM**) are often included in diets. The hypothesis is that by providing some of the enzymes needed for hydrolysis of fermentable fiber, the microbes will have an increased availability of fiber and may, therefore, be able to increase fermentability of fiber. It is also believed that certain DFM will secrete enzymes in the intestinal tract of pigs, which may contribute to an increased fermentability of fiber (Jaworski et al., 2017), but evidence that this has a measurable impact on fiber fermentation is still lacking.

Although a number of carbohydrases are available for inclusion in diets fed to pigs, the most commonly used carbohydrase is xylanase (also known as endoxylanase). The reason for the widespread use of xylanase

is that the most abundant source of fiber in most cereal grains is arabinoxylans (Jaworski et al., 2015) and xylanase is hypothesized to increase fermentability of arabinoxylans. However, as indicated above, a total of 9 enzymes are needed for the complete hydrolysis of the glycosidic bonds in arabinoxylans and it may therefore, be optimistic to expect that addition of only one enzyme will improve fermentability. Although improved digestibility of energy has been reported from some studies in which xylanase was used (Nortey et al., 2008; Yanes et al., 2011; Casas and Stein, 2016), results from most experiments with xylanase have been negative in terms of demonstrating increased energy utilization. It is possible that the reason it has been difficult to demonstrate positive effects of xylanase is that even if this enzyme is effective in hydrolyzing some glycosidic bonds in the xylose backbone, the bonds that require other enzymes for hydrolysis prevent effective fermentation of arabinoxylans. As a consequence, it is not uncommon to include arabinofuranosidase in diets along with xylanase to increase the likelihood of increased fermentation. The hypothesis is that if xylanase and arabinofuranosidase can hydrolyze the backbone and some of the side chains in arabinoxylans, then the microbes will be able to ferment the resulting oligosaccharides. Whether or not this hypothesis will prove to be true is still unknown, but it is likely that to effectively ferment arabinoxylans, it is necessary to delignify arabinoxylans because lignin is the greatest barrier to fermentation. Inclusion of esterases that can hydrolyze the bonds between ferulic acids or coumaric acids and lignin may, therefore, be necessary to increase fermentability of arabinoxylans (Liu et al., 2015). Thus a combination of more than one enzyme is likely needed to maximize fermentability and therefore improve energy release from the fiber in cereal grains and cereal grain co-products. Likewise, to effectively increase fermentability of other fiber components, it is likely that combinations of enzymes that will hydrolyze the same fiber component are needed. The use of enzyme cocktails is not uncommon, but usually the enzymes included in these cocktails are specific for different fiber components and not for the same component (Agyekum et al., 2015). Considering that all fiber components require more than one enzyme for hydrolysis, it may be more effective to include several enzymes that will target a specific fiber component in the cocktail. Specifically, for lignified fiber components, it is likely that esterases aimed at delignifying the fiber is a prerequisite for improved fermentability.

Conclusions

The increased use of cereal co-products in diets fed to pigs has increased the concentration of fiber in many diets. However, fermentability of fiber is usually low, and the utilization of energy from fiber is, therefore, less than from other nutrients. To increase the fermentability of fiber, fiber degrading enzymes may be used. However, because enzymes target only specific bonds in the fiber, it is necessary to know the composition of fiber in feed ingredients. Cereal grains and cereal grain co-products primarily contain cellulose, arabinoxylans, xyloglucans, and sometimes also beta-glucans. In contrast, oilseed meals contain cellulose and pectic polysaccharides including rhamnogalactans I and II, arabinogalactans I and II, arabinans, xyloglucans, and galactomannans. Most of these fiber components consist of a backbone and often very complex side chains that may or may not be esterified to lignin. For all fiber components, several enzymes are needed for complete hydrolysis and for some components more than 10 enzymes are needed. It is therefore likely that if exogenous enzymes are used, it will be necessary to include more than one enzyme to increase fermentability and therefore energy contribution from the fiber. The focus should be on using cocktails of enzymes that target the same fiber component to increase the likelyhood that microbial fermentation is increased.

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Effect of Nutrition on Sow Behavior

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Summary

Gestating sows are typically limit fed to maintain body weight and condition, which may not provide sufficient satiety, and does not allow sows to fully meet their motivation to express foraging and feeding behaviors. Feed restriction may lead to high occurrences of non-feeding oral activities, stereotypies, restlessness, and aggressive behavior in group-housed sows. Inclusion of fibrous feedstuffs in the diet reduces the energy density of diets and allows for larger meal sizes without increasing the energy supplied to the sow. This feeding method can enhance satiety and reduce the occurrence of stereotypies and decrease restlessness, activity, and aggression. The extent of the response to dietary fiber is, however, variable and depends on the characteristics of the fibrous diet (inclusion rate, fiber source, fermentation characteristics, duration fed), housing and feeding conditions, and characteristics of the sows (life cycle stage, genetics, parity). Elevated dietary tryptophan (2-4 times the requirement) as a precursor to serotonin has been shown to reduce aggression in developing gilts but not consistently in mixed sow groups. However, tryptophan supplemented to farrowing sows may reduce stillborns and increase feed intake immediately post-farrowing.

Introduction

External pressure from consumer groups and retail markets have been moving the US swine industry from individual stalls to group housing of pregnant sows and is based on an expectation of improved sow welfare. The increased freedom of movement expected to improve sow welfare can be erased by increased aggression among sows in group-housing systems. Aggression at the time sows are mixed in the group and daily aggression, particularly around the time of feeding, can cause injury, lameness, low feed intake, and poor performance of sows. One of the most intense aggression periods among sows is at the time of mixing. Minimizing aggression at this time would be very useful in helping mitigate the negative effects of aggression on sow welfare and performance.

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. The benefits of fiber diluted diets are seen with a greater display of foraging behaviors (Bergeron et al., 2000), increased time spent eating (Robert et al., 1993), and a reduction in stereotypic behaviors (Bergeron et al., 2000; Robert et al., 1993, 1997), decrease sow activity (Bolhuis et al. 2008) and aggression (Bolhuis et al., 2010), suggesting that these diets increased satiety. In a review which evaluated the usefulness of fiber and fermentable carbohydrates, de Leeuw et al. (2008) noted that high fiber diets appear to cause satiety in the short term, partly through gut distension. Fermentable fiber diets are slower to release nutrients into the blood and thus increase satiety less immediately after a meal but for a longer duration (da Silva et al., 2013, 2014). Additionally, in a review of several fiber feeding studies using a variety of feedstuffs, Reese et al. (2008) determined that feeding 350 g/d of neutral detergent fiber (**NDF**) from the fibrous feedstuffs could increase litter size on average 0.6 pigs/litter, providing a non-behavior benefit to feeding high fiber diets.

Tryptophan, an essential amino acid acquired through the diet, is the precursor for serotonin (5-HT). Because tryptophan can cross the blood-brain-barrier, dietary elevations of tryptophan have been applied in an attempt to reduce stress in group housed pigs. A group of studies have shown that increasing tryptophan in the diet can decrease measures of aggression in piglets at weaning and mixing, and in nursery, grow-finish pigs (Poletto et al., 2010) and sows at mixing (Poletto et al., 2014). Some other studies have found no effect of increased tryptophan on aggression, but there is great variation in the concentrations of tryptophan fed and the duration of feeding before observations are carried out (Li et al., 2011). Piglet mortality remains a serious welfare and economic problem. Much of the early mor-

tality is due to crushing by the sow. Tryptophan has been shown to reduce aggression and have a calming effect on behavior and perhaps may reduce piglet mortality and crushing around farrowing.

The objectives of these fiber supplementation during early gestation experiments were to design diets that would increase satiety of sows when feeding approximately 350 g/d of NDF from a variety of sources and therefore reduce aggression at the time of mixing sow groups. The aims of the tryptophan experiment were to determine if feeding dietary tryptophan around pre- and immediately post-farrowing would affect posture-changing behavior and piglet mortality.

Experimental Procedures

Experiment 1

A total of 200 sows, Yorkshire × Landrace (25 sows/replication × 8 replications; parity 1 to 6) were used. Sows were fed one of five diets: 1) corn-SBM diet (**CTL**, 2.0 kg/day); 2) resistant starch (**RS**, 10.8%, 2.0 kg/day); 3) beet pulp (**BP**, 27.2%, 2.0 kg/day); 4) soyhull (**SH**, 19.1%, 2.0 kg/day); 5) increased intake with soyhulls (**INCSH**, 14.05%, 2.2 kg/day) (Table 1). Forty sows were used for each treatment. Sows were bred, then between days 7 to 14 post-breeding, sows were moved into the experimental building and housed individually in 0.61 × 2.13 m gestation stalls. Sows were maintained on these diets in the gestation stalls for 21 days prior to mixing and during the 3 days of mixing. On day 22, sows were moved into group pens of 5 sows/pen by dietary treatment (days 28-35 post-breeding). When grouped, sows were housed in 2.13 × 3.05 m pens and fed their same diets in stalls (0.61 × 2.13 m) connected to the pen area. The behaviors of the sows were recorded weekly (24 hours every week) in the stalls and for 3 days at mixing. Heart rates were collected on two focal sows in each treatment when they were individually housed in stalls on days 1, 7, 14 and 21. On days 2, 8, 15, 22, and 25 (3 days post-mixing) blood samples were collected at approximately 4 hours post-feeding from the same focal sows. The serum samples were assayed for non-esterified fatty acids (**NEFA**), blood urea nitrogen (**BUN**), glucose, and lactate. Sow body condition score, backfat thickness, and weights were collected on days 1 and 21 of individual housing. Numbers of lesions on the front, mid, and back quadrants of both sides of the sows were assessed before grouping and daily during 3 days of mixing as an additional measure of aggression.

Table 1. Composition of diets provided during a 25-day feeding period, Experiment 1.

Ingredients, %	CTL[1]	RS[2]	BP[3]	SH[4]	INCSH[5]
Corn	83.11	66.85	49.62	58.53	73.98
SBM, 48%	12.00	13.18	11.90	11.00	8.60
Soybean hulls	0.00	0.00	0.00	19.05	14.05
Beet pulp	0.00	0.00	27.20	0.00	0.00
Resistant starch-maltodextrin[6]	0.00	10.80	0.00	0.00	0.00
Swine grease	0.82	5.07	7.62	7.53	0.00
Limestone	1.25	1.21	0.72	1.00	0.97
Monocal phos.	1.52	1.59	1.64	1.59	1.35
Vit. premix	0.50	0.50	0.50	0.50	0.25
TM premix	0.20	0.20	0.20	0.20	0.20
Phytase	0.10	0.10	0.10	0.10	0.10
Salt	0.50	0.50	0.50	0.50	0.50
Calculated nutrients					
ADFI, kg/d	2.00	2.00	2.00	2.00	2.20
NE, kcal/d	5,000	5,000	5,000	5,000	5,000
NDF, %	9.23	17.51	17.51	17.52	15.91
NDF, g/d	184.7	350.3	350.2	350.3	350.1
ADF, %	3.10	2.72	8.75	10.05	8.31
Crude fiber, %	2.33	11.71	6.49	8.24	6.81
Sol. fiber, %	1.59	11.05	4.19	2.75	2.56
SID Lys, %	0.50	0.50	0.50	0.50	0.45
Ca, %	0.80	0.80	0.80	0.80	0.72
Avail. P, %	0.45	0.45	0.45	0.45	0.40
Analyzed nutrients					
CP, %	12.83	12.15	12.88	12.41	11.87
Fat, %	4.55	9.42	9.43	9.51	2.88
Crude fiber, %	1.80	1.60	5.06	7.75	6.20
NDF, %	7.86	6.65	13.40	16.37	13.72
ADF, %	2.85	2.75	8.08	10.13	8.55

1 CTL: corn-SBM diet with no extra fiber, 2.0 kg/d, 185 g/d NDF.
2 RS: 10.8% resistant starch, 2.0 kg/d, 350 g/d NDF.
3 BP: 27.2 % sugar beet pulp, 2.0 kg/d, 350 g/d NDF.
4 SH: 19.1% soybean hulls, 2.0 kg/d, 350 g/d NDF.
5 INCSH: 14.05% soybean hulls, 2.2 kg/d, 350 g/d NDF.
6 Resistant starch was Premidex™ from ADM, Decatur IL.

