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Global Demand for Animal Protein and its Implications for the Feed Industry

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Summary

Global demands for food are expected to increase 100% by 2050 driven by an increase in global population to 9+ billion and a growth in affluence primarily in China, India, Eastern Europe and Latin America. Twenty percent of this increased food demand can come from increased land put into production; however, environmental concerns and competing use for biofuel production will challenge this opportunity. Ten percent can come from increased cropping intensity. The remaining 70% must come from improved efficiency through the use of technology. The challenge will be to meet this tremendous demand in food in a sustainable manner (environmentally friendly, socially responsible, economically viable and scientifically verified).

Historically, we have been able to make great strides in agricultural technology to allow for the continued production of safe, affordable food in ample supplies. However, redefining these technologies and discovering new ones will be critical to expanding productivity improvement going forward. There are tremendous challenges that reduce our ability to achieve these goals (consumer demands, activist groups, government regulations, poor economics in production agriculture, funding needs for research and development, alignment in agriculture on key issues and challenges to keep science at the table in food policy decisions). Animal production will happen in countries with a favorable climate, available land, available water, resource accountability, human resources, production technologies, low cost of production and global quality standards. The feed industry will undergo continued consolidation as the customer base consolidates and changes. Growth and profitability will be challenged by raw material pricing and availability, development of new technologies, feed safety issues, consumer demands, regulatory issues, political influences and quality people.

Introduction

In the U.S. and other developed countries, it is difficult to fully appreciate the global challenges of feeding a growing population because of the relative abundance of safe and affordable food. It is estimated that nearly 1 billion people are hungry today around the globe (UN FAO, 2008a). With current population growth projections, the global population is expected to exceed 9 billion by 2050 versus the current 6.7 billion. Coupled with this increase in population is the increase in affluence that is expected to occur in countries like China, India, Eastern Europe and Latin America (Hines, 2008). This increase in affluence has been shown to be linked to a higher level of food consumption with a high percentage of that growth occurring with increased animal protein consumption (meat, milk and eggs) (Steinfeld et al., 2006). These changes in population and food consumption patterns clearly indicated that we will need 100% more food in 2050 (Green et al., 2005) (Tilman et al., 2002). This is a tremendous increase that will depend primarily on the development and application of technology. It is estimated that 70% will need to come from technology. This represents a unique challenge and opportunity for agriculture to step up to this formable task. Production agriculture, agribusiness,

government agencies involved with agricultural policy and university research, teaching and extension must work together to accomplish this key role in future food production.

Global Issues Affecting Animal Nutrition Industry

- Growing population
- Demands for more food and animal protein
- Sustainability of our food supply
  —Environmentally friendly
  —Socially responsible
  —Economically viable
  —Scientifically verified
- Keeping science at the table
- Communication with the consumer
- Political influences
- Individual response to these changes

Each of these issues present challenges and opportunities for the animal nutrition industry as it strives to do its part in meeting the demands of the growing global population. Economists classify our world in three socioeconomic groups:

- First World (W1): Affluent, industrialized nations and regions including US, Western Europe, Japan, S. Korea and Australia. 2008, population 1 billion
- Second World (W2): Nations where the key challenge is balancing resources and needs: China, India, Eastern Europe and Latin America. 2008, population 3-4 billion
- Third World (W3): Nations that are consistently in dire straits, such as Bangladesh, Haiti and most of Africa. 2008, population 1-2 billion (Hines, 2008).

Population growth is related to economic growth and food demands:

- Nearly 1 billion people didn't get enough to eat in 2008 (UN FAO, 2008a)
- 42% of these chronically hungry people live in India and China (UN FAO, 2008b)
- One in every four children in W2 and W3 nations is underweight for his or her age (UN FAO, 2008c)
- Expected rise in population by 2050 will be characterized by growth in affluence in W2 nations leading to the greatest rise in meat, milk and egg consumption in history (Hines, 2008) (Simmons, 2009).

It is projected that the world food demand will increase by 100% by 2050 (Green et al., 2005) (Tilman et al., 2002). This will require the global production of meat and dairy protein to double by 2050 (Steinfeld et al., 2006). The U.N. FAO further states that 70% of this additional food supply must come from the use of efficiency enhancing technologies (Simmons, 2009). Long term trends (2005-2050) in meat consumption clearly show that Latin America and Asia have the largest increases expected (Latin America-28 to 47 million metric tonnes; Asia-116-153 million metric tonnes) (Roppa, 2007).

Sustainability's Role in Meeting Future Food Demands

Sustainability can be defined in many ways but most agree on the following: meeting the needs of the present without compromising the ability of future generations to meet their own needs. There are many factors that are challenging our ability to produce sufficient food to sustain life:

- Population growth expected to exceed 9 billion by 2050
- Demand for food to be produced organically to reduce fossil fuel fertilizer use and no pesticides
- Demand for locally produced food to reduce dependence on fossil fuel for transportation
- Animal rightists pushing legislation to stop animal production as they promote zero meat consumption
- Global government regulations that restrict the latest scientific technology especially related to GMO
- Shrinking land available for production and environment concerns with deforestation and destruction of the rainforests

Eating is basic to our sustainability. Economic, cultural and religious differences affect food needs in different parts of the globe. There are major concerns dealing with food production, food distribution, food safety and food security. Consumers are more health conscious and safety concerned. We have all seen the growth of organic and locally grown as trends in consumer choice even at higher prices. Animal rightists continue to grow their consumer and financial base as they attack animal agriculture in several fronts (research centers, retail food chains, corporate meetings as shareholders, political front, mass media, children's educational material, etc.). Global warming and the potential affects and opportunities for agriculture of a carbon cap and trade initiative are actively being developed.

If technology is to provide 70% of the projected food demands by 2050 we must work together in a sustainable manner, keeping in mind that our efforts must be: environmentally friendly; socially responsible; economically viable; and, scientifically verified. Keeping science at the table will require a coordinated effort on all parties along the food chain.

Technology's Role in the 21st Century as Related to Food Economics and Consumer Choice

Simmons (2009) covered this topic in detail as he described why agriculture needs technology to help meet a growing demand for safe, nutritious and affordable food. He stresses that driven by production efficiency; agriculture can achieve the "ultimate win" for consumers worldwide—affordability, supply, food safety, sustainability and ample supplies of grain for biofuels. He points out three key concepts—collaboration, choice and technology—emerge as the pathway to this success.

Implications for the Feed Industry

The following are some of the factors that will result from this increased demand for animal protein and the changing production side of meat, milk and eggs:

- Consolidating customer base
- Concerns as to development of new technologies
- Wide swings in raw material costs
- Raw material shortages
- Feed safety issues
- Regulatory and political issues
- Consumer demands
- Quality people
- Financial expectations

How the feed industry will respond to these factors will depend on their size, offer segmentation, commitment to research, optimization of physical assets, ability to find and keep quality people, financial strength and access to global raw materials and technology. Regardless of their response, all players involved in the feed/nutrition chain must be efficient, quality focused and add value at some stage in the process.

Where Will the Animals be Produced?

It is clear that there are many factors that will influence where the animals will be produced in order to meet this growing demand for meat, milk and eggs:

- Favorable climate
- Land and water availability
- Land consciousness
- Human resources
- Production technologies
- Capability to produce a safe, high quality product
- Low cost of production (Roppa 2007).

We can certainly add factors such as environmental constraints, animal rightist activities, political influences and regulatory guidelines as ones that will play a key role in where the animals will be produced.

European studies clearly show that animal production costs will be influenced by factors such as: environmental concerns, public health, production rights, spatial planning and animal welfare. A producer survey in 2003 projected the following as the greatest challenges to the US pork industry over the next 5 years: air quality regulations-65%; water quality regulations-39%; restrictions on antibiotic use-35%; civil suits against production units-74%; animal rights issues-61%;

packer concentration-4%; vertical integration-4%; over-supply of hogs-100%; adoption of COOL-9% (U.S. Pork Industry Structure Study, 2003). As we look at these concerns today, we can see that this survey was rather accurate.

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Feeding DDGS to swine and resulting impact on air emissions

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Summary

A study was conducted to evaluate air emissions that resulted from feeding distillers dried grains with soluble (DDGS) to pigs during the grow-finish phase. A control diet (0% DDGS) was compared to a diet containing 20% DDGS and customary inorganic mineral sources and a diet containing 20% DDGS with organic mineral sources. Organic mineral sources were used as a means of mitigating increased S emissions that might be observed as a result of the DDGS S content. Findings demonstrated that feeding organic mineral sources alleviated increased H_2S emissions that resulted from including DDGS at 20% of the diet. However, feeding DDGS increased emissions of NH_3, CH_4 and non-methane hydrocarbons. Further increases in these emissions were observed as a result of feeding the organic minerals. Further work is needed in order to better understand the mechanism for these observations.

Introduction

While growth in the U.S. ethanol industry has slowed in the last year, corn co-products such as distillers dried grains with soluble (DDGS) remain important feed ingredients. Air emissions from animal feeding operations continue to draw attention at both the state and federal levels. A study conducted at Michigan State University demonstrated that as much as 30% inclusion of DDGS in swine diets can be fed without negative impacts on animal performance or carcass composition provided that DDGS is removed from diets 30 d before harvest (Hill et al., 2008). Feeding corn DDGS was shown to increase hydrogen sulfide emissions (H_2S) from swine when inclusion levels increased from 0 to 30% diet during a 6-phase grow-finish feeding program (Powers et al., 2007a). Development of practices to reduce emissions is therefore of great importance to producers as they consider how future regulations may impact their operations.

The objectives of this study were to 1) determine the effect of feeding DDGS to swine throughout the grow-finish phase on gaseous emissions and nutrient excretions and to 2) evaluate the use of organic trace mineral sources as a means of mitigating increased S emissions that may occur as a result of DDGS feeding.

Materials and Methods

Experimental Animals, Design and Management

All animal procedures were approved by the Michigan State University Institutional Animal Care and Use Committee. Seventy-two crossbred barrows (six per chamber at the start of the project; initial BW= 25 kg) were housed in 12 environmentally-controlled rooms at the Animal Air Quality Research Facility at Michigan State University. Pigs were allocated to chambers by weight in order to minimize BW differences within each chamber. Two weight blocks were created (heavy and light). The animals were confined in a 3.1 x 1.5 m raised deck pen with a plastic-coated woven wire floor. Swinging nipple waterers (Trojan Specialty Products, Dodge City, KS) were located above the middle of the pens and a one-hole feeder was located at one end. Chamber temperatures (18.3 to 25.6°C) were adjusted weekly, based on the average BW of the barrows within the

chamber, to remain within the thermoneutral zone of the animals. Fluorescent lighting was programmed to come on at 06:00 h and go off at 20:00 h. Galvanized steel manure collection pans (3.05 m x 1.52 m x 7.5 cm-deep) were placed underneath the flooring of each pen to collect urine, feces, and wasted feed and water. Collection pans were partially cleaned twice weekly to remove some manure and prevent overflow. The weight of manure removed from the pan was recorded and a sub-sample was collected and frozen for future compositional analyses. On the first day of each new feeding phase, the manure pans were cleaned completely, the mass of manure removed from the pan was recorded, and a homogenous sub-sample was frozen. Following each feeding phase, all sub-samples were thawed, and combined into a composite sample, by phase, based on the amount removed each day (weighted proportion to the total composite). A sub-sample was removed and sent to Dairy One Laboratory (Ithaca, NY) for compositional analyses.

Dietary Treatments

Diets were formulated into 4 feeding phases: phase 1 beginning at an average BW of 25 kg (38 d), phase 2 (21 d; 58 kg BW), phase 3 (28 d; 80 kg BW), and phase 4 (11 d; 109 kg BW). Barrows were fed 1 of 3 treatments (3 trt; 2 reps per trt within a block): a corn control diet (C), a diet containing 20% DDGS and inorganic trace minerals (20In), and a diet containing 20% DDGS with organic trace minerals (20Org; Pancosma, Geneva, Switzerland). Table 1 illustrates the formulated diet compositions and analyzed CP, Lys, and S contents of the diets. Diets were formulated to maintain similar Lys and energy contents. Barrows were provided *ad libitum* access to feed and water. New feed was provided daily between 06:00 and 09:00 h. Each day, feed was added, the amount of feed added was recorded, and feeders were adjusted to provide adequate access to feed while minimizing feed wasting. Each week, feed was removed from the feeders and weighed, and average daily intake was calculated. Diets were sampled weekly, and samples were pooled at the end of each feeding phase for proximate and amino acid analyses.

Measurements of Gaseous Concentrations

Twelve rooms (H 2.14 m × W 3.97 m × L 2.59 m) were designed to continuously monitor incoming and exhaust concentrations of gases as described previously (Powers et al., 2007b). Ammonia (NH_3) was measured using a chemiluminescence ammonia analyzer (Model 17 C, Thermo Fisher, Franklin, MA) which is a combination NH_3 converter and NO-NO_2-NOx analyzer. Hydrogen sulfide (H_2S) was analyzed using pulsed fluorescence SO_2-H_2S Analyzer (TEI Model 45C, Franklin, MA). Non-methane total hydrocarbon (NMTHC), CO2, CH4, and N2O were measured using a INNOVA 1412 photoacoustic analyzer (Lumasense Technologies, Ballerup, Denmark). As described previously (Powers et al., 2007), through software control (LabVIEW Version 8.2; National Instruments Corp., Austin, TX), gaseous concentration monitoring of each room occurred in sequential manner. Cumulative emissions of gases were calculated daily by summing the mass emitted during each period for that day (7 to 8 daily observations per room).

Chemical Analyses

Feed and manure nitrogen (N) content was determined using the Kjeldahl method (AOAC, 2000; Method 928.08). Feed amino acid content was analyzed by the University of Missouri Ag Experiment Station Laboratory. Feed energy and mineral content was analyzed by the University of Arkansas Center for Excellence in Poultry Science laboratory. Manure mineral content was analyzed Dairy One (Dairy One Inc.; Ithaca, New York) using a Foss NIR Systems Model 6500 with Win ISI II v1.5.

Statistical Analysis

Swine performance data were analyzed using a GLM procedure (SAS Institute, 2002). The model tested the fixed effects of diet. Emissions data were analyzed using a MIXED procedure of SAS (SAS Institute, 2002). The model tested the fixed effects of diet with day as a random variable. Significant differences among the means were declared at $P \leq 0.05$.

Results and Conclusions

Animal performance

Animal performance data are shown in Table 2. Pigs fed the 20Org diet demonstrated lower feed intakes than pigs fed the C or 20In diets. No diet effects on weight gain or efficiency of feed conversion to gain were observed. Feeding phase effects were observed for feed intake and weight gain. These were expected because pigs were growing, consuming more as they increased in size, and lengths of phases were not equal. As expected, efficiency of feed conversion to weight gain decreased as pigs aged (phase effect).

Air emissions

Treatment effects were observed for ammonia emissions (Table 3). Feeding the control diet resulted in the lowest ammonia emission rate. Feeding the 20Org diet produced the highest ammonia emission rate. The ammonia emission rate was intermediate when pigs were fed the 20In diet. Similarly, mass of ammonia emitted per day was lowest when the C diet was fed and highest when the 20Org diet was fed. Feeding the 20In diet produced an intermediate mass of ammonia. Expressing the mass of daily ammonia emission as a function of BW, N consumption or per animal produced the same pattern as observed for the rate of ammonia emissions. Thus, feeding a corn control diet resulted in the lowest emission factor compared to feeding a diet containing DDGS. Within the 2 DDGS treatments, the emission factors were greater as a result of feeding the organic trace mineral sources. Note that all emission factors are calculated from emission mass which is calculated based on the emission rate (the product of concentration and airflow).

Hydrogen sulfide concentration, emission rate, mass emitted and emission factors calculated based on BW and animal number were all greatest in rooms where pigs were fed the DDGS diet containing inorganic trace mineral sources (20In; Table 4). No differences were observed between the C and the 20Org diet suggesting that feeding organic trace minerals alleviated increases in hydrogen sulfide emissions that occurred due to dietary inclusion of 20% DDGS.

Methane concentration, emission rate, daily mass emitted, and emission factors (Table 5) were lowest in rooms where the C diet was fed, greatest in rooms where the 20Org diet was fed, and intermediate in rooms where the 20In diet was fed. Non-methane total hydrocarbon followed the same pattern. This follows the same pattern observed for ammonia. An explanation for this observation is not apparent at present. Literature data on methane and non-methane total hydrocarbon emissions from swine is sparse.

Nitrous oxide emission data are depicted in Table 6. A dietary effect was only observed for mass emitted per unit of feed intake. Rooms where the 20Org diet was fed produced a greater emission factor compared to rooms where the other 2 diets were fed. While other variables were not different the observed difference for the emission factor related to feed intake is the result of reduced feed intake in rooms where the 20Org diet was fed coupled with nitrous oxide emission rates that were not different between diets.

Phase effects, though difficult to explain, were observed for gaseous emissions. In general, ammonia was lower during the first feeding phase than in the other 3 phases. The exception to this was when emissions were expressed per unit of BW or per unit of N consumed (Table 3). The second feeding phase demonstrated the intermediate hydrogen sulfide emissions and concentration compared to the first feeding phase (greatest) and phases 3 and 4 (lowest phases). Methane and non-methane total hydrocarbon were generally lowest during feeding phase 1, intermediate in feeding phase 2 and greatest during phases 3 and 4 (Table 5). Nitrous oxide emission factors (per unit of BW and per head) were lower during feeding phases 3 and 4 compared to feeding phases 1 and 2. Concentration, however, was lowest during phase 4 and highest during phases 1 and 2. Phase 3 was not different from the other 3 phases.