Experiment 2

Experiment 2 followed the exact same procedures as Experiment 1. However, sows were fed one of four diets: 1) corn-SBM control; 2) corn-based diet fed ad libitum; 3) resistant starch at 1.5 times the levels as fed in Experiment 1 (**RS150**); or 4) a combination of resistant starch and soyhulls at one-half the levels for each as used in Experiment 1 (**RSSH**) (Table 2). In total, 160 sows were assigned to one of four treatments (40 sows/treatment) and there were eight replicate groups of sows.

Experiment 3

The aims of this experiment were to determine if feeding dietary tryptophan around farrowing time would affect posture-changing behavior and piglet mortality. Twenty-four multiparous sows (parity 2-4) were moved to the farrowing house on day 110 of pregnancy and randomly assigned to one of two treatments; 1) standard lactation diet (**CTL**) with 0.2% SID tryptophan, or 2) standard lactation diet with three times the amount of tryptophan (0.6% SID tryptophan) contained in the standard diet (**TRYP**). Diets were fed from

Table 2. Composition of diets provided during a 25-day feeding period, Experiment 2.

Ingredient, %	Control[1]	AdLib	RS150	RSSH
Corn	76.100	98.507	52.715	48.080
SBM	17.800	0.000	19.690	18.570
Soybean hulls	0.000	0.000	0.000	9.600
Resistant starch[2]	0.000	0.000	15.330	10.220
Swine grease	1.800	0.000	7.860	9.220
Limestone	1.220	0.530	1.180	1.070
Monocal phos.	1.480	0.200	1.560	1.570
Sow Vitamin premix	0.250	0.085	0.250	0.250
Swine Vitamin premix	0.250	0.085	0.250	0.250
TM	0.150	0.050	0.150	0.150
Se 600	0.050	0.020	0.050	0.050
Phytase	0.100	0.100	0.100	0.100
Salt	0.500	0.170	0.500	0.500
DL-Methionine	0.000	0.000	0.040	0.045
L-Threonine	0.050	0.000	0.075	0.075
L-Tryptophan	0.000	0.003	0.000	0.000
Defusion Plus	0.250	0.250	0.250	0.250
Total	100.000	100.000	100.000	100.000
Calculated nutrients				
Feed intake, g/d	2,000	6,000	2,000	2,000
NE, kcal/kg	2,500	2,613	2,500	2,500
CP, %	14.81	8.18	13.81	14.01
SID Lys, %	0.64	0.21	0.64	0.64
Ca, %	0.80	0.27	0.80	0.80
Avail. P, %	0.45	0.15	0.45	0.45
NDF, %	9.1	9.5	21.6	21.6
NDF, g/d	182	567	433	433

[1] Control = Corn-SBM gestation diet; AdLib = Corn based diet targeting 6+ kg/d intake. RS150 = Resistant starch fed at 150% of Exp. 1 level; RSSH = a blend of resistant starch and soybean hulls both at 50% of the levels fed in Exp. 1.
[2] Resistant starch was Premidex™ from ADM, Decatur IL.

entry into the farrowing house until 3 days post-farrowing. Feeding level was 2.7 kg/day pre-farrowing and ad libitum starting on the day of farrowing. Sow behavior was recorded continuously from entry until day 7 post-farrowing and extracted to determine number and type of posture changes. Production data recorded included sow weight on entry to the farrowing stall and at weaning, daily sow feed intake, number of piglets born alive, dead, and mummified, piglet birth weight, 24-hour weight, mortality and cause (in conjunction with video data), number weaned, and weaning weight.

Results

Experiment 1

When in stalls, the sows fed the BP diet stood more than all other diets with the sows fed the other four diets spending equal amounts of time standing ($P<0.05$). The percentage of sows resting was highest when fed SH and lowest on the BP diet ($P<0.05$). Sham-chewing was not affected by diet. When sows were mixed on day 21 of treatment, biting frequency in the first hour of mixing was highest in the CTL and SH treatment and lowest for sows on the RS diet ($P<0.05$; Table 3). Total aggression was numerically lowest in the first hour for sows fed RS diet, less than one-half of the CTL sows, but due to the large degree of variation did not prove to be significant (Figure 1). However, fighting frequency in the first hour tended to be lower ($P<0.10$) for sows on the RS diet and the INCSH diet when compared to CTL (12.7, 11.4, and 18.7, respec-

Table 3. Measures of aggressive interaction during first four hours of mixing sows, Experiment 1.

	Diets				
	CTL[1]	RS[2]	BP[3]	SH[4]	INCSH[5]
Bite frequency (no.)					
h1 ($P<0.05$)	236.5 ± 62.6[a]	90.5 ± 30.5[b]	157.7 ± 41.0[ab]	175.0 ± 22.3[a]	111.2 ± 46.3[ab]
h 2	127.2 ± 64.2	43.5 ± 9.7	52.5 ± 17.7	30.5 ± 10.0	57.2 ± 21.1
h 3	59.5 ± 48.9	18.2 ± 6.7	50.7 ± 22.2	5.3 ± 3.2	28.8 ± 7.4
h 4	7.8 ± 3.9	29.2 ± 17.0	2.8 ± 1.8	13.8 ± 11.7	14.8 ± 6.2
Fight duration (min per h)					
h 1	11.7 ± 5.1	5.0 ± 1.9	14.3 ± 5.8	8.9 ± 2.7	10.6 ± 4.8
h 2	4.9 ± 2.5	3.2 ± 1.7	2.1 ± 1.1	1.0 ± 0.5	2.4 ± 0.6
h 3	3.8 ± 3.7	1.1 ± 0.5	2.3 ± 1.3	0.2 ± 0.2	1.0 ± 0.4
h 4	0.3 ± 0.2	2.3 ± 1.4	0.2 ± 0.1	1.1 ± 0.9	0.7 ± 0.2
Fight frequency (no.)					
h 1 ($P<0.1$)	18.7 ± 2.6[a]	12.7 ± 3.5[b]	17.2 ± 3.3[ab]	16.2 ± 3.0[ab]	11.4 ± 4.7[ab]
h 2	9.8 ± 4.0	5.0 ± 1.6	6.0 ± 1.4	4.7 ± 1.2	10.0 ± 0.8
h 3	3.0 ± 1.1	3.5 ± 1.3	3.8 ± 1.2	1.0 ± 0.4	4.0 ± 2.1
h 4 ($P<0.05$)	3.0 ± 1.7[ab]	5.5 ± 1.5[a]	2.0 ± 1.6[ab]	1.0 ± 0.4[b]	3.8 ± 0.5[a]

[a, b] Means within a row with different superscripts differ ($P<0.05$).
[1] CTL: corn-SBM diet with no extra fiber, 2.0 kg/d, 185 g/d NDF
[2] RS: 10.8% resistant starch, 2.0 kg/d, 350 g/d NDF
[3] BP: 27.2 % sugar beet pulp, 2.0 kg/d, 350 g/d NDF
[4] SH: 19.1% soybean hulls, 2.0 kg/d, 350 g/d NDF
[5] INCSH: 14.05% soybean hulls, 2.2 kg/d, 350 g/d NDF

Adapted from Sapkota et al., 2016

tively; Table 3). Biting frequency, fighting duration, and head-knock frequency in hours 2, 3 and 4 did not differ among diets. Fighting frequency during the fourth hour was lower for sows fed SH compared to RS ($P<0.05$).

Diet did not affect the total number of skin lesions at 24, 48, or 72 h post-mixing. However, as expected, total number of skin lesions were higher ($P<0.05$) in sows fed each diet after 24 h of mixing (day 23) compared to baseline (day 21). The number of skin lesions did not differ with respect to the different body areas (front, mid and rear) on any of the days of mixing.

The blood urea nitrogen concentration (Table 4) was highest on day 2 compared to days 8, 15, 22, and 25 ($P<0.001$) and sows fed BP and SH had lower BUN than the other three treatments ($P<0.05$). Serum glucose concentration was elevated by the RS and BP diets compared to the CTL diet ($P<0.05$). Non-esterified fatty acids were lowest and different ($P<0.05$) for CTL and INCSH fed sows compared to the other three treatments and SH fed sows had higher NEFA concentrations than RS and BP fed sows ($P<0.05$).

The sows fed INCSH and SH diets had lowest average heart rate compared to other diets ($P<0.05$). Diets, days on diets, or interaction of days and diets did not affect other respiration or heart rate variables. Diets did not affect sow body weight, backfat, and body condition score nor did diets affect the number of piglets born or average weaning weight.

Experiment 2

An analysis of the behavioral data after mixing showed that aggressive interactions (Figure 2), bites, and head knocks were not different among treatments ($P>0.10$). It is also noted that in this experiment aggression was much lower for control sows compared to that found in Experiment 1, which likely prevented treatment differences from being detected. Overall skin lesions were not different across treatments which is in agreement with the behavioral data which showed aggression to be the same for all sows. The reason for this low rate of aggression in this experiment is unclear. It may be related to this experiment being conducted primarily during the summer months and the heat reducing the sows overall activity or shifting their activity to the evenings/nights when we did not record sow activity.

Non-esterified fatty acids were greater in sows fed the RSSH and RS150 diets when compared to the ADLIB and Control treatments ($P<0.05$; Table 5). No treatment differences in glucose or lactate were observed. Blood urea nitrogen was lower for most days for sows fed the RS150 and the RSSH diets compared to Control and ADLIB treatments ($P<0.05$).

As expected, sows on ad libitum feed had greater backfat, body condition scores, and body weight at the

Figure 1. Experiment 1. Aggression during the 1st, 2nd, 3rd, and 4th hours after mixing; for sows on the control diet, resistant starch diet, beet pulp diet, soyhull diet, and soyhull diet with 0.2 kg/d extra feed provided (INCSOY). No differences among treatments ($P>0.05$). Adapted from Sapkota et al., 2016

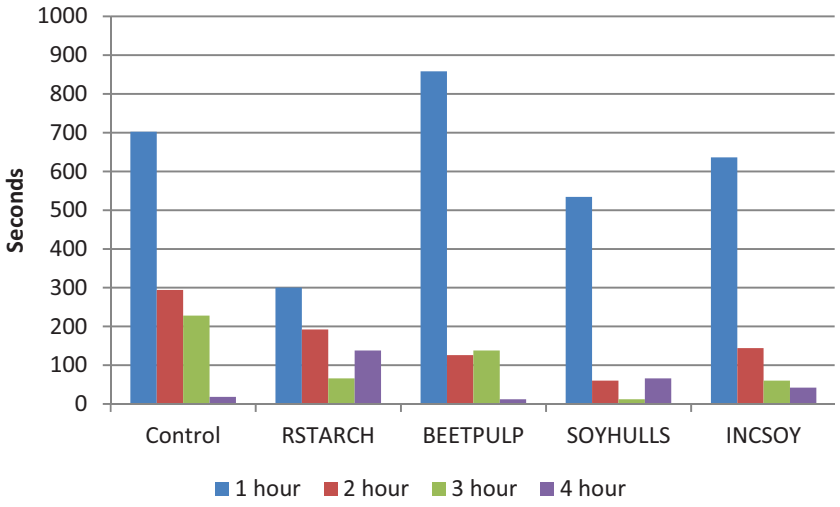

Figure 2. Experiment 2. Aggression during the 1st, 2nd, 3rd, and 4th hours after mixing; for sows on the control diet, ad libitum diet, 1.5 x resistant starch as used in Exp. 1 (RS150), and diet with both resistant starch and soyhulls (RSSH). No differences among treatments ($P>0.05$).

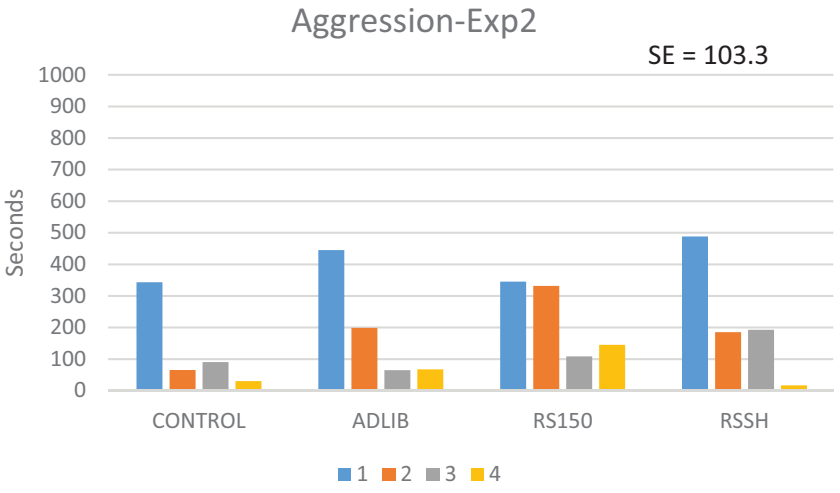

Table 4. Effect of diet on blood metabolites concentrations by treatment on average, Exp. 1.