Excretion characteristics

Manure mass and N content data are shown in Table 7. Feeding the 20Org diet produced the least mass of manure (wet weight). This may be reflective of the reduced feed intake observed in pigs offered this diet (Table 2). Excreted manure contained more N when pigs were fed the 20Org diet (wet basis; Table 7) and may explain, in part, the higher ammonia emissions observed with this treatment (Table 3).

These data show that feeding 20% DDGS to swine results in increased hydrogen sulfide, methane, non-methane hydrocarbon, and ammonia emissions.

Findings suggest that feeding organic trace mineral sources to pigs may mitigate the increased hydrogen sulfide emissions that result from dietary inclusion of 20% DDGS. However, N excretion and emissions and methane and non-methane hydrocarbon are increased beyond that observed as a result of 20% DDGS, alone. Further work is needed to confirm these findings and suggest a mechanism.

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Table 1. Diet and nutrient composition (as fed-basis) of a control diet or diets containing distillers dried grains with soluble (DDGS) with inorganic or organic trace minerals[†].

Item	Phase[‡] 1			Phase 2			Phase 3			Phase 4		
	C[‡]	20In	20Org	C	20In	20Org	C	20In	20Org	C	20In	20Org
Ingredient, g kg^{-1} (as-fed basis)												
Corn	63.71	55.164	55.106	66.993	58.508	58.454	71.864	63.573	63.465	75.857	68.321	68.263
DDGS		20.0	20.0		20.0	20.0		20.0	20.0		20.0	20.0
Soybean meal	20.85	17.95	17.95	17.45	14.8	14.8	12.75	10.05	10.1	8.0	5.45	5.45
Wheat midds	8.2			8.45			8.65			9.6		
Animal fat	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Phosphate, 21%	0.8		0.45	0.75	0.385	0.385	0.6	0.24	0.24	0.5	0.14	0.14
Limestone	1.105	1.105	1.165	1.08	1.08	1.135	1.03	1.015	1.075	0.99	1.005	1.065
Salt	0.45	0.45	0.45	0.408	0.425	0.425	0.408	0.425	0.425	0.408	0.425	0.425
Potassium chloride	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Vitamin mix	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Trace mineral mix	0.063	0.063		0.063	0.063		0.063	0.063		0.063	0.063	
Traxim minerals			0.112			0.112			0.112			0.112
L-Lysine/HCl	0.36	0.408	0.408	0.334	0.376	0.376	0.284	0.326	0.326	0.259	0.3	0.3
Methionine, hydroxy A	0.104	0.075	0.075	0.07	0.038	0.038						
L-Threonine	0.094	0.07	0.07	0.088	0.06	0.06	0.07	0.043	0.043	0.058	0.03	0.03
Luprosil salt	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Sel, 0.06% yellow	0.05	0.05		0.05	0.05		0.05	0.05		0.05	0.05	
Phyzyme 2500	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Analyzed composition (dry matter basis)												
Crude protein, g kg^{-1}	185	201	209	179	170	164	162	175	169	86	139	107
Lysine, g ^{kg}-1	12.5	11.5	12.7	10.6	11	11.4	9.2	8.1	7.7	7.5	7.9	7.0
Methionine, g kg^{-1}	2.5	3	3	2.3	2.8	2.8	2	2.4	2.4	2.1	2.4	2.3
Ca, g kg^{-1}	7.9	7.6	8	9	12.1	9.5	6.5	9.5	7.1	6.8	8.9	6.6
P, g kg^{-1}	6.9	6.2	6.1	5.9	4.8	4.7	5.1	5.7	4.4	4.1	4.9	3.4
S, g kg^{-1}	1.99	2.14	1.83	1.93	2.06	1.80	1.90	2.00	1.90	1.70	1.90	1.70
Cu, mg kg^{-1}	29	19	13	0.025	27	277	21	57	49	22	21	25
Zn, mg kg^{-1}	293	159	195	213	404	317	156	302	282	245	295	377
Fe, mg kg^{-1}	431	318	303	325	424	426	252	316	260	433	352	263

[†]C, corn control diet; 20In, 20% distillers dried grains with solubles diet with inorganic source of minerals; 20Org, 20% distillers dried grains with solubles diet with organic source of minerals.

[‡]Phase 1: 38 d, average initial BW = 25 kg; phase 2: 21 d, average initial BW = 58 kg, phase 3: 28 d, average initial BW = 80 kg; phase 4: 11 d, average initial BW = 109 kg.

Table 2. Pen performance, over 4 feeding phases (98-d total feeding period), for pigs (6 pigs per pen; 4 pens per treatment) fed a control diet or diets containing distillers dried grains with solubles with inorganic or organic trace minerals[†].

Dietary treatment[†]	Feeding phase[‡]	Weight gain, kg[§]	Feed intake, kg[§]	G:F[¶]
C	1	196.5	388.5	0.51
	2	131.7	337.4	0.39
	3	181.2	525.0	0.35
	4	58.6	211.5	0.28
20In	1	205.2	420.3	0.49
	2	136.1	337.9	0.40
	3	167.2	522.4	0.32
	4	61.7	206.2	0.30
20Org	1	200.0	396.6	0.50
	2	131.8	323.7	0.41
	3	171.9	497.2	0.35
	4	50.0	182.9	0.27
Treatment means (pooled across block and phase)				
C		568.1	1462.5[b]	0.39
20In		570.3	1486.8[b]	0.38
20Org		553.6	1400.4[a]	0.40
SEM[#]		14.71	30.94	0.022
Phase means (pooled across treatment and block)				
Phase 1		200.56[d]	401.78[c]	0.50[d]
Phase 2		133.19[b]	333.01[b]	0.40[c]
Phase 3		173.46[c]	514.87[d]	0.34[b]
Phase 4		56.79[a]	200.22[a]	0.28[a]
SEM[#]		2.19	5.21	0.0057
Source of variation				
Treatment		0.36	<.01	0.79
Phase		<.01	<.01	<0.01
Block		<.01	<.01	<0.01
Phase×Block		<.01	<.01	0.10
Phase×Treatment		0.18	0.31	0.14
Block×Treatment		0.62	0.40	0.48
Diet×Block×Phase		0.44	0.19	0.75

[†]C, corn control diet; 20In, 20% distillers dried grains with solubles diet with inorganic source of minerals 20Org, 20% distillers dried grains with solubles diet with organic source of minerals.

[‡]98 d total project period; Phase 1: 38 d, average initial BW = 25 kg; phase 2: 21 d, average initial BW = 58 kg, phase 3: 28 d, average initial BW = 80 kg; phase 4: 11 d, average initial BW = 109 kg.

[§]6 pigs per pen 4 pens per treatment.

[¶]G:F, gain to feed ratio (feed efficiency).

[#]SEM, standard error of the mean.

[a,b,c,d]Significant differences observed at the P<0.05 probability level.

Table 3. Least squares means of NH_3 emissions from pens of pigs (6 pigs per pen) fed a control diet or diets containing distillers dried grains with soluble with inorganic or organic trace minerals[†].

Item	Phase[‡] 1			Phase 2			Phase 3			Phase 4		
	C	20In	20Org	C	20In	20Org	C	20In	20Org	C	20In	20Org
Average daily concentration, mg kg^{-1}	1.23	1.20	1.54	2.38	3.11	3.44	2.90	2.43	2.95	2.50	2.89	2.87
Average daily emission rate, mg min^{-1}	14.89	14.66	19.18	29.57	39.72	43.43	37.06	31.16	37.56	31.64	36.76	35.63
Cumulative average daily emission mass, mg d^{-1}	23241	22873	29886	46133	61961	67752	57816	48615	58596	49357	57340	55587
Daily emissions, mg kg^{-1} BW[§]	92.49	96.98	122.83	112.63	146.29	162.10	102.30	85.42	103.93	71.69	83.01	81.76
Daily emissions, mg g^{-1} N consumed	**75.42**	**67.55**	**87.92**	**99.81**	**139.86**	**166.20**	**119.34**	**93.36**	**122.34**	**185.90**	**138.61**	**194.72**
Daily emissions, mg $head^{-1}$	3873.44	3812.20	4981.05	7688.86	10327	11292	9636.02	8102.42	9766.05	8226.09	9556.68	9264.55

Main effect means	Average daily concentration, mg kg^{-1}	Average daily emission rate, mg min^{-1}	Cumulative average daily emission mass, mg d^{-1}	Daily emissions, mg kg^{-1} BW	Daily emissions, mg g^{-1} N consumed	Daily emissions, mg $head^{-1}$
Diet						
Control	2.30^{a}	28.29^{a}	44137^{a}	94.77^{a}	**120.12^{b}**	7356.10^{a}
20In	2.46^{b}	30.57^{b}	47697^{b}	102.93^{b}	**109.84^{a}**	7949.54^{b}
20Org	2.75^{c}	33.94^{c}	52955^{c}	117.66^{c}	**142.80^{c}**	8825.90^{c}
Phase						
Phase 1	1.36^{a}	16.23^{a}	25333^{a}	104.11^{b}	**76.97^{a}**	4222.23^{a}
Phase	3.20^{b}	37.57^{b}	58615^{b}	140.34^{c}	**135.29^{c}**	9769.23^{b}

2						
Phase 3	2.87[b]	35.26[b]	55009[b]	97.22[ab]	**111.68[b]**	9168.16[b]
Phase 4	2.59[b]	34.68[b]	54095[b]	78.82[a]	**173.08[d]**	9015.77[b]
SEM[¶]	0.078	0.934	1456.82	3.378	**6.806**	242.8
Source of variation						
Diet	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phase	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Block	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Diet × Phase	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Diet × Block	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Block × Phase	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Diet × Block × Phase	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[†]C, corn control diet; 20In, 20% distillers dried grains with solubles diet with inorganic source of minerals; 20Org, 20% distillers dried grains with solubles diet with organic source of minerals.
[‡]Phase 1: 38 d, average initial BW = 25 kg; phase 2: 21 d, average initial BW = 58 kg, phase 3: 28 d, average initial BW = 80 kg; phase 4: 11 d, average initial BW = 109 kg.
[¶]SEM, standard error of the mean.
[a,b,c,d]Significant differences observed at the P<0.05 probability level.

Table 4. Least squares means of H_2S emissions from pens of pigs (6 pigs per pen) fed a control diet or diets containing distillers dried grains with soluble with inorganic or organic trace minerals[†].

Item	Phase[‡] 1			Phase 2			Phase 3			Phase 4		
	C	20In	20Org	C	20In	20Org	C	20In	20Org	C	20In	20Org
Average daily concentration, mg kg^{-1}	0.035	0.041	0.028	0.013	0.021	0.020	0.0049	0.0034	0.0041	0.0041	0.0031	0.0026
Average daily emission rate, mg min^{-1}	0.51	0.65	0.31	0.20	0.40	0.38	0.12	0.081	0.10	0.08	0.057	0.042
Cumulative average daily emission mass, mg d^{-1}	791.53	1011.60	477.95	310.21	622.50	593.11	190.77	126.58	155.08	125.97	88.36	66.28
Daily emissions, mg kg^{-1} BW	3.13	3.76	1.92	0.76	1.48	1.44	0.33	0.22	0.28	0.18	0.13	0.10
Daily emissions, mg g^{-1} S consumed	**37.55**	**38.62**	**24.52**	**10.05**	**18.52**	**20.76**	**5.95**	**2.33**	**4.65**	**4.06**	**2.32**	**2.23**
Daily emissions, mg head^{-1}	131.78	168.60	79.66	51.70	103.75	97.28	31.53	20.64	25.85	20.99	13.77	10.60

	Average daily concentration, mg kg^{-1}	Average daily emission rate, mg min^{-1}	Cumulative average daily emission mass, mg d^{-1}	Daily emissions, mg kg^{-1} BW	Daily emissions, mg g^{-1} S consumed	Daily emissions, mg head^{-1}
SEM[¶]	0.00212	0.0334	51.984	0.1786	**2.06**	8.554
Diet						
C	0.014^{a}	0.23^{a}	354.62^{a}	1.10^{a}	**14.40**	59.00^{a}
20In	0.017^{b}	0.29^{b}	462.26^{b}	1.40^{b}	**15.70**	76.69^{b}
20Org	0.014^{a}	0.21^{a}	323.10^{a}	0.93^{a}	**13.04**	53.35^{a}
Phase						
Phase 1	0.034^{c}	0.49^{b}	760.36^{b}	2.94^{c}	**33.57**^{c}	126.68^{c}
Phase 2	0.018^{b}	0.33^{b}	508.61^{b}	1.23^{b}	**16.44**^{b}	84.24^{b}
Phase 3	0.0041^{a}	0.10^{a}	157.48^{a}	0.28^{a}	**4.64**^{a}	26.00^{a}
Phase 4	0.0033^{a}	0.060^{a}	93.54^{a}	0.14^{a}	**2.87**^{a}	15.12^{a}

Source of variation						
Diet	0.03	0.03	0.03	0.06	**0.47**	0.03
Phase	<0.01	<0.01	<0.01	<0.01	**<0.01**	<0.01
Block	<0.01	<0.01	<0.01	<0.01	**<0.01**	<0.01
Diet×Phase	<0.01	<0.01	<0.01	<0.01	**<0.01**	<0.01
Diet×Block	0.04	0.04	0.04	0.31	**0.20**	0.04
Block×Phase	<0.01	<0.01	<0.01	<0.01	**<0.01**	<0.01
Diet×Block×Phase	0.05	0.05	0.05	0.30	**0.20**	0.05

[†]C, corn control diet; 20In, 20% distillers dried grains with solubles diet with inorganic source of minerals; 20Org, 20% distillers dried grains with solubles diet with organic source of minerals.
[‡]Phase 1: 38 d, average initial BW = 25 kg; phase 2: 21 d, average initial BW = 58 kg, phase 3: 28 d, average initial BW = 80 kg; phase 4: 11 d, average initial BW = 109 kg.
[¶]SEM, standard error of the mean.
[a,b,c,d]Significant differences observed at the P<0.05 probability level.

Table 5. Least squares means of hydrocarbon emissions from pens of pigs (6 pigs per pen) fed a control diet or diets containing distillers dried grains with soluble with inorganic or organic trace minerals.

	Average daily concentration, mg kg $^{-1}$		Average daily emission rate, mg min^{-1}		Cumulative average daily emission mass, mg d^{-1}		Daily emissions, mg kg^{-1} BW[†]		Daily emissions, mg kg^{-1} feed intake		Daily emissions, mg head^{-1}	
	CH_4	NMTHC[‡]	CH_4	NMTHC	CH_4	NMTHC	CH_4	NMTHC	CH_4	NMTHC	CH_4	NMTHC
Diet means												
C[§]	4.25^{a}	0.67^{a}	12.33^{a}	5.80^{a}	19236^{a}	9052.43^{a}	42.04^{a}	20.57^{a}	1182.82^{a}	571.05^{a}	7.01^{a}	3.42^{a}
20In	4.89^{b}	0.77^{b}	20.22^{b}	9.30^{b}	31537^{b}	14513^{b}	66.49^{b}	31.50^{b}	1901.05^{b}	888.88^{b}	11.08^{b}	5.25^{b}
20Org	5.22^{c}	0.82^{c}	23.74^{c}	10.64^{c}	37030^{c}	16594^{c}	78.99^{c}	36.43^{c}	2384.33^{c}	1089.05^{c}	13.16^{c}	6.07^{c}
Phase means												
Phase[¶] 1	4.05	0.66^{a}	10.93^{a}	5.26^{a}	17054^{a}	8201.22^{a}	68.59	34.81^{b}	1565.08^{a}	794.31	11.43	**5.80^{c}**
Phase 2	4.32	0.78^{ab}	15.67^{b}	7.54^{b}	24448^{b}	11757^{b}	59.29	28.83^{a}	1545.60^{a}	746.92	9.88	**4.80^{b}**
Phase 3	4,73	0.79^{b}	23.51^{c}	10.42^{c}	36677^{c}	16248^{c}	65.10	28.90^{a}	2008.68^{b}	890.10	10.85	**4.81^{b}**
Phase 4	4.86	0.77^{ab}	24.93^{c}	11.12^{c}	38892^{c}	17340^{c}	57.04	25.47^{a}	2171.58^{b}	967.31	9.50	**4.24^{a}**
SEM[¶]	0.1364	0.01902	0.532	0.232	829.5	217.28	1.996	0.992	50.678	24.738	0.332	0.1652
Source of variation												
Diet	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Phase	0.07	<0.01	<0.01	<0.01	<0.01	<0.01	0.07	<0.01	<0.01	0.03	0.07	<0.01
Block	0.99	0.50	0.25	0.04	0.25	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Diet×Phase	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.03	0.09	<0.01	<0.01	0.03	0.09
Diet×Block	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Block×Phase	0.23	<0.01	0.35	<0.01	0.35	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Diet×Block×Phase	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[†]BW, body weight.

[‡]NMTHC, non-methane total hydrocarbon.

[§]C, corn control diet; 20In, 20% distillers dried grains with solubles diet with inorganic source of minerals; 20Org, 20% distillers dried grains with solubles diet with organic source of minerals.

[¶] Phase 1: 38 d, average initial BW = 25 kg; phase 2: 21 d, average initial BW = 58 kg, phase 3: 28 d, average initial BW = 80 kg; phase 4: 11 d, average initial BW = 109 kg..

[¶]SEM, standard error of the mean.

[a,b,c,d]Significant differences observed at the P<0.05 probability level.

Table 6. Least squares means of N_2O emissions from pens of pigs (6 pigs per pen) fed a control diet or diets containing distillers dried grains with soluble with inorganic or organic trace minerals.