	Diets					P<	
Metabolites	**CTL[1]**	**RS[2]**	**BP[3]**	**SH[4]**	**INCSH[5]**	**Diet**	**Day**
BUN (mg/dl)	10.7 ± 0.4[a]	10.0 ± 0.5[a]	8.2 ± 0.4[b]	8.8 ± 0.4[b]	10.1 ± 0.4[a]	0.001	0.001
Glucose (mg/dl)	71.3 ± 1.3[a]	75.2 ± 1.4[bc]	76.4 ± 1.3[c]	72.8 ± 1.2[ab]	72.4 ± 1.1[ab]	0.04	0.62
NEFA (mmol/l)	0.5 ± 0.05[a]	0.7 ± 0.06[b]	0.7 ± 0.05[b]	0.8 ± 0.04[c]	0.6 ± 0.04[a]	0.001	0.36

[a,b,c] Means within a row with different superscripts differ ($P<0.05$).
1 CTL: Corn-SBM diet with no extra fiber, 2.0 kg/d, 185 g/d NDF
2 RS: 10.8% resistant starch, 2.0 kg/d, 350 g/d NDF
3 BP: 27.2 % sugar beet pulp, 2.0 kg/d, 350 g/d NDF
4 SH: 19.1% soybean hulls, 2.0 kg/d, 350 g/d NDF
5 INCSH: 14.05% soybean hulls, 2.2 kg/d, 350 g/d NDF

Adapted from Sapkota et al., 2016

end of the study ($P<0.05$; Table 6). No differences in farrowing production measures were found among diets.

Experiment 3

Late gestation dietary TRYP level had no effect on total litter size or number of piglets born alive ($P>0.05$), but TRYP sows tended to give birth to fewer dead piglets than CTL sows (1.0 ± 0.4 vs. 2.5 ± 0.7, $P<0.1$). Total feed intake over the immediate pre- and post-farrowing period and sow lactation weight loss was not different between treatments, but on the day of farrowing, TRYP sows tended to eat more than CTL sows (3.0 ± 0.4 vs. 1.8 ± 0.4 kg, $P<0.1$). Piglet birth weight, weaning weight and growth rates did not differ and total percent piglet mortality (born dead + liveborn mortality) was similar between treatments (TRYP 17.0 ± 2.8 vs. CTL 24.3 ± 5.4 %, $P>0.10$). The number and type of posture changes varied over time, but there were no differences between treatments in the critical immediate post-farrowing period. Overall, feeding a high tryptophan diet around the time of farrowing did not appear to influence sow posture-changing behavior or liveborn piglet mortality.

Table 5. Select sow blood metabolites from day 7 to 32 of gestation, Exp. 2.

	CONTROL[1]	ADLIB	RS150	RSSH	Diet, P<
NEFA (mmol/l)					
d2	0.24 ± 0.07	0.30 ± 0.07	0.46 ± 0.07	0.34 ± 0.07	0.18
d8	0.24 ± 0.04[a]	0.20 ± 0.04[a]	0.32 ± 0.04[b]	0.46 ± 0.04[c]	0.001
d15	0.27 ± 0.04[ab]	0.17 ± 0.04[a]	0.38 ± 0.04[b]	0.33 ± 0.04[b]	0.005
d22	0.25 ± 0.04[abd]	0.19 ± 0.04[b]	0.38 ± 0.04[c]	0.36 ± 0.04[cd]	0.002
d25	0.27 ± 0.05[a]	0.17 ± 0.04[a]	0.55 ± 0.04[b]	0.46 ± 0.05[b]	0.001
BUN (mg/dl)					
d2	10.6 ± 0.6	11.9 ± 0.6	12.4 ± 0.6	11.8 ± 0.6	0.20
d8	10.2 ± 0.5[a]	8.2 ± 0.4[b]	9.1 ± 0.4[ab]	8.6 ± 0.4[b]	0.01
d15	9.9 ± 0.6[a]	9.3 ± 0.5[a]	8.6 ± 0.5[ab]	7.7 ± 0.5[b]	0.05
d22	9.6 ± 0.6[ab]	10.5 ± 0.5[a]	8.2 ± 0.5[b]	8.2 ± 0.5[b]	0.006
d25	10.6 ± 0.5[a]	9.6 ± 0.4[ab]	8.6 ± 0.5[b]	8.5 ± 0.5[b]	0.02

[a,b,c,d] Means within a row with different superscripts differ ($P<0.05$).
1 Control = Corn-SBM gestation diet; AdLib = Corn based diet targeting 6+ kg/d intake; RS150 = Resistant starch fed at 150% of Exp. 1 level; RSSH = a blend of resistant starch and soybean hulls both at 50% of the levels fed in Exp. 1.

Table 6. Sow changes in backfat (BF), weight (BW), and body condition scores (BCS) from day 7 to 32 of gestation, Exp. 2.

	CONTROL[1]	ADLIB	RS150	RSSH	Diet, P<
BF d1, cm	1.8 ± 0.1	1.8 ± 0.1	2.0 ± 0.1	1.7 ± 0.1	0.4
BF d22, cm	2.1 ± 0.1	2.4 ± 0.1	2.1 ± 0.1	2.1 ± 0.1	0.009
BW d1, kg	189.2 ± 6.5	187.8 ± 6.5	192.1 ± 6.5	191.4 ± 6.5	0.96
BW d22, kg	194.6 ± 1.4	215.5 ± 1.4	192.6 ± 1.4	192.2 ± 1.4	0.001
BCS d1	2.8 ± 0.1	2.8 ± 0.1	2.9 ± 0.1	2.8 ± 0.1	0.7
BCS d22	2.7 ± 0.1	3.0 ± 0.1	2.7 ± 0.1	2.8 ± 0.1	0.04

A covariate of the start value was included in the ANOVA for end BF, BW and BCS.
1 Control = Corn-SBM gestation diet; AdLib = Corn based diet targeting 6+ kg/d intake; RS150 = Resistant starch fed at 150% of Exp. 1 level; RSSH = a blend of resistant starch and soybean hulls both at 50% of the levels fed in Exp. 1.

Discussion

One of the periods of most intense aggression among sows is at the time of mixing. Controlling aggression at this time would be very useful in helping mitigate the negative effects of aggression on sow welfare and performance. In Experiment 1, RS did reduce aggression in the first hour of mixing (bite frequency, fight frequency, and fight durations). Additionally, when we sum the total number of bites in the first 4 hours of mixing over the 3 days, bites are reduced by 58% in the RS fed sows compared to the CTL fed sows and the other fiber sources also had approximately a 40% decrease in the total number of bites during this same time period. This is similar to Stewart et al. (2010) who reported a 50% decrease in biting behavior when group housed sows were fed a higher fiber diet consisting of a blend of SH and BP. However, the fiber sources might not be different from the control diet

in terms of affecting overall behavior in the gestation stall, skin lesions after mixing, or heart rate variability. The diets did not affect farrowing performance likely because they were only fed during the premixing period and not the entire duration of gestation where fiber supplementation has been shown to increase litter size, especially when fed over more than a single parity. Both diets with soy hulls reduced heart rate and this could be related to potentially increased soy isoflavones or other compounds unique to the soy hulls in this study

In Experiment 2, we found very little differences across treatments to indicate any behavior, physiology, or welfare benefits of feeding these diets, including ad libitum fed sows. The ad libitum treatment was designed to remove the hunger/food resource aggression and provide a value for the aggression remaining for establishing social hierarchy and other pen resources. This study had less than half of the aggression of the first experiment and so this creates difficulty in finding treatment effects when there is less aggression to start with. This may be related to the second experiment being conducted during the summer and the extra heat may have decreased the sow interest in aggression in the first 4 hours after eating their morning feeding. The differences that were observed in the blood parameters were those that would be expected from feeding an ad libitum diet compared to the limit fed treatments.

In Experiment 3, the feeding of high level of tryptophan did not alter the sows behavor during farrowing, however there was a reduction in stillbirths and increased feed intake immediately post-farrowing. In conclusion, including resistant starch and soy hulls in the diet fed 3 weeks prior to mixing might be effective in overall reduction of aggression, restlessness, and heart rate and improve sow welfare during mixing. There may be a beneficial effect on stillbirth incidence and farrowing day feed intake, which could affect early lactation milk production, but sow studies similar to these require further investigation.

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Is There Antioxidant Protection for Sows and Nursery Pigs with Additional Vitamins A, D, and E?

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Summary

Much of the data relative to dietary needs for vitamins A, D, and E in swine diets was published more than 3 decades ago prior to the genetics, diseases, management, feedstuffs, feed manufacturing technologies, and facilities used in today's production. Additionally, the bioavailability of various forms of these vitamins and often their functions were not known at that time and even today. Hence, we explored the benefit of injectable and oral forms of these vitamins in sow and nursery pig diets.

Introduction

Vitamin E

While vitamin E deficiency was discovered in 1922 when rancid fat was fed to rats, its specific function is still unknown (Zempleni et al., 2007). With 8 known structural isomers with vitamin E activity (tocopherols and tocotrienols), α-tocopherol is the predominant form in blood and tissues, and *RRR-α*-tocopherol (natural form) being more bioactive than the synthetic *all-rac-α*-tocopherol. Additionally, hepatic α-tocopherol transfer protein preferentially binds *RRR-α*-tocopherol and the synthetic 2R stereoisomers (Traber and Arai, 1999). When a deficient vitamin E diet was fed to humans for over 6 years, it took 2 years for serum vitamin E to decrease. Thus, indicating that serum values are not always an indicator of vitamin E intake and perhaps may not be useful in indicating status (Horwitt, 1960). Loudenslager et al., (1986) were the first to report that supplementation of vitamin E (50 IU/kg) and Se (0.1 ppm) to sows during gestation and lactation increased α-tocopherol in colostrum and milk and plasma glutathione peroxidase activity at 2 d of age both before or after Fe injections compared to when no vitamin E and Se were added. An increased number of pigs, decreased mastitis, metritis, and agalactia and increased concentrations of α-tocopherol in colostrum and milk were observed by Mahan (1994) when the concentration of vitamin E was increased (22, 44, 66 IU/kg). There is no organ that functions as a storage site for vitamin E, and approximately 90% of α-tocopherol is believed to be located in adipose tissue in humans (Zempleni et al., 2007).

Vitamin A

The essentially of vitamin A compounds with biological activity as retinol has been known for vision, growth, maintenance of tissue, mucosal secretion and reproduction in mammals (Zempleni et al., 2007). There are retinol-binding proteins involved in the transport of retinol in plasma. Like other transporters, they are dependent on adequate protein, calories, and micronutrients that are often reduced in the newly weaned pig. Retinyl esters are cleared from the plasma to the liver for storage in a short period of time. Hence, low plasma retinol is not always an indicator of low vitamin A status.

Vitamin D

Vitamin D_2 is derived from plant sources and is most often used in feeds while vitamin D_3 results from the sun converting 7-dehydrocholesterol to cholecalciferol (D_3). Since the body can produce D_3, it is often referred to as a prohormone and not a vitamin. While it is most associated with Ca homeostasis and hence bone metabolism, it is also important in immunity and as an immunosuppressive agent. A healthy gut is essential for the absorption of dietary vitamin D with the aid of bile salts. As with vitamins E and A, it is transported by a specific binding protein (vitamin D-binding protein), which may also be important as a reservoir for D metabolites throughout the body. Following absorption, D is

quickly cleared to the liver, but can also be found stored in fat and muscle (Rungby et al., 1993).