	Average daily concentration, mg kg $^{-1}$	Average daily emission rate, mg min^{-1}	Cumulative average daily emission mass, mg d^{-1}	Daily emissions, mg kg^{-1} BW[†]	Daily emissions, mg kg^{-1} feed intake	Daily emissions, mg head^{-1}
Diet means						
C[§]	1.20	3.07	4786.29	11.48	310.24^{a}	1.91
20In	1.20	3.09	4824.02	11.65	310.27^{a}	1.95
20Org	1.21	3.24	5055.55	12.41	348.26^{b}	2.07
Phase means						
Phase[¶] 1	1.33^{bc}	2.49	3887.39	17.09^{b}	385.31	2.85^{b}
Phase 2	1.36^{bc}	4.07	6353.64	15.16^{b}	396.54	2.53^{b}
Phase 3	1.13^{ab}	3.03	4733.31	8.42^{a}	258.05	1.40^{a}
Phase 4	1.01^{a}	2.94	4580.14	6.73^{a}	251.81	1.12^{a}
SEM[¶]	0.0354	0.312	486.3	1.572	36.466	0.262
Source of variation						
Diet	0.06	0.32	0.3215	0.23	<0.01	0.23
Phase	<0.01	0.21	0.2062	0.03	0.26	0.03
Block	0.46	0.24	0.2354	<0.01	0.03	<0.01
Diet×Phase	<0.01	<0.01	<0.01	0.03	<0.01	0.03
Diet×Block	0.03	0.0180	0.0180	0.07	0.06	0.07
Block×Phase	0.82	0.9390	0.9390	0.11	0.06	0.11
Diet×Block×Phase	0.85	0.9611	0.9611	0.98	0.87	0.98

[†]BW, body weight.
[‡]NMTHC, non-methane total hydrocarbon.
[§]C, corn control diet; 20In, 20% distillers dried grains with solubles diet with inorganic source of minerals; 20Org, 20% distillers dried grains with solubles diet with organic source of minerals.
[¶] Phase 1: 38 d, average initial BW = 25 kg; phase 2: 21 d, average initial BW = 58 kg, phase 3: 28 d, average initial BW = 80 kg; phase 4: 11 d, average initial BW = 109 kg..
[¶]SEM, standard error of the mean.
[a,b,c,d]Significant differences observed at the P<0.05 probability level.

Table 7. Mass and composition of swine manure from pens of pigs (6 pigs per pen; 4 pens per treatment) fed a control diet or diets containing distillers dried grains with soluble with inorganic or organic trace minerals[†].

	Mass, kg wet			Total N, g kg^{-1} (wet basis)		
				Diet effect		
Phase means[‡]	Control	20In	20Org	Control	20In	20Org
Phase 1	1489.8	1442.5	1222.1	**2.53**	**3.95**	**4.47**
Phase 2	1302.9	1141.8	932.4	2.38	**3.83**	4.01
Phase 3	1096.4	1339.3	1010.7	**3.79**	5.38	**5.41**
Phase 4	299.0	407.8	319.9	5.35	5.11	4.98
Diet means	Mass, kg wet weight			Total N, g kg^{-1} (wet basis)		
C	4340.4[b]			**3.06**[a]		
20In	4331.4[b]			**4.45**[a]		
20Org	3485.2[a]			**4.71**[b]		
Source of variation						
Diet	<0.01			**0.04**		
Phase	<0.01			**<0.01**		
Block	0.04			**0.38**		
Diet×Phase	0.55			**0.64**		
Diet×Block	<0.01			**0.29**		
Block×Phase	0.53			**0.25**		
Diet×Block×Phase	0.18			**0.89**		

[†]C, corn control diet; 20In, 20% distillers dried grains with solubles diet with inorganic source of minerals; 20Org, 20% distillers dried grains with solubles diet with organic source of minerals.

[‡]Phase 1: 38 d, average initial BW = 25 kg; phase 2: 21 d, average initial BW = 58 kg, phase 3: 28 d, average initial BW = 80 kg; phase 4: 11 d, average initial BW = 109 kg.

[a,b,c,d]Significant differences observed at the P<0.05 probability level.

Recent Studies with High Levels of DDGS in Diets for Growing-Finishing Swine

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Summary

Distillers dried grains with solubles (DDGS), a byproduct of ethanol production, has become a popular alternative feed ingredient for use in swine feeds. The amount of DDGS that can be used in swine diets without negatively impacting growth and carcass quality, particularly carcass firmness, is a question that is often asked. This paper summarizes a large collaborative study conducted by a regional multi-state group of researchers in an attempt to shed some light on this important question.

Introduction

Numerous ethanol plants have been built in the Midwest over the past several years. The high demand for corn as a substrate for ethanol production has resulted in greatly inflated corn prices, and this has resulted in increased feed costs and reduced profits for swine producers. Large amounts of byproducts of the distillery industry, one of which is DDGS, are now readily available as alternative feed ingredients for swine, cattle, and poultry. The abundance and availability of DDGS has resulted in numerous research studies the past few years designed to evaluate its use as an alternative feed ingredient in swine diets.

It was known many years ago that DDGS produced from the beverage alcohol industry was well utilized by swine. As an example, 25 years ago we reported that relatively large amounts of high-quality DDGS could be used in growing-finishing diets without depressing performance (Cromwell et al., 1983). Even at that time, it was known that different sources of DDGS varied in nutrient composition, color, and overall nutritional value (Cromwell et al., 1993). Some recent studies have also shown that different sources of DDGS vary in nutritional quality (Spiehs et al., 2002).

Several recent reviews have been written on the nutritional value of DDGS produced from fuel ethanol plants. This subject was addressed in four papers presented at this conference in the past three years. In a review, Stein (2007) concluded that the data were inconsistent with respect to the maximum amount of DDGS that could be included in swine diets without negatively affecting performance or carcass firmness. He pointed out that many swine producers were using up to 20% DDGS in finishing diets, but some producers were using greater inclusion rates (up to 35% DDGS) without affecting performance or carcass quality. He further concluded that more research was needed to evaluate moderate to high levels of DDGS in diets on growth performance and belly firmness of hog carcasses.

Some of the confusion regarding the effects of various levels of DDGS on swine performance and carcass firmness is likely due to variability in the quality of DDGS used in the studies, variation in genetic and environmental factors, and quite often, experiments that are too small with an inadequate number of replications per treatment to provide meaningful and reproducible results.

To overcome the problem of inadequate replications, a large, well-replicated experiment was initiated by members of a regional multi-state

committee. The study was partially funded by the National Pork Board checkoff. The following is a description of that experiment and the results that were reported at the Midwestern Section of the American Society of Animal Science this past spring (Cromwell et al., 2009).

NCCC-42 Collaborative Study

A large collaborative study involving 560 crossbred pigs was conducted at nine universities to determine the effects of moderate to high levels of DDGS in growing and finishing diets on performance and carcass quality, particularly belly firmness, of market hogs. The nine collaborators were members of a regional multi-state committee called the NCCC-42 (formerly NCR-42) Committee on Swine Nutrition. A common protocol was followed at each participating station. In order to participate, each station was required to collect and contribute data from a minimum of two replications and a minimum of four pigs per pen for each of four treatment groups.

The study was designed to evaluate four dietary treatments consisting of corn-soybean meal diets containing 0, 15, 30, or 45% DDGS. The diets were fed to growing-finishing pigs from 33 to 121 kg body weight in three phases. The objective was to determine if moderate to high levels of DDGS could be fed without depressing performance or negatively affecting carcass quality, particularly belly firmness, of swine.

A total of 28 replications of four to six pigs per pen were included in the study. Table 1 shows the stations and collaborators that participated in the study, the number of replications per station, the number of pigs per pen, and the total number of pigs.

A common source of DDGS obtained from a single plant was obtained for the study. The DDGS was supplied by Archer Daniel Midland, Decatur, IL. Two semi-truck loads of DDGS were obtained from the plant on the same day. The DDGS was then bagged at a commercial mill and shipped to each of the participating stations. The DDGS was analyzed at a commercial laboratory and the results are shown in Table 2. The dry matter, crude protein, crude fat, and amino acid levels were typical of a high quality DDGS product.

Each station mixed their diets using their own ingredients. Each station used the same diet formulas which are shown in Table 3. The diets were formulated on a true ileal digestible (TID) lysine basis. They were formulated to contain 0.83, 0.70, and 0.58% TID lysine during the three phases with diet changes made at 60 and 91 kg body weight, respectively. The DDGS replaced corn and soybean meal, and up to 0.22% L-lysine-HCl (which supplied 0.17% L-lysine) and 0.04% L-tryptophan were added to maintain constant TID levels of these amino acids in each phase. The calcium and digestible phosphorus levels were held constant during each phase. Because of the high level of digestible phosphorus in DDGS, no supplemental phosphorus was needed in the diets containing the highest level of DDGS. All diets were fortified with salt, vitamins, and trace minerals to meet or exceed NRC (1998) standards, and tylosin was included in all diets. The diets at each station were analyzed for crude protein and fat at the University of Kentucky and for fatty acid composition and iodine number at the University of Georgia.

At each station, the pigs were randomly allotted to treatments in a randomized complete block design. Sexes were penned separately at each station. Pigs were weighed and feed intake was determined at periodic intervals and at the end of each phase. Diets were in meal form and were consumed by pigs from self feeders on an ad libitum basis. The growth performance aspect of the experiment was terminated on a replication basis when the pigs in the control pen (Diet 1) of a given replication reached an average weight of 120 kg. At most stations, any pens within a replication that did not reach the targeted weight were continued on their respective diets until they reached the target weight of 120 kg. This procedure allowed the growth rate, feed intake, and feed/gain data to be summarized on a constant time basis and the carcass data on a constant weight basis.

At the end of the experiment, two pigs from each pen that were closest to the pen mean weight were killed and hot carcass weight, 10th rib backfat, and loin eye area were determined so as to calculate estimated carcass fat free lean using the NPPC (2000) equation. A sample of backfat at the 10th rib was collected for determination of fatty acid profile and iodine number (a measure of carcass firmness). The samples were packed in dry ice and sent by overnight mail to Dr. Michael Azain, University of Georgia, who determined the fatty acid profiles of the inner and outer portions of the subcutaneous adipose tissue. Fatty acid profiles were determined by gas chromatography (Park and Goins, 1994). Iodine

value was calculated by multiplying the unsaturated fatty acids by factors and summing the result, as follows (AOCS, 1998): iodine number = 16:1 (0.95) + 18:1 (0.86) + 18:2 (1.732) + 18:3 (2.616) + 20:1 (0.785) + 22:1 (0.723).

Six stations determined belly firmness using a flex test developed by Rentfrow et al. (2003). Spareribs and cartilage were removed from the bellies; they were then squared (approximately 35 x 48 cm), and all remaining leaf fat was removed. The fresh bellies were centered, fat side down, on a 7.5 cm diameter polyvinyl chloride (PVC) pipe mounted perpendicular to a board marked with a 2.54-cm grid matrix. Lateral and vertical flexes were determined from the degree of belly flex relative to the grid matrix. A vertical belly flex of zero meant the belly was completely parallel to the floor and completely stiff. A lateral belly flex of 6 meant that the belly flexed to a point where there was 15.24 cm (6 in.) between the ends of the squared belly. Thus, a lower lateral and a higher vertical flex indicated a softer, more flexible belly.

All data were statistically analyzed using the GLM procedure of SAS with pen as the experimental unit. The data were analyzed as a split-plot design with station as the main plot and treatment as the subplot. Replication within station was the main plot error and replication within station x treatment was the subplot error. Treatment responses were partitioned into linear and nonlinear trends.

Results of the NCCC-42 Study

As expected, there were large and significant ($P < 0.001$) differences among stations in the performance and carcass traits, but in most cases, the station x treatment interactions were not significant. Table 4 summarizes the performance data. Growth rate during the early portion of the study was reduced slightly in pigs fed the two higher levels of DDGS, and this difference was significant during Phase I (quadratic, $P < 0.03$) and Phase II (linear, $P < 0.08$). This trend continued throughout the study and the growth response was significant over the entire experimental period (linear, $P < 0.03$). However it represents only a 2.9% decrease in growth rate at the highest level of DDGS inclusion. Daily feed intake and efficiency of feed utilization were not significantly affected by DDGS over the entire experiment. These data indicate that high levels of DDGS can be fed to growing pigs without having much effect on pig performance provided the diets are properly formulated (on a TID lysine basis and with supplemental amino acids so that the dietary protein level is not excessive).

A summary of the carcass traits is shown in Table 5. Carcass yield (dressing percent) was numerically decreased at the highest level of DDGS inclusion (74.3 vs 74.8% for the controls), but the difference was not significant. Pigs fed the two higher levels of DDGS had less backfat (linear, $P < 0.02$), and loin eye area tended to be less (but not significantly) for these pigs. Calculated fat-free lean in the carcass was not affected by dietary treatment.

Belly flex measurements, also shown in Table 5, were significantly affected by DDGS level in the diet. Lateral flex measurements decreased linearly ($P < 0.001$) and vertical flex increased linearly ($P < 0.003$) with increasing level of DDGS in the diet. Both of these measures indicated that bellies became progressively softer and more flexible as the level of DDGS increased in the diet.

The fatty acid composition (expressed as a percentage of the total fatty acids) of the extracted fat from the inner and outer backfat is shown in Table 6. Major changes in fatty acid composition occurred with increasing amounts of DDGS fed, and all of the changes were linear ($P < 0.001$). The total polyunsaturated fatty acids doubled in the backfat of pigs when the dietary level of DDGS was increased from 0 to 45%. Most of this change is attributed to the increase in linoleic acid, the major polyunsaturated fatty acid in pork fat. The higher percentage of polyunsaturated fatty acids and lower percentage of saturated and monounsaturated fatty acids are indicative of a softer carcass.

The iodine values calculated from the fatty acids in the extracted fat increased from 61.1 in the inner backfat of the controls to 82.5 in that of pigs fed the highest level of DDGS. Iodine values in outer backfat increased from 67.8 in controls to 85.7 in pigs fed 45% DDGS. The increases in iodine values were significantly linear ($P < 0.001$). These changes varied some among the nine stations, but iodine values increased with increasing level of DDGS at every station (Table 7). On average, the increase in iodine value was 6.5 units for every 15% DDGS included in the diet.

From this large collaborative study, one can conclude that rather high levels of DDGS (up to 45% DDGS in the diet) can be fed to growing-

finishing pigs without having much of an effect on growth performance or carcass leanness. However, these high levels do result in a higher proportion of polyunsaturated fatty acids in the backfat, higher iodine values in the backfat, and softer, more flexible bellies.

Are Soft Bellies a Problem and are They Preventable?

Soft pork is discriminated against by pork processors for several reasons. One reason is that after curing and smoking, soft pork bellies are claimed to be more difficult to slice into bacon. There are also questions regarding whether bacon slices from soft bellies are as acceptable to consumers and whether their shelf life is reduced due to the greater susceptibility of unsaturated fatty acids to oxidative damage which can result in off-flavor. This is an area that certainly needs more research. We are currently evaluating some of these characteristics in pork from the carcasses of the 60 University of Kentucky pigs that were involved in the NCCC-42 study. Although the results are preliminary, it appears that slicing efficiency of the bellies, characteristics of the bacon slices, and taste panel characteristics were not affected by any of the dietary treatments. We also are evaluating Bratwurst sausage and loin chops from these pigs for color, shelf life, and eating quality and are not finding any treatment differences.

Some studies have shown that the soft carcass problem can be partially alleviated by including conjugated linoleic acid (CLA) in diets containing high levels of DDGS during the finishing stage (White et al., 2009), but the addition of tallow to such diets has not consistently improved carcass firmness (Feoli et al., 2007; Stevens et al., 2009). Other studies have shown that withdrawing DDGS from the diet during the latter part of the finishing phase will partially restore carcass firmness (Hill et al., 2008; Stevens et al, 2009). More research is needed to determine the length of time necessary to achieve the restoration of carcass firmness in pigs fed high levels of DDGS in their diets.

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Table 1. Participating stations and their contributions to the study

Station	Investigator	No. reps	No. pigs per pen	Total no. pigs	Initial weight, kg	Final weight, kg
Univ. of Wisconsin	T. D. Crenshaw	3	4	48	34	120
N. Carolina State Univ.	S. W. Kim	2	5	40	34	116
Ohio State Univ.	D. C. Mahan	2	6	48	33	125
Univ. of Kentucky	G. L. Cromwell	3	5	60	34	120
Univ. of Nebraska	P. S. Miller	3	6	72	34	120
Univ. of Minnesota	S. K. Baidoo	4	5	80	27	119
Oklahoma State Univ.	S. D. Carter	3	4, 6	68	32	125
Purdue Univ.	O. Adeola	4	5	80	35	120
Univ. of Missouri	M. C. Shannon	4	4	64	31	120
Univ. of Georgia[1]	M. J. Azain[1]	-	-	-	-	-
Total		28		560		

[1]Conducted the fatty acid analysis for all stations.