Vitamin E Injections in Sows

Hypothesis

- Vitamins (E, D, A) are below sow's requirement in gestation and supplementation would reduce farrowing times and stillborn pigs.
- Injected Vitamins E, D, A prior to farrowing will improve the anti-oxidant status of their offspring.

Methods

- Sows and gilts (n = 50) injected with 5 ml i.m. at 107 to 109 d gestation with Vital E - Repro (Stuart Products, Bedford, TX) or saline (n = 41).
- Time of birth recorded for each pig.
- Pigs weighed at 6 to 24 h, approximately 5, 21 and 42 d of age.
- Blood collected from:
  1. sows (n = 12) prior to injection and 2 to 5 d post-farrowing.
  2. pigs (n = 35) 2 to 5 d of age.
  3. barrows (n = 12: 6/sow treatment) d 5, 25, 45.
- Weaning: 21 to 25 d of age.
- Blood sample analysis:
  1. antioxidant enzymes
  2. vitamin E

Results

Table 1 provides data showing that our hypothesis was invalid with a limited number of sows because number of offspring born (total and live), assists/sow, farrowing duration, and farrowing time per pig were not altered by treatment.

Utilizing plasma and red blood cells from a subsample of pigs (n = 12) in a 45 d study, antioxidant enzymes and plasma vitamin E were altered primarily by time. Plasma vitamin E in pigs (Figure 1) did not differ by treatment of the dam, but was significantly lower for pigs as the study progressed.

In the offspring, ceruloplasmin (requires Cu) and superoxide dismutase (requires Cu and Zn) activities (Figures 2 and 3) were not affected by the treatment of their dams, but significantly increased over time. A significant treatment x time interaction for the activity of glutathione peroxidase (requires Se) was observed because activities were similar at d 5 and 25, but pigs from dams injected with saline increased to a greater degree than pigs from sows given a vitamin injection at d 45 (Figure 4). This suggests that the stored vitamin E in pigs from the injected sows protected the offspring from as greater need for glutathione peroxidase production.

Table 1. Effect of saline or vitamin injection at 107 d gestation on farrowing parameters.

	Treatment[1]			
Item	Saline injection	Vitamin injection	SE	*P*-value
n	50	41		
Offspring/litter	12.8	12.2	0.6	0.4318
Assists/farrowing	1.0	0.8	0.2	0.4765
Farrowing duration, min	205.0	201.3	22.1	0.8684
Farrowing time/pig, min	17.7	17.7	2.2	0.9992
Live births/litter	11.9	11.3	0.8	0.4008

[1] Vitamin injection was 5 ml i.m. of Vital E - Repro (Stuart Products, Bedford, TX) given at d 107 to 109 of gestation. The product contains 300 IU vitamin E (as d-α-tocopherol), 200,000 IU vitamin A (as retinyl-palmitate) and 100,000 IU vitamin D_3 compounded with 18% ethyl alcohol and 1% benzyl alcohol in an emulsifiable base. The saline injection was 5 ml of 0.9% sterile NaCl.

This small sub-sample illustrated that pigs from the vitamin injected sows ate more feed and had better ADG that those whose dams were injected with saline (Figure 5). A larger group of pigs (n = 264) from the original population illustrates this same benefit to pigs from sows injected with vitamins.

Conclusion

Providing vitamins to sows via injection may benefit the antioxidant status and performance of their offspring.

Impact of Vitamins E and D_3 Supplementation in Water of Nursery Pigs

Hypothesis

- Nursery pigs under stress from weaning would have improved performance and antioxidant status if additional vitamins E and D_3 were provided in their water.

Methods

- 150 pigs were weaned at 23 ± 3 d of age.
- Treatments:
  1. vitamins E and D_3 (Emcelle E-D_3 Liquid, Stuart Products, Bedford, TX) were administered in the water - 15 pens.
  2. no additional vitamins were added to water - 15 pens.
- Pigs were weighed at 35, 44, and 55 d of age.
- Blood was collected from 12 randomly selected pigs/ treatment at 55 d of age.
- Antioxidant enzyme (ceruloplasmin, Cu/Zn superoxide dismutase and glutathione peroxidase) activities and concentrations of vitamins E and D_3. were determined.

Results

- Performance was not altered by the addition of vitamins E and D_3 in water.
- Ceruloplasmin activity was not different for the pigs from the 2 treatments (Table 2).
- Activity of red blood cell Cu/Zn superoxide dismutase and Se requiring glutathione peroxidase were reduced when vitamins E and D_3 were added to the drinking water (Table 2).
- Vitamins E and D_3 in water significantly increased the plasma concentration of these vitamins vs. unsupplemented water (Table 2).

Conclusion

These results illustrate that nursery pigs can utilize vitamins E and D_3 in water to reduce the need for additional antioxidant enzyme activity in the stressed weanling pigs. Thus, this could provide the potential for greater protection if challenged by disease.

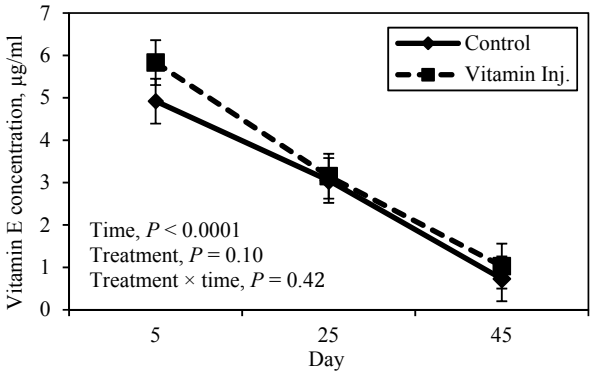

Figure 1. Effect of saline or vitamin injection in sows on offspring plasma vitamin E concentration. Vitamin injection was 5 ml i.m. of Vital E – Repro (Stuart Products, Bedford, TX) given at d 107 to 109 of gestation. The product contained 300 IU vitamin E (as d-α-tocopherol), 200,000 IU vitamin A (as retinyl-palmitate) and 100,000 IU vitamin D_3 compounded with 18% ethyl alcohol and 1% benzyl alcohol in an emulsifiable base. The saline injection was 5 ml of 0.9% sterile NaCl. Serum was collected at 5, 25, and 45 d post-weaning.

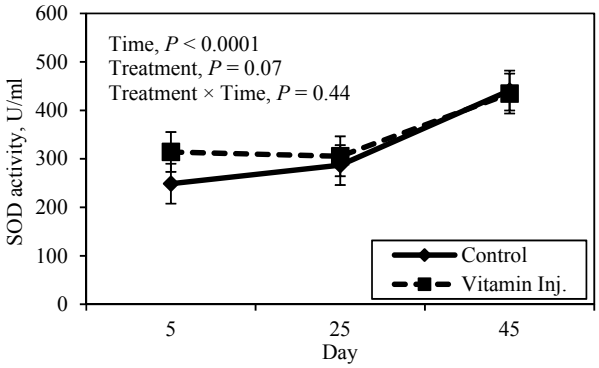

Figure 3. Effect of saline or vitamin injection in sows on offspring red blood cell superoxide dismutase (SOD) activity. Vitamin injection was 5 ml i.m. of Vital E – Repro (Stuart Products, Bedford, TX) given at d 107 to 109 of gestation. The product contained 300 IU vitamin E (as d-α-tocopherol), 200,000 IU vitamin A (as retinyl-palmitate) and 100,000 IU vitamin D_3 compounded with 18% ethyl alcohol and 1 % benzyl alcohol in an emulsifiable base. The saline injection was 5 ml of 0.9% sterile NaCl. Blood was collected at 5, 25, and 45 d post-weaning.

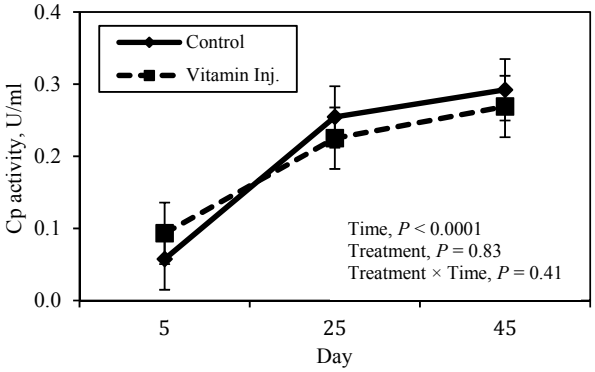

Figure 2. Effect of saline or vitamin injection in sows on offspring plasma ceruloplasmin (Cp) activity. Vitamin injection was 5 ml i.m. of Vital E – Repro (Stuart Products, Bedford, TX) given at d 107 to 109 of gestation. The product contained 300 IU vitamin E (as d-α-tocopherol), 200,000 IU vitamin A (as retinyl-palmitate) and 100,000 IU vitamin D_3 compounded with 18% ethyl alcohol and 1 % benzyl alcohol in an emulsifiable base. The saline injection was 5 ml of 0.9% sterile NaCl. Serum was collected at 5, 25, and 45 d post-weaning.

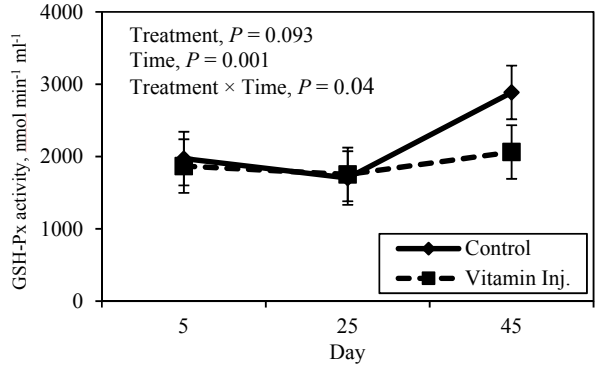

Figure 4. Effect of saline or vitamin injection in sows on offspring red blood cell glutathione peroxidase (GSH-Px) activity. Vitamin injection was 5 ml i.m. of Vital E – Repro (Stuart Products, Bedford, TX) given at d 107 to 109 of gestation. The product contained 300 IU vitamin E (as d-α-tocopherol), 200,000 IU vitamin A (as retinyl-palmitate) and 100,000 IU vitamin D_3 compounded with 18% ethyl alcohol and 1 % benzyl alcohol in an emulsifiable base. The saline injection was 5 ml of 0.9% sterile NaCl. Blood was collected at 5, 25, and 45 d post-weaning.

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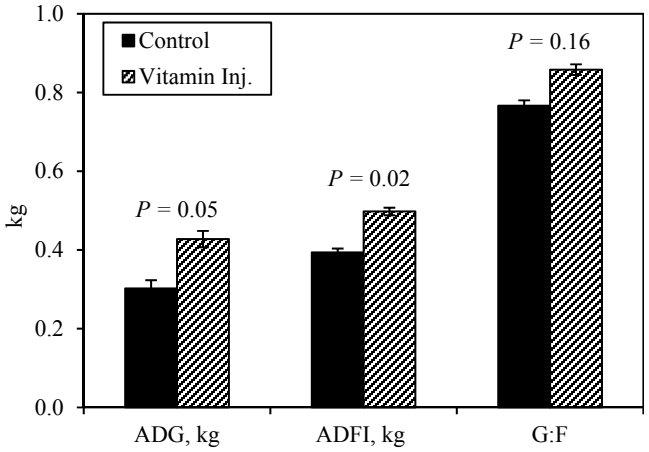

Figure 5. Effect of saline or vitamin injection in sows on offspring growth performance. Vitamin injection was 5 ml i.m. of Vital E – Repro (Stuart Products, Bedford, TX) given at d 107 to 109 of gestation. The product contained 300 IU vitamin E (as d-α-tocopherol), 200,000 IU vitamin A (as retinyl-palmitate) and 100,000 IU vitamin D$_3$ compounded with 18% ethyl alcohol and 1 % benzyl alcohol in an emulsifiable base. The saline injection was 5 ml of 0.9% sterile NaCl. ADG, ADFI, and G:F were determined at 5, 25, and 45 d post-weaning.