Table 2. Composition of the DDGS used in the study

Item	%
Dry matter	88.9
Crude protein	26.3
Crude fat	9.7
Acid detergent fiber	14.0
Neutral detergent fiber	34.6
Crude fiber	6.5
Ash	5.1
Calcium	0.03
Phosphorus	0.86
Sulfur	0.68
Lysine	0.96
Tryptophan	0.18
Threonine	0.99
Methionine	0.50
Cysteine	0.50
Valine	1.35
Isoleucine	1.01
Linoleic acid, % of total	57
Iodine value	124

Table 3. Composition of diets (%, as fed basis)

	---------- Phase I ----------				----------Phase II --------				----------Phase III ---------			
Diet:	1	2	3	4	1	2	3	4	1	2	3	4
Corn	72.48	61.94	51.40	40.87	77.91	67.56	57.21	46.86	82.71	72.10	61.50	50.89
Soybean meal, dehulled	25.20	20.80	16.40	12.00	19.80	15.20	10.60	6.00	15.00	10.67	6.33	2.00
DDGS	--	15.00	30.00	45.00	--	15.00	30.00	45.00	--	15.00	30.00	45.00
L-lysine-HCl	--	0.067	0.133	0.200	--	0.073	0.147	0.220	--	0.065	0.130	0.195
DL-tryptophan	--	0.011	0.022	0.033	--	0.014	0.027	0.041	--	0.012	0.024	0.036
Dicalcium phosphate	1.24	0.83	0.41	--	1.24	0.83	0.41	--	1.24	0.83	0.41	--
Ground limestone	0.58	0.85	1.13	1.40	0.58	0.85	1.13	1.40	0.58	0.85	1.13	1.40
Salt	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Vitamins, trace minerals	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Tylan-40	0.05	0.05	0.05	0.05	0.025	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Calculated analysis												
Protein, %	18.0	19.0	20.0	20.9	15.9	16.8	17.7	18.6	14.0	15.0	16.0	17.0
Total lysine, %	0.95	0.98	1.02	1.06	0.80	0.84	0.87	0.91	0.67	0.70	0.74	0.78
TID lysine, %[1]	0.83	0.83	0.83	0.83	0.70	0.70	0.70	0.70	0.58	0.58	0.58	0.58
TID tryptophan, %	0.18	0.18	0.18	0.18	0.16	0.16	0.16	0.16	0.13	0.13	0.13	0.13
Fat, %	3.6	4.5	5.4	6.3	3.6	4.6	5.5	6.4	3.7	4.6	5.5	6.4
NDF, %	9.2	13.0	16.8	20.6	9.2	13.0	16.8	20.6	9.3	13.1	16.9	20.6
Ca, %	0.60	0.60	0.60	0.60	0.58	0.58	0.58	0.58	0.57	0.57	0.57	0.57
Total P, %	0.61	0.60	0.59	0.58	0.58	0.58	0.57	0.56	0.56	0.56	0.55	0.54
Digestible P, %	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.25	0.25	0.25	0.25
ME, Mcal/kg	3.33	3.33	3.34	3.34	3.33	3.34	3.34	3.34	3.34	3.34	3.34	3.35

[1]The true ileal digestible (TID) lysine requirement (NRC, 1998) for pigs at the midpoint of the three phases is 0.80, 0.67, and 0.62%, respectively.

Table 4. Performance traits of pigs fed four levels of DDGS during three phases[1]

	DDGS, %					
Item	0	15	30	45	CV	Significance
Initial weight, kg	32.6	32.7	32.5	32.4	1.91	
Final weight, kg	119.2	120.1	117.6	117.0	2.95	Linear (P < .02)
Phase I						
Daily gain, kg	0.95	0.96	0.92	0.92	5.42	Quadratic (P < 0.03)
Daily feed intake, kg	2.18	2.21	2.15	2.15	4.81	
Feed/gain	2.30	2.31	2.35	2.36	5.93	Linear (P < 0.10)
Phase II						
Daily gain, kg	1.00	0.98	0.97	0.96	7.35	Linear (P < 0.08)
Daily feed intake, kg	2.86	2.86	2.77	2.83	4.94	
Feed/gain	2.87	2.94	2.92	2.98	6.22	
Phase III						
Daily gain, kg	0.90	0.93	0.90	0.88	8.71	
Daily feed intake, kg	3.14	3.17	3.11	3.10	7.20	
Feed/gain	3.53	3.46	3.50	3.57	8.84	
Final						
Daily gain, kg	0.94	0.95	0.93	0.91	4.89	Linear (P < 0.03)
Daily feed intake, kg	2.73	2.76	2.68	2.70	4.61	
Feed/gain	2.90	2.91	2.92	2.96	4.78	

[1]Data based on 28 replications of four to six pigs per pen from nine stations.

Table 5. Carcass traits and belly firmness of pigs fed four levels of DDGS

	DDGS, %					
Item	0	15	30	45	CV	Significance
Kill weight, kg	121.5	122.9	120.5	119.8	2.80	
Hot carcass weight, kg	90.8	91.9	89.9	89.0	2.82	Linear ($P < 0.04$)
Hot carcass yield, %	74.8	74.8	74.7	74.3	1.44	
Backfat, 10th rib, mm	22.5	22.7	21.4	21.6	11.97	Linear ($P < 0.02$)
Loin eye area, sq cm	7.35	7.34	7.15	7.03	5.96	
Carcass fat-free lean, %	51.9	52.2	52.4	52.1	2.81	
Belly flex[1]						
Lateral, cm	11.9	8.6	8.4	6.6	25.80	Linear ($P < 0.001$)
Vertical, cm	26.1	27.4	28.2	28.7	6.59	Linear ($P < 0.003$)

[1]Six stations determined belly flex measurements. A lower lateral score and a higher vertical score indicate a softer, more flexible belly.

Table 6. Fatty acid composition and iodine value of fat in backfat tissue of pigs fed four levels of DDGS

	DDGS, %				
Item	0	15	30	45	CV
Fat composition in inner backfat[1]					
Fatty acids, % of total					
Saturated fatty acids	40.9	38.2	35.9	32.7	7.33
Monounsaturated fatty acids	46.5	43.2	40.4	37.4	6.06
Polyunsaturated fatty acids	12.6	18.5	23.8	29.7	11.78
Linoleic acid	12.6	18.5	23.7	29.9	12.03
Iodine value of lipid	61.1	68.5	74.6	82.5	5.43
Fat composition in outer backfat[1]					
Fatty acids, % of total					
Saturated fatty acids	35.6	33.5	31.0	28.4	7.46
Monounsaturated fatty acids	49.4	47.1	44.6	42.2	3.20
Polyunsaturated fatty acids	14.9	19.4	24.3	29.3	11.87
Linoleic acid	13.7	17.9	22.7	27.5	12.26
Iodine value of lipid	67.8	73.3	79.4	85.7	4.29

[1]All of the responses were linear ($P < 0.001$).

Table 7. Increase in iodine values in backfat of pigs fed three levels of DDGS as compared with pigs fed the control diet

	DDGS, %			
Item	0	15	30	45
	Increase in iodine value compared with the iodine value of pigs fed the control diet			
University of Kentucky	--	6.1	11.8	19.6.
University of Minnesota	--	4.6	14.5	19.8
University of Missouri	--	6.8	12.3	15.9
North Carolina State University	--	2.6	14.0	17.0
University of Nebraska	--	4.5	10.2	16.3
Ohio State University	--	7.0	6.3	18.0
Oklahoma State University	--	6.0	12.9	21.5
Purdue University	--	5.7	14.4	22.1
University of Wisconsin	--	13.2	15.3	24.5
Average of all stations[1]		6.3	12.4	19.4

[1]On average, the iodine value increased 6.5 units for every 15% DDGS included in the diet.

Can Feeding Rice or Barley Improve Health of Nursery Pigs?

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Summary

Our results show clearly that complete replacement of corn with rice in the first nursery diet for pigs reduces the number of pigs removed because of death or sickness. Immediate application may be possible. We also need to build on these initial studies to learn much more about the mechanisms and practical application of rice in nursery diets. In our hands, barley also provides health benefits but slows growth.

Introduction

There is accumulating evidence, both mechanistic and empirical, that dietary factors may be useful tools in the daunting challenge of keeping pigs healthy. Dietary factors will not replace established practices such as all-in/all-out pig flow, age segregation, sanitation, biosecurity and vaccines, but they may be valuable adjuncts to those conventional health practices. Most dietary factors that improve pig health either modify microbial populations in the digestive tract or modulate immune function. The focus herein is on microbial populations.

Several factors influence microbial populations in the digestive tract of pigs, but the substrate supply is presumably one of the most powerful. The substrate supply to microbes living in the lower gut is largely undigested components of the diet, and that directs attention to dietary fiber. One prevailing notion is that a high level of fermentable fiber in the lower gut supports the growth of large populations of commensal (normal) bacteria, and these commensal bacteria inhibit, through various means, the growth of pathogens. There is also evidence that fermentable fiber may be detrimental to pig health, perhaps by serving as a substrate for pathogens. Some dietary fibers may have other physiological effects that potentially impact health. The impact of dietary fiber on health of pigs is the target of a great deal of research worldwide, with no clear pattern emerging, but further consideration of the mechanisms and the empirical responses to fiber is outside the scope of this paper.

Suffice it to say here that different cereal grains contain different levels and types of fiber so comparison of cereals in diets of newly weaned pigs susceptible to enteric diseases is of interest. In this paper we place emphasis on rice (very low in fiber) and include some discussion of barley (high in fiber).