Table 2. Effect of oral vitamins supplied in the water on antioxidant enzyme activities and plasma vitamin E, D$_3$ and A concentrations in weanling pigs

	Treatment[1]			
Parameter	**Water**	**Vitamin product in water**	**SE**	***P*-value treatment**
RBC superoxide dismutase activity, U/ml	362.86	324.17	12.32	0.0048
RBC glutathione peroxidase activity, nmol min-1 ml-1	10,525	8,105	554	0.0002
Plasma ceruloplasmin oxidase activity, U/ml	0.1767	0.1786	0.007	0.8384
Plasma vitamin E, µg/ml	0.95	1.67	0.11	0.0001
Plasma vitamin D$_3$, ng/ml	40.51	82.02	3.46	< 0.0001
Plasma vitamin A, µg/ml	0.57	0.50	0.03	0.0798

[1] Vitamin treatment in water, Emcelle E-D$_3$ liquid (Stuart Products, Bedford, TX), supplied 120 to 360 IU vitamin E and 7,200 to 21,500 IU vitamin D$_3$ per 3.78 L of water.

The 2018 Farm Bill: Its Potential Impact on Animal Agriculture

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Summary

Agriculture policy faces budgetary challenges as Congress and the Trump Administration begin work on the 2018 Farm Bill. However, within these challenges, opportunities are available to advance important priorities for animal agriculture and animal science. Unlike many of the past Farm Bill debates, animal agriculture is coming together early in the process to play "offense" and work together to build support for funding a suite of programs through the Farm Bill to address emerging animal disease and pest threats.

2018 Farm Bill

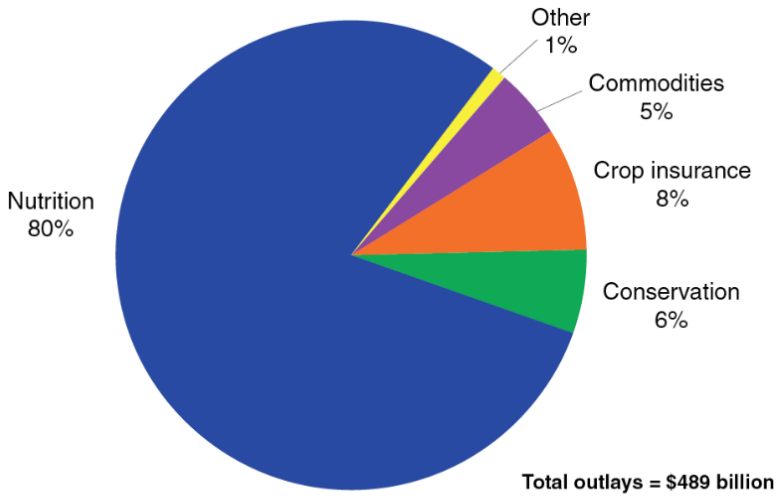
The current Farm Bill, passed in 2014, is set to expire on September 30, 2018. The House and Senate Agriculture Committees began a series of hearings early in 2017 to examine how current programs are working and hear from stakeholders about priorities for the 2018 Farm Bill.

One of the biggest challenges facing the Agriculture Committees is the budget. The 2014 Farm Bill has cost over $100 billion less over the 10-year budget window than was originally projected. While this has been good for the overall federal budget, it also decreases the baseline of spending that the Agriculture Committees will have to craft the next Farm Bill. The committees won't get credit for the unexpected savings, and the budget starting point for the next bill will be lower.

In addition, Congress is seeking to make significant reductions in overall federal spending, including agriculture programs. House Agriculture Committee Chairman Mike Conaway has fought hard to minimize the reductions to the agriculture portion of the budget and it has been reported that Chairman Conaway has reached a deal with House Budget Committee Chairwoman Diane Black that agriculture's contribution to budget reduction will be approximately $10 billion. This is significantly less than the $70 billion originally sought from agriculture programs.

While the budget situation for the Farm Bill could be worse, the shrinking amount of funds will make it difficult for the committees to support a variety of competing priorities. For example, major changes are needed to both the Dairy Margin Protection Program and the cotton support program. Nutrition programs, which make up approximately 80 percent of the Farm Bill, are an important component of keeping a broad base of support for the overall passage of the Farm Bill. Stakeholders of popular programs related to crop insurance and conservation will be pushing to maintain and increase their support within the Farm Bill. In addition to these competing Farm Bill priorities, animal agriculture is co-

Figure 1. Projected outlays under the 2014 Farm Act, 2014-2018.



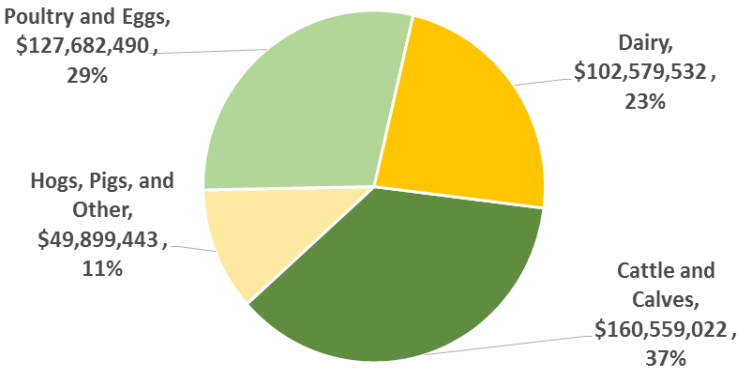
Source: USDA Economic Research Service using data from Congressional Budget Office, Cost Estimates for the Agricultural Act of 2014, Jan 2014.

alescing around three proposals that would provide critical support for animal health and production.

Animal Agriculture and the Farm Bill

In recent Farm Bill debates, animal agriculture was fractionated and forced to play defense against policies and regulations that threatened to harm the industry. Issues such as packer concentration and country of origin labeling drew the focus of key animal industry organizations and made the advancement of proactive policies to benefit animal agriculture more difficult.

Figure 2. U.S. Total 2014 Output ($1,000).



Source: 2014 Economic Analysis of Animal Agriculture, United Soybean Board

As preparations began for the 2018 Farm Bill, there was a consensus within animal agriculture that the industry and its stakeholders should take a more offensive position this cycle. The Animal Agriculture Coalition, a group of animal producer and related organizations in Washington, DC, formed a task force to look at potential initiatives to support the needs of animal agriculture. That process produced three initiatives focused on addressing the threats of emerging animal diseases and pests that have each drawn broad support from groups around the country.

Background

Animal agriculture is a major economic driver for our nation. According to the Farm Income Atlas administered by USDA's Economic Research Service, total cash receipts for animal and animal products was over $189.7 billion in 2015. This represents over fifty percent of all farm cash receipts. In addition, a recent study entitled "Economic Analysis of Animal Agriculture 2004-2014", commissioned by the United Soybean Board, found that the total economic impact of the livestock and poultry industry in the United States was $440.7 billion in 2014. This represents over 2.3 million jobs and almost $77 billion in farm income. Animal agriculture is also responsible for approximately $20 billion in income taxes and over $7 billion in property taxes.

Unfortunately, the economic contributions of the animal agriculture industry in the United States are under the constant threat of emerging animal pests and diseases that have the potential to devastate production capacity and competitiveness. In recent years, disease outbreaks have cost billions in production losses and response costs. According to the Animal and Plant Health Inspection Service (**APHIS**), the recent avian influenza outbreak cost taxpayers $1 billion in response, clean up, and indemnity costs and required the depopulation of nearly 50 million birds. That doesn't include lost export markets, temporary shortages, or price increases for certain poultry and their products.

Threats to animal agriculture span multiple species and disease type. Other examples include:

- Porcine Reproductive and Respiratory Syndrome (**PRRS**)–Recent estimates show that the annual economic impact of porcine reproductive and respiratory syndrome is $664 million.
- Foot and Mouth Disease (**FMD**)—Experts estimate it cost the United Kingdom $4.7 billion to eradicate its 2001 FMD outbreak. An uncontrolled outbreak of FMD in the United States could have as much as a $200 billion impact over 10 years.
- Exotic Newcastle Disease—The 2002 outbreak of exotic Newcastle disease in Western states which cost over $160 million and caused 4.5 million birds to be depopulated.

Such outbreaks can have a major impact on trade, lasting long after the outbreak is under control. In addition to high profile outbreaks, there are also critical gaps in meeting pest and disease challenges facing minor species. Investments in safeguarding animal agriculture promotes sustainable economic development and prevents catastrophic events that could threaten our nation's food supply.

A proactive and concerted effort by the federal government, states, industry and universities is needed to help address these threats and protect the nation's animal agriculture industry. In response to this need, the following three initiatives have been developed for the 2018 Farm Bill.

Expanded Sec. 1433 Competitive Research Grants

Current funding by USDA to support the animal sciences is not proportionate with the economic contributions of animal agriculture. In fact, investment in the

animal sciences has been stagnant for many years. This disturbing trend was highlighted by National Academy of Sciences in its report "Critical Role of Animal Science Research in Food Security and Sustainability" released in 2015. The report recognizes the historic underfunding of animal sciences and calls for increased investments.

The current funding imbalance puts U.S. animal agriculture at a major disadvantage at a critical time when livestock and poultry producers are facing serious threats from pests and disease. To help meet these threats, the inclusion of $25 million in annual mandatory funding is requested in the 2018 Farm Bill to support Sec. 1433 Continuing Animal Health and Disease Programs.

Sec. 1433 was expanded during the last Farm Bill to authorize a competitive grants mechanism to address high priority research needs. Mandatory funding for Sec. 1433 would build on the efforts from the 2014 Farm Bill by funding the competitive grants program and enabling the support of critical research to provide science-based solutions to animal pest and disease threats.

Animal Pest and Disease Disaster Prevention Program

In addition to research, there are immediate needs to bolster the Animal and Plant Health Inspection Service's support for disease and pest prevention and mitigation efforts. To help build this capacity, the creation of an Animal Pest and Disease Disaster Prevention Program to is being proposed for inclusion in the 2018 Farm Bill. Modeled after the successful Plant Pest and Disease Disaster Prevention Program and building on the 2014 Farm Bill's authorization of the National Animal Health Laboratory Network, the Animal Disease and Disaster Prevention Program will bring together the federal government with states, industry, universities, and other interested groups to reduce the impact of high-consequence animal diseases, provide rapid detection and response capabilities to respond to animal diseases, develop disease prevention and mitigation technologies including vaccines, prevent the entrance and spread of foreign animal diseases into the United States, and identify and support critical research needs.

The Animal Disease and Disaster Prevention Program would support projects organized around eight goal areas:

- Maintain and enhance exports
- Enhancing animal pest and disease analysis and survey
- Targeting domestic inspection activities at vulnerable points in the safeguarding continuum
- Enhancing and strengthening threat identification and technology
- Safeguarding animal production
- Improving biosecurity
- Enhancing response and mitigation capacity
- Conducting technology development, enhancing electronic sharing of animal health data for risk analysis between State and federal animal health officials, outreach and education about these issues.

These goals represent critical needs and opportunities to strengthen, prevent, detect, and mitigate animal pests and diseases.

The program would also support the National Animal Health Laboratory Network (NAHLN) and its efforts to establish a surveillance, emergency response and technology development system that provides resources for surveillance testing, information management, quality assurance and the development and validation of new diagnostic tests. The importance of the NAHLN is highlighted in the October 2015 bipartisan Blue Ribbon Panel report: *A National Blueprint for Biodefense*, which calls on the federal government to provide full funding for the NAHLN. Funding will support the network's early warning system so that veterinarians and scientists can quickly detect emerging and foreign zoonotic diseases as well as support applied research and technology development to ensure that science based tools are available to prevent and mitigate impacts to animal or public health or the food supply.

FMD Vaccine Bank

To complement the research and prevention programs, additional infrastructure is needed to ensure the capacity to deliver vaccines for high consequence diseases such as FMD. An outbreak of FMD would immediately close all export markets. Economists at Iowa State University examined the economy-wide impacts of eliminating export markets for 10 years for beef and pork and found the cumulative impact on the beef and pork sectors over the 10-year period would be $128.23 billion, an average of $12.8 billion per year. The annual jobs impact of such reduction in industry revenue is 58,066 in direct employment and 153,876 in total employment. Corn and soybean farmers would lose $44 billion and nearly $25 billion, respectively, making the impact on these four industries alone almost $200 billion.

Currently, the U.S. does not have access to enough FMD vaccine. The current vaccine bank arrangement has several problems in addition to insufficient funding. These include the turn-around time from the onset of an outbreak until finished vaccine can be delivered and

the limited number of doses and antigen strains maintained. Worldwide vaccine production is limited, and there is no surge capacity available to produce the millions of doses needed in the event of a large-scale outbreak in the United States.

Funds are requested through the 2018 Farm Bill to establish and maintain a rapidly deployable FMD vaccine bank. The ability to rapidly vaccinate against FMD, is central to the U.S. disease control strategy should an outbreak occur. Such an arrangement would, at minimum, provide vaccine antigen concentrate for all FMD strains currently circulating in the world. Additionally, it would ensure resources are in place for production capacity (including surge capacity) that would produce, in the shortest amount of time possible, a sufficient vaccine to meet needs in the early stages of an outbreak.

Summary

Animal agriculture is coming together in a proactive way to advance three initiatives to address critical threats related to emerging diseases and pests. By going on offense, animal agriculture has a good opportunity to make the case for investments in research, disease prevention and vaccine infrastructure and build momentum for success during the 2018 Farm Bill process. While the budget climate will be challenging, the stakes for inaction are high.

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Modern Plant Breeding and the Improvement of Corn Hybrids and Soybean Varieties

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Summary

DuPont Pioneer is the world's leading developer and supplier of advanced plant genetics providing high-quality seeds to farmers around the world. With business operations in more than 90 countries, DuPont Pioneer develops and distributes high-quality corn, soybeans, sorghum, sunflower, alfalfa, canola, wheat, rice, cotton, pearl millet, and mustard seed, as well as forage additives and a variety of services and expertise. For American livestock producers, Pioneer is committed to increasing feed production and quality with high yielding corn hybrids and soybean varieties.

CRISPR-Cas and Corn Breeding

DuPont Pioneer is committed to help growers produce more and better food, with fewer resources, through improved plant genetics. The organization's legacy in plant breeding has resulted in an industry leader in hybrid corn development. Pioneer has continuously made advancements in corn breeding since the first commercially available corn hybrid was introduced in the mid-1920s by Henry A. Wallace, Pioneer's founder (Troyer, 1998). During the past 90 years, the breeding organization within Pioneer has developed the most extensive germplasm libraries in the world including a wide range of diversity for many traits of importance, including kernel composition, as well as native resistance to important disease and pests covering an extensive range of maturities. Pioneer has always been on the forefront of advancing technologies to improve crop development and are continuously enabling technologies to leverage the maximum capacity of the germplasm. Two examples are the collaboration with Dow AgroSciences to develop one of the first biotech traits in the 1990s and being an early adopter and leader of the new gene editing tool CRISPR-Cas for development of agricultural products.

Pioneer is constantly improving and expanding the product line-up with enhanced end-use options for yellow and white corn markets. In addition to traditional breeding methods and molecular genetic strategies, newer gene editing technologies such as CRISPR-Cas are utilized. One of the first products developed using CRISPR-Cas are next generation waxy corn hybrids (Chilcoat et al., 2017). Waxy hybrids differentiate from yellow number 2 corn hybrids by their high amylopectin starch content and are used for processed foods, adhesives, and high-gloss paper. Waxy corn grain is also exported for feed in the livestock, dairy, and poultry industries. This new technology allows for improved waxy hybrids with fewer unfavorable characteristics from older donor inbreds carrying the native waxy gene. It is also a more time efficient method since the it excludes traditional backcrossing methods which typically take two to three years.

The CRISPR-Cas technology has applicability for a number of different traits. Tools like CRISPR-Cas, combined with the strength of traditional methods and technologies in the Pioneer corn breeding model, have been implemented globally across other crops like soybean, canola, sunflower, rice, and wheat.

Soybean Breeding and Improvement of Meal Quality

Protein meal makes up a critical piece of livestock nutrition. Soybean meal constitutes the vast majority of protein meal consumed by livestock worldwide. Total worldwide soybean meal consumption was 225.1 metric tons in 2016; comparatively, the second and third most consumed protein meals are sourced from canola (38.1 metric tons) and sunflower (17.7 metric tons) (ASA, 2017). In 2016, American swine consumed 7.7 million metric tons of soybean meal, accounting for approximately 19% of total U.S. soybean meal produced.

Trading rules set by the National Oilseed Processors Association require dehulled soybean meal to contain a minimum of 47.5 to 49.0% protein by weight (NOPA, 2016). Final protein content in soybean meal is a function of protein content as well as oil content in the raw grain. In 2015, the average seed composition of the

U.S. crop contained 34% protein and 19% oil by weight (USB, 2017). However, at 19% oil content, protein content needs to be in the 34.5 to 36% range to consistently produce meal exceeding the 47.5% NOPA minimum specification (Brumm et al. 2004). Significant variation for raw protein content exists across U.S. growing regions as well. Soybeans produced in the upper Corn Belt states (notably Minnesota, North Dakota, South Dakota) are consistently lower in protein content than crops produced in the lower Corn Belt and the southern U.S. (Rotundo et al., 2016); the U.S. Soybean Quality Survey reported an average protein content of 33.8% in 2016 for the upper Corn Belt crop compared to the national average of 34.4% (Miller-Garvin and Naeve, 2016).

Historically, yield improvement has driven the bulk of variety selection decisions in private industry soybean breeding programs. However, protein content has a negative genetic correlation with both oil content as well as yield (Wilcox and Guodong, 1997). Selection for higher seed yield in modern soybean varieties typically comes at the cost of decreased protein content. Recently, a proof-of-concept study initiated by the United Soybean Board and DuPont Pioneer aims to improve protein quality and content in maturity group 0 – I soybean varieties (common maturities for the upper Corn Belt) without sacrificing yield potential or oil content (USB, 2017). The main goal of the project is to determine if it's genetically and economically feasible to increase protein levels in upper Corn Belt soybean varieties before any wide-scale breeding efforts would begin.

Breeding for complex quantitative traits in soybean, like protein content and yield, has been a historically slow process. In the past, DuPont Pioneer soybean breeders relied on unreplicated single-location progeny row yield trials (PRYTs, for short) for the first year of yield and agronomic testing for potential new varieties. Such unreplicated trials are prone to high levels of experimental error due to issues like field variability, severe weather events, and disease and insect pressure. This error had limited the ability of soybean breeders to make rapid genetic gains in complex traits. However, the development of Accelerated Yield Technology (**AYT**), in combination with expanded molecular breeding capabilities and increased investment in additional research centers and on-farm yield trials, has greatly improved the ability of DuPont Pioneer soybean breeders to make rapid gains in yield and other traits (Sebastian et al., 2010). The AYT strategy involves testing thousands of new experimental lines each year across a wide range of growing environments in the U.S. and Canada. Yield (as well as other agronomic and quality traits) and molecular marker data are collected from each line, and genetic regions for yield are identified in the DNA sequence of each experimental line. Information from these regions is used to identify the highest-yielding experimental varieties within the Pioneer research pipeline, which helps to mitigate much of the experimental error associated with early-generation soybean breeding. The high confidence and accuracy associated with AYT has allowed breeders to double the rate of genetic gain of experimental varieties in the research pipeline and reduced the time to bring products to market.

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Mycotoxins: When, Where, and Why

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Summary

Mycotoxins are one of the many issues that swine producers must contend with as they manage feed quality and maintain a healthy herd. These natural chemicals are produced by fungi in cereal grains, which are major carbon sources for swine feed. Predicting whether mycotoxins will be a problem is difficult and testing is expensive. The answers to questions about when, where, and why mycotoxins are produced have not totally been found. However, research has given us some insights. This article highlights what we know about the major mycotoxins that impact swine health and provides a starting point for a discussion about how to manage crop production to reduce the risks of mycotoxin contamination.

Introduction

Although there are hundreds of mycotoxigenic compounds, four classes of mycotoxins (aflatoxins, trichothecenes, zearalenones, and fumonisins) impact swine production. Aflatoxins and fumonisins are primarily found in corn-based feed sources and trichothecenes and zearalenones are common contaminants of corn and wheat (Table 1). These mycotoxins are produced by plant pathogens that infect the seeds prior to harvest and if the grain is not properly handled during drying, storage, and processing, the concentration of mycotoxin can increase dramatically.

The effects of mycotoxins are complex and often difficult to diagnose. Factors such as the mycotoxin type, concentration in feed, animal age, and duration of exposure will determine the severity of the mycotoxicosis and the symptoms expressed. While most producers will observe poor growth or reproductive performance caused by mycotoxin-contaminated feed, many studies by animal scientists have focused on the hematological, biochemical, and molecular effects of mycotoxins on systems that control immunity, reproduction, and digestion. These studies have led to the discovery of specific biomarkers associated with mycotoxin exposure.

Table 1. Major fungal producers of mycotoxins affecting swine health.

Mycotoxins	Major Producer	Feed Sources
Trichothecenes (DON)	*F. graminearum*	Maize, Wheat, Barley
Zearalenones	*F. graminearum*	Maize, Wheat, Barley
Fumonisins (FB1)	*F. verticillioides*	Maize
Aflatoxins (B1)	*A. flavus*	Maize, cottonseed

Trichothecenes

Trichothecenes are a large group of structurally similar metabolites produced by many fungi, but most notably by *Fusarium* species. Trichothecenes are divided into four groups (A-D) based on specific structural differences (Wu et al., 2013). The Group A trichothecenes are the most toxic, and T-2 toxin was developed as a biological weapon. Fortunately, Group B trichothecenes are the most common mycotoxins encountered in the United States. A variety of similar chemotypes can be isolated from corn and wheat, with deoxynivalenol (**DON**, vomitoxin) being the most predominate. For swine production, DON is one of the most important mycotoxins. DON is a gastrointestinal toxin that can also affect the immune system (Girardet et al., 2011; Pinton and Oswald, 2014). At high dosage, symptoms include vomiting and diarrhea, and lower dosage causes feed refusal and reduced weight gain.

Fusarium graminearum (Gibberella zeae) is the major species associated with DON contamination in US corn and wheat (Figures 1 A and B). This pathogen, which resides on crop residue, infects both crops, and attacks during the flower and silking periods. Environmental conditions are crucial for disease (Fusarium head blight of wheat and Gibberella ear rot of corn) development. Ideal conditions for infection are rainy conditions when plants are flowering with temperatures in the 70s F (20s C). For corn, the warmer temperatures in the most southern regions of the corn belt are usually not conducive for infection. In wheat, the mycotoxin is a virulence factor that enhances disease development (Desjardins et al., 1996). Wheat flowers produce polyamine compounds that induce DON production upon initial infection by the pathogen (Gardiner et al. 2010).

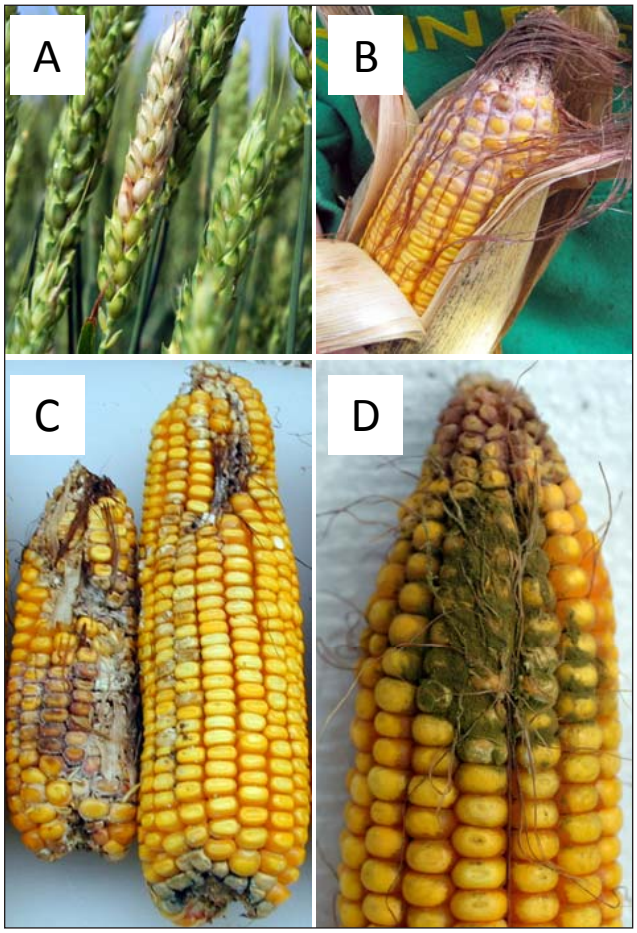

Figure 1. Disease symptoms caused by *Fusarium graminearum* (A & B), *Fusarium verticillioides* (C), and *Aspergillus flavus* (D).

Less is known about the trigger for DON production in corn but there is evidence that it is a virulence factor (Harris et al. 1999). Generally, one can expect that DON concentrations correlate to the severity of visible disease symptoms. However, there are many cases in which high DON contamination is found in grain with very little rot symptoms, making management decisions more difficult.

Zearalenones

Zearalenones are potent mycotoxins that can be devastating to swine breeding operations. At relatively low dosages, the hyperestrogenic effects of zearalenones can disrupt the reproductive systems of both gilts and sow, although gilts are more sensitive (Kanora and Maes, 2009). Zearalenone is produced by many of the same *Fusarium* species that produce DON (Table 1). The biosynthetic pathways for zearalenone is different from DON, thus production of the two mycotoxins is not coordinated in infected seeds. One often finds grain that is contaminated with DON, but contains no detectable zearalenone. In contrast, grain contaminated with only zearalenone is rare, probably due to the role of DON as a virulence factor. The reason why fungi produce zearalenone is unknown.

Fumonisins

Fumonisins are best known for their lethal effects on equine and their potential to cause cancer and birth defects in humans. In swine, fumonisins can cause the buildup of fluids in the lung, known as pulmonary edema (Harrison et al., 1990). Fumonisin specifically inhibits an enzyme in the sphingolipid biosynthetic pathway, which produces metabolites crucial to cellular structure and regulation. One of the hallmark effects of fumonisin on both plants and animal cells is the induction of a phenomenon known as programmed cell death, which is a cellular suicide mechanism.

Fumonisin is produced by the corn pathogen *Fusarium verticillioides*, which causes Fusarium ear rot (Table 1). Despite its ability to induce cell death, there is conflicting evidence about whether the mycotoxin has a role in disease. Despite this debate, evidence clearly shows that non-fumonisin-producing strains cause similar levels of disease as wildtype strains. Disease is most severe during hot dry weather and when insect damage provides entry points into the kernel (Figure 1C). Thus, BT hybrids that target the ear insects have less disease and subsequently less fumonisin contamination. Unlike Gibberella ear rot, there is no correlation between the severity of Fusarium ear rot and the amount of fumonisin contamination. The conditions needed for fumonisin production are complex. One of the major inducers of synthesis is the kernel starch, especially the branched molecules of amylopectin (Bluhm and Woloshuk, 2005). As a result, fumonisin production occurs primarily in the endosperm tissues, comprising 90% of the fumonisin found in the kernels. Although the fungus grows well in germ tissues, conditions are not conducive for fumonisin production (Shim et al., 2003).

Aflatoxins

Aflatoxins are potent liver toxins that impacts the health of all livestock and even humans. Swine are not particularly sensitive to the toxin, but piglets are most vulnerable. The effects of contaminated feed will be slow growth and at high dosage, death can occur. Long term effects of feeding aflatoxin-contaminated feed results in suppression of the swine's immune system. Furthermore, aflatoxin consumed by sows can pass through the mammary glands to nursing piglets.

Aspergillus flavus is the predominate aflatoxin-producer on corn ears (Table 1). The pathogen, which survives in the soil, has been referred to as an oppor-

tunistic pathogen because infection occurs when corn plants are weakened by drought and heat stress (Shu et al., 2015). Although aflatoxin has some insecticidal activity, which some scientists believe evolved to protect the fungus' niche, damage to the kernel by insects helps provide points of entry for the fungus to invade (Zeng et al., 2006). Once infection has occurred (Figure 1D), the fungus can colonize all tissues of the kernel, however the oil rich germ is where aflatoxin accumulates most extensively.

Harvest

The decision on when to harvest grain is one of economics and capacity of the producer's grain handling system. Delaying harvest to allow in-field drying can save the producer in drying cost. Weather conditions also play a major factor in this decision making. With respect to mycotoxin contamination, any delay in harvest brings the risk that fields with minor levels of disease will quickly experience a rise in mycotoxin contamination. Spring rains during harvest season of winter wheat or fall rains brought on by hurricanes, interrupt the dry-down process and can even cause rewetting of the grain. These conditions may not result in more disease, but the pathogens often continue to produce mycotoxins in the infected kernels. Extension specialists and crop advisers need to educate producers on these potential risks. Identifying which fields are infected with mycotoxin-producing fungi, whether low or high in incidence and severity, is crucial. Harvesting these fields early before weather conditions can cause delays will reduce the risk of mycotoxin buildup.

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Inflammation: Costs and Control

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Summary

The inflammatory response to infection or other insults results in a series of biochemical, physiological, and behavioral changes that have important nutritional consequences. Most important among these is a decrease in food intake. Also important are a decrease in the digestibility of key nutrients such as lipids and fat soluble vitamins and the shunting of nutrients to support the proliferation of responding leukocytes. The liver transitions from maintaining homeostasis and supporting the nutritional demands of growth or reproduction to the production of protective proteins such as complement, mannan binding protein, and C-reactive protein that aid in the detection and neutralization of pathogens. The ideal balance of amino acids for the acute phase of an inflammatory response differs greatly from that needed for growth and there is a critical need for additional cysteine and threonine. Together, these costs result in decreased productivity that cannot be completely reversed by supplying additional nutrients

Introduction

The quantitative investment in immune defenses (costs) is thought to be under tight evolutionary control because they must be sufficient to thwart pathogens without excessively consuming resources (e.g., nutrients and energy) needed for other important processes that are required for the survival and expansion of a species (Ardia et al., 2010, Schmid-Hempel, 2011). Thus, in animal production there is concern that the immune system competes for nutrients with anabolic processes that determine the rates and efficiencies of growth and reproduction. The practical implications are twofold. First, unnecessary or overly robust immune responses may diminish the rate and efficiency of production. Second, that intensive genetic selection of livestock and poultry for efficient growth and reproduction for many decades may have diminished the immune system and consequently reduced disease resistance.

Overview of the Dynamics of an Immune Response

Individual components of the immune system respond to an infectious challenge at very different rates. Innate immune cells respond quickly to a challenge due to the presence of a common set of receptors on all phagocytic cells (e.g., macrophages and neutrophils) that recognize broad categories of pathogens (Medzhitov, 2001). Thus, a very large number of cells can recognize invading microbes and respond to them quickly. Conversely, the lymphocytes that mediate adaptive immunity have receptors that are narrowly tuned to a specific antigen and a diverse population of lymphocytes exists in order to identify a very large number of antigens. Because the initial population of lymphocytes that possess the appropriate receptor for a given pathogen is very small, this subset of lymphocytes must proliferate for several days to reach protective numbers. These responding lymphocytes transition from the least metabolically active cells in the body to some of the most active in order to support their rapid replication and copious secretion of effector molecules such as immunoglobulins.

The largest source of protective proteins during an immune response is hepatocytes. During the first day of an inflammatory response to a pathogen challenge the liver transitions from maintaining homeostasis and supporting the nutritional demands of growth or reproduction to the production of proteins such as complement, mannan binding protein, and C-reactive protein that aid in the detection and neutralization of pathogens. During the acute phase response against a successful pathogen, the liver becomes the most important organ of the immune system—when using nutritional demands as the metric. By five to seven days of a typical immune response the production of lymphocytes and immunoglobulin become quantitatively greater than the production of acute phase proteins. Overall the inflammatory (innate) and lymphocyte (adaptive) responses work sequentially to provide an immediate response to infection via innate processes, while slowly developing a specific response that is mediated by lymphocytes. This temporal division serves to spread the nutritional costs of a response over a longer period of time.

Size and Nutrient Content of the Immune System

Nutritionist have rigorously applied quantitative theory and mathematical modeling to nutrient needs for growth and reproduction as influenced by dietary and environmental factors. However nutritionists have generally been remiss in applying robust quantitative tools to tradeoffs between performance and immunity. We have endeavored to make quantitative estimates of the size of these tradeoffs as well as each of the underlying processes that siphon nutrients away from growth and reproduction. To do this we have assessed the amount of nutrients needed for mounting an immune response using both direct and indirect estimates.

Indirect estimates were made by quantifying the magnitude of growth depression that occurs during the periods of time that growing broiler chicks mount an initial innate response and also a subsequent adaptive immune response. We estimate that a robust acute phase immune response against a simulated infection with dead *Escherichia coli* decreases growth by about 25-30% but there is no decrease in growth during the subsequent adaptive response. About two-thirds of the growth depression during the acute phase response is due to a decrease in appetite and about a third is due to nutrient diversions or losses related to the immune response.

Direct estimates were made by quantifying the whole body dynamics and nutrient content of the myriad of cells and proteins responsible for protective immunity during the innate (inflammatory) and adaptive (lymphocyte) responses to a simulated infection with *E. coli* (Iseri and Klasing, 2013; 2014). Although energy expenditure or any one of the dozens of dietary essential nutrients might be used as a metric for nutritional expenditures by the immune system relative to other tissues, the essential amino acid lysine was initially used as a reference nutrient. This is because lysine is the reference amino acid in the ideal protein system used commonly in non-ruminant nutrition because it functions almost exclusively as a substrate for protein synthesis and cannot be stored or synthesized.

The studies by Iseri and Klasing (2013, 2014) examined the amount of lysine in six different leukocyte types in five different tissues (blood, spleen, bursa, thymus, bone marrow) and 12 protective protein/immunoglobulin pools, all at several time points. The immune system has both systemic and mucosal components; however, we limited this investigation to the systemic system due to the extreme difficulty of quantifying the diffusely organized mucosal immune system. A summary of the data is shown in Figure 1 and indicates that the amount of lysine in protective proteins, such as the acute phase

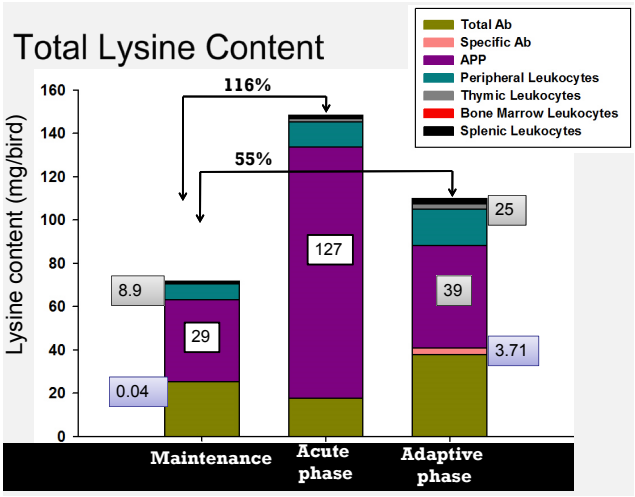

Figure 1. Lysine content (mg lysine/g lysine in the whole body) of cellular and effector protein components of the systemic immune system at time 0 (maintenance) and during the early response (24 hr) or late response (5 d) following an i.v. *E. coli* injection.

proteins and immunoglobulins, greatly exceed that in the cellular component of the immune system, regardless of whether the immune system is responding or not. During the acute phase of the immune response the liver hypertrophies markedly for the rapid production of acute phase proteins. The liver is recruited to become part of the immune defenses during the acute phase response and becomes the most expensive part of the response. The amount of lysine needed for the adaptive phase of the response (antibody production and new lymphocytes) is much less than that needed for the acute phase of the response and is incurred following the acute phase response (i.e., after 3 days). During the transition from the acute phase response to the time when the adaptive response begins to utilize significant quantities of lysine, the size of the liver and levels of protective proteins return toward normal. The lysine liberated from protein catabolism of hepatic tissue and acute phase proteins would provide a surplus of lysine to provision the anabolic processes of the adaptive response.

The amount of lysine consumed by the immune system during a robust response accounts for only a 5% decrease in growth, which is not sufficient to account for the 25-30% decrease that is observed during the response. This means that the cost of an immune response is mostly due to protective processes and physiological adjustments that are unrelated to the needs of leukocytes or the production of protective proteins. Even when the hypertrophy of the liver and the massive production of acute phase proteins are included, the amount of nutrients diverted to protective processes accounts for very little of the depression in growth or reproduction that occurs during the response.

Table 1. Mismatch between the balances of amino acids in the immune system versus in skeletal muscle (Ratio of amino acid in the immune system to that in skeletal muscle).

	Innate System		Adaptive System
Amino acid	**24hr Ratio**	**5d Ratio**	**5d Ratio**
Arginine	0.81	0.94	0.82
Cysteine	**1.88**	**1.62**	1.67
Glycine	1.53	1.42	1.43
Histidine	0.76	0.79	0.42
Isoleucine	0.83	0.80	0.50
Leucine	0.96	1.00	0.89
Lysine	0.69	0.72	0.42
Methionine	0.72	0.61	0.36
Phenylalanine	0.82	0.90	0.66
Proline	0.99	1.04	2.11
Threonine	1.40	1.29	1.04
Valine	1.09	1.18	**2.26**

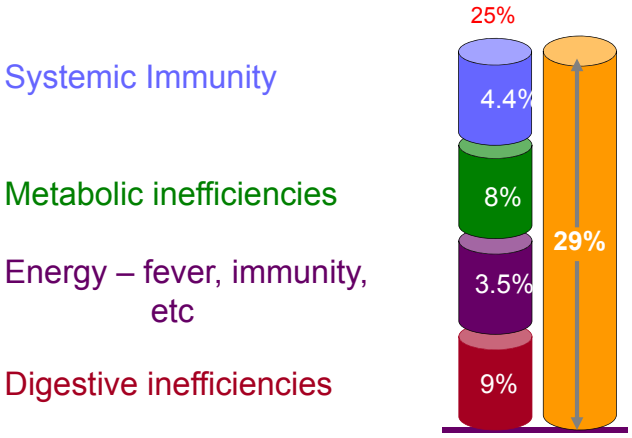

Figure 2. Contribution of various factors to the growth depression that accompanies an immune response to *E. coli.* A decrease feed intake is responsible for 68% of the decreased growth and other factors, including those below, account for 32% of the decreased growth.

More recently, we have examined the ideal balance of amino acids for the immune response to a pathogen and found that lysine needs are relatively lower for immunity compared to muscle deposition in chickens (Table 1.). Of all of the essential and semi-essential amino acids, cysteine is the most limiting amino acid during the acute phase response (Table 1; Iseri and Klasing, 2013; Sirimongkolkasem, 2017) and this has also been shown in rats (Breuille et al., 2006). This is due to a mismatch between muscle cysteine release and hepatic demand for the markedly enhanced production of acute phase proteins and glutathione, which serves as an antioxidant. This large difference in the balance of amino acids needed for the immune response relative to accretion of body tissue greatly increases the protein cost of an immune response. Ongoing research indicates that fever, metabolic inefficiencies due to futile metabolic cycles, and less efficient digestion that accompany a robust immune response are, together, nutritionally more important than the diversion of nutritional resources to the immune system (Figure 2). Quantitatively, a decrease in digestion of nutrients, especially fat and some amino acids (Table 2) is the second most important physiological change after food intake when the nutritional impact is used as a metric.

Mitigation of the Nutritional Costs

Obviously prevention of immune responses is the most direct way to minimize their costs. Management for a high level of sanitation and specific pathogen free (SPF) facilities reduce the probability of animals encountering most of the pathogens that trigger robust inflammatory responses. Vaccination against infectious agents that are likely to be a problem is useful when the cost of the immune response against the vaccine is less than probable losses due to a challenge from a pathogen. Vaccines have nutritional costs (Cook, 1999) and it is certainly lower than the cost of the robust inflammatory response elicited by most pathogens. Thus, the cost of the insurance (vaccination) must be weighed against the probability and cost of the potential losses.

Nutritional approaches to minimize the inflammatory response have been clearly shown to be effective at decreasing inflammation in controlled academic studies. A variety of nutrients modulate the immune system by direct actions on regulatory mechanisms of leukocytes. Required nutrients with indisputable immunoregulatory actions in rodents and livestock include linoleic acid and vitamins A, D, and E. Many nutrients that are not normally considered as being dietary essential also modulate immunity, including carotenoids, vitamin C, and phytonutrients (e.g., capsicum, genistein, curcumin, essential oils, conjugated linoleic acids). In general, those nutrients that are not structural components or co-factors for enzymes are most likely to be immunomodulatory. Supplementation of immunomodulatory nutrients causes some components of

Table 2. Ileum digestibility of nutrients following an iv. challenge with *E. coli* in broiler chicks

Nutrient	Control (pair fed)	+ E.coli	SEM	Significant *P* Value
Starch	100	96	2.8	-
Lysine	100	98	2.6	-
Methionine	100	92	2.0	0.05
Cysteine	100	97	2.4	-
Glutamine	100	101	2.4	-
Lipid	100	81	2.2	< 0.01
Retinol	100	56	2.1	< 0.01
Lutein	100	36	3.0	< 0.01
Ca	100	89	2.8	0.03
Fe	100	63	2.9	< 0.01
Zn	100	95	1.5	0.06
Cu	100	92	2.8	0.06

immunity to be elevated and others to be diminished; in other words, the type and intensities of responses have been changed (i.e., immunomodulated). Thus, immunomodulatory nutrients that dampen inflammation also impact lymphocyte mediated immunity and resistance to infectious diseases.

Immunomodulatory nutrients influence the balance of cytokines and eicosanoids released by regulatory cells (Fritsche, 2006). Usually, these changes dampen the inflammatory response but also and shift lymphocyte responses from T-cytotoxic (Th1, cell-mediated) towards antibody responses (Th2). This polarization of adaptive immunity has implications for the susceptibility of experimental animals to authentic infections and may result in a greater incidence of many infectious diseases if challenges occur. Unfortunately, the use of nutrients that dampen the inflammatory response may increase susceptibility to some infectious diseases resulting negative outcomes.

In the few studies that have looked, the specific effects of immunomodulatory nutrients are highly dose dependent. This has been clearly shown for PUFAs, vitamin E and vitamin A, where the immunomodulatory actions follow a bell-shaped curve and high levels may not be as useful as moderate levels (Leshchinsky and Klasing, 2001; Sklan et al., 1994).

Further complicating the picture, the net immunomodulatory influence of a diet is not a simple sum of the actions of the individual immunomodulating nutrients because there are robust and sometimes unpredictable nutrient interactions. For example, the anti-inflammatory effect of dietary lutein on chicken macrophages depends on the amount of PUFAs in the diet (Selvaraj and Klasing, 2006; Selvaraj et al., 2011), The converse is also true in that the anti-inflammatory effects of n-3 PUFAs are dependent on the amount of lutein in the diet. This interaction is mediated by nuclear hormone receptors that respond to these two nutrients (RXR for lutein and PPAR for PUFAs), which in turn affect the expression of immuneregulatory cytokines. Similarly, different dietary fatty acids of the n-3 and the n-6 series have separate and interactive effects when supplemented to diets of broiler chicks (Parmentier et al., 2002). Both experimental and clinical results clearly indicate that the specific immunomodulatory actions of a nutrient and its interactions with other dietary nutrients must be understood before application to animal populations because its efficacy is dependent on the milieu of infectious and metabolic diseases that are present.

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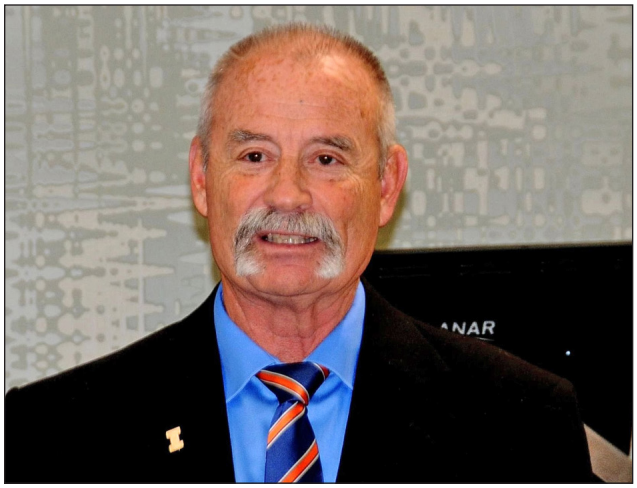
Anna Dilger, University of Illinois, Speaker

Hans, Stein, University of Illinois, Speaker



Steven Loerch, University of Illinois, Moderator

Alan Mathew, Purdue University, Moderator

Scott Radcliffe, Purdue University, Videographer

Over 100 guests in attendance.

2016 Conference

Attendees in the lunch line.

Roast pork loin with all the trimmings for lunch.

Attendees enjoying lunch.

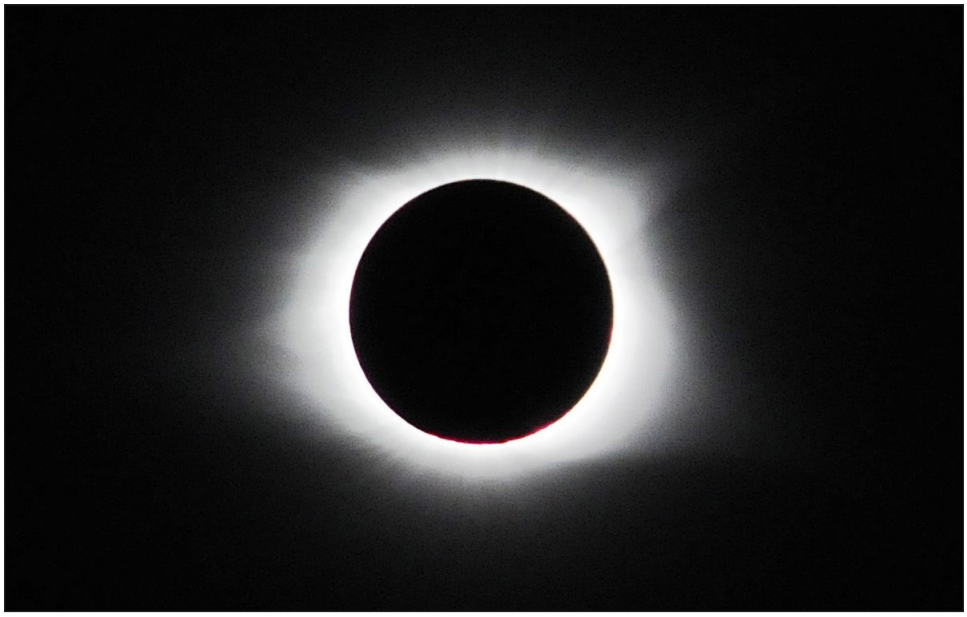
Don Orr, JBS United (left) visits with Bob Easter, University of Illinois (right).

Rob Stuart, Stuart Products (left) and Gretchen Hill, Michigan State University (right) catch up on the latest news.

Conference Room, Indiana Farm Bureau Building, Indianapolis

2017—The Year of the Eclipse

The total number of sponsors this year (n = 46) "eclipsed" the previous record of 43 sponsors in 2014 and 2016.



Thanks to all the 2017 sponsors.

Photos of the eclipse taken by Gary Cromwell in Nashville, Tennessee on August 21, 2017.

Number of Years of Sponsorship

No. of Years	Company
17	Alltech
	JBS United
16	Elanco Animal Health
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	Purina Animal Nutrition (previously Land O'Lakes/Purina Mills)
15	PIC North America
	Zinpro Corporation
14	Ajinomoto Heartland
	APC Company
	DSM Nutritional Products
	Evonik-Degussa Corporation
	International Ingredient Corporation
	Novus International
	Prince Agri Products
13	Agri-King
	BASF Corporation
	Fats and Proteins Research Foundation
12	Cooper Farms
	DuPont (previously Danisco Animal Nutrition)
	National Pork Board
	Ralco Nutrition
	Zoetis (previously Pfizer Animal Health, Alpharma)
11	ADM Animal Nutrition
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	Darling Ingredients (previously Griffin Industries)
	Kemin
10	Kent Nutrition Group
	Phibro Animal Health
9	Pioneer Hi-Bred International
	POET Nutrition
8	Novartis Animal Health
	The Maschhoffs
7	Lallemand Animal Nutrition
	Micronutrients
	Stuart Products
6	AB Vista Feed Ingredients
	Diamond V Mills
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