Previous research

Barley is the major feed grain grown in Europe and some states in the U.S. It can be used in the diets for growing and finishing pigs, sows, and to a lesser extent for nursery pigs. A recent study has shown that barley-based diets fed to weanling pigs may cause a negative impact on health of nursery pigs (Hopwood et al., 2004). This may be because barley contains a high level of soluble non-starch polysaccharides which causes an increased viscosity of digesta leading to greater incidence of diarrhea and proliferation of potential harmful bacteria, e.g. enterotoxigenic *E. coli* (McDonald et al., 2001; Francis et al., 2002). However, Paulicks et al. (2000) reported no difference in diarrhea score and growth performance in pigs fed barley as compared to those fed wheat or corn. It may be argued that barley with high dietary fiber would provide more substrates available for microbial fermentation which results in increased production of volatile fatty acids. This activity reduces the pH in the large intestine to levels that are likely unfavorable for the growth of pathogens. Generally speaking, the beneficial or

detrimental effects of barley on health and growth of nursery pigs need further investigation.

Contrary to barley, rice which contains little fiber has been reported to improve pig performance in studies conducted at university research farms. It was found that pigs fed a rice-based diet grew faster than those fed a corn-based diet (Martin et al., 2003; Vicente et al., 2008). In another study using brown rice, Li et al. (2002) found that 50% or complete replacement of corn with brown rice in nursery diets significantly improved feed efficiency. In comparison to wheat, pigs fed rice-based diets from 46 to 63 days of age, regardless of low or high dietary protein, ate more, gained faster, and had better feed efficiency than those fed wheat-based diets (Bonet et al., 2003).

Rice is characterized by its high starch content and low fiber content, so it may have a major impact on the digestibility of dietary nutrients and microbial populations through providing fewer substrates for bacterial fermentation in the large intestine. It has been shown that rice-based diets have a higher apparent total tract digestibility of nutrients than corn-based diets (Li et al., 2002; Mateos et al., 2006). Because rice contains a higher level of starch, in comparison to other cereals, gelatinization of the starch might improve nutrient utilization. However, Vicente et al. (2008) reported that heat processing did not affect the digestibility of nutrients in rice-based diets. The higher digestibility of rice-based diets is likely to explain the improved growth performance in nursery pigs mentioned above.

Because of its high digestibility and low fiber content, rice-based diets may greatly influence the activity of microbial fermentation and gut health. A rice-based diet fed to nursery pigs resulted in a higher pH in the large intestine as compared to a wheat-based diet (Pluske et al., 2003) or barley-based diet (Hopwood et al., 2004). The decreased pH in pigs fed barley or wheat indicates that more fermentable substrates are available for microbes to produce volatile fatty acids which lower the intestinal pH. In addition, cereals with high soluble fiber level have been reported to increase intestinal viscosity which may have a major impact on proliferation of intestinal microbes including pathogens and gut health (Pluske et al., 2003; Hopwood et al., 2004). Indeed, rice, when compared to other cereals including barley, has been shown to reduce diarrhea, intestinal colonization of pathogens, and the severity of enteric bacterial diseases such as enterotoxigenic *Escherichia coli, Brachyspira hyodysenteriae,* and *Brachyspira pilosicoli* (Pluske et al., 1996, Hampson et al., 2000; Lindecrona et al., 2004; Montagne et al, 2004; Mateos et al., 2006).

The beneficial effects of rice-based diets in nursery pigs have been demonstrated at the university farm level as mentioned above. In the next section, we demonstrated effects of rice and other cereals on growth performance and health of weanling pigs under commercial conditions.

Our data from commercial farm trials

Materials and Methods

Three experiments were conducted at the same commercial pig farm. A total of 1004 to 1008 crossbred pigs (PIC x Monsanto) were used in each experiment. In all three experiments, pigs were allotted to treatments in a randomized complete block design. Pigs were divided into three weight blocks (heavy, medium, and light) in each of four rooms, resulting in 12 blocks or 12 pens per treatment. Each pen within a block housed 21 pigs and had the same number of males and females. Pigs were fed a 4-phase feeding program with declining diet complexity. Diets were formulated to contain the levels of all essential nutrients which met or exceeded the nutritional requirements of pigs (NRC, 1998) during the nursery period, and had constant levels of metabolizable energy and standardized ileal digestible lysine. Pigs were housed in an environmentally controlled nursery and had *ad libitum* access to feed and water at all time. The initial average body weights were recorded at the commencement of the experiment. Subsequent pig weights and feed disappearance measurements were determined at d 7, 14, 28, and 42 post-weaning. The ADG, ADFI, and G:F were calculated on a per-pen basis. The number of pigs removed because of death or sickness was recorded daily to calculate the removal rate. The number of antibiotic treatments per pig was also daily taken.

Weaned pigs at about 21 days of age with average initial weights of 6.0, 5.5, and 5.9 kg were used in Exp. 1, 2, and 3, respectively. In Exp. 1, pigs were allotted to four different dietary treatments including corn, barley, rolled oats, or rice. Diets for phases 1 and 2 were in mini-pellet form and in meal form for phases 3 and 4. The composition of cereal-based diets in phase 1 is presented in Table 1. No

antibiotic was added to diets. In Exp. 2, pigs were fed four dietary treatments which were as follows: corn diet fed for 6 weeks; rice diet fed for 1 week (Rice1); rice diet fed for 2 weeks (Rice2); and rice diet fed for 4 weeks (Rice4). After the rice feeding period, pigs were fed the corn diet and all pigs received a common diet during weeks 5 and 6. In Exp. 3, in the treatment diets rice replaced 0, 50, 75, and 100% of corn in week 1. All pigs received common diets from phase 2 to 4 (week 2 through 6 post-weaning). The phase 1 and 2 diets in Exp. 2 & 3 were in crumble form and the phase 3 and 4 diets were in meal form. All diets in phases 1, 2, and 3 in Exp. 2 & 3 contained carbadox and zinc oxide.

Results and discussion

Over a 6-week period, ADG of pigs fed rice in Exp. 1 was significantly higher than that of pigs fed barley or rolled oats ($P < 0.05$), but not different from that of pigs fed corn (Table 2). Pigs fed corn, rolled oats, and rice had the same ADFI which was significantly higher ($P < 0.05$) than ADFI of pigs fed barley. The result of Exp. 1 directed us to conduct the Exp. 2 & 3 in which rice and corn were evaluated. In Exp. 2 & 3, there were no differences in pig performance among the treatment diets (Tables 3 & 4), so our data were not in agreement with those reported in previous studies conducted at university research farms (Li et al., 2002; Martin et al., 2003; Vicente et al., 2008). The better performance of pigs obtained in those studies may be because of the smaller number of pigs used and differences in experimental environments. Under commercial conditions, our study suggests that rice can substitute for corn in the diet for weaned pigs without affecting the growth performance of pigs.

In order to evaluate pig health, we measured the removal rate (dead and sick pigs) and the number of antibiotic treatment. In Exp. 1, the removal rate of pigs fed rice (3.6%) or barley (3.6%) was greatly lower ($P < 0.05$) than that of pigs fed rolled oats (8.3%), and 50% lower ($P < 0.1$) than that of pigs fed corn (7.1%, Figure 1). In Exp. 2, pigs fed rice diets for 1 (3.6%), 2 (4.0%), or 4 weeks (5.2%) had a lower removal rate ($P < 0.05$) than those fed the corn diet (10.3%, Figure 2). In Exp. 3, pigs fed the diet with 100% replacement of corn had a substantially lower ($P = 0.055$) removal rate (2.0%) than those fed the corn diet (5.2%). Partial replacement of corn with rice did not significantly reduce the pig removal (Figure 3). No difference among treatments was seen in the number of antibiotic treatments in Exp. 2 & 3 (Figure 4). These data indicated that despite no major effect on pig performance, feeding rice-based diets to pigs substantially cut the removal rate of pig about in half as compared to corn-based diets, even when rice was fed to pigs for only one week right after weaning. Feeding rice or barley to pigs resulted in a similar pig removal and this made our data interpretation difficult because rice almost contains no fiber, whereas barley has a high fiber level. Therefore, other factors, apart from fiber, in rice or barley might contribute to the decreased pig removals and further investigation of barley and rice under commercial conditions should be done. In addition, although bringing about a decrease in the number of pigs removed, rice appeared not to influence the number of antibiotic treatments.

Potential mechanisms

The data from our laboratory presented above, especially when combined with the results of disease-challenge studies from Australia (Hampson et al., 2000; Pluske et al. 2003, Montagne et al., 2004), show clearly that rice in the diet improves the health of young pigs. The mechanisms through which that benefit derives are not clear, but we suggest two possibilities:

The near absence of fiber in rice may deprive enteric pathogens of the substrate supply they need to proliferate.

A poorly described component of rice, often called simply the “rice factor”, appears to have specific physiological effects on the gut that may be protective (Macleod et al., 1995). In particular, it inhibits (Mathews et al., 1999) the cystic fibrosis transmembrane conductance regulator (CFTR), which is the final step in the cascade of events through which some *E. coli* toxins cause diarrhea (Nagy and Fekete, 1999). We need much more in research on this topic.

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Table 1. Composition of phase 1 cereal diets (as-fed basis, Exp. 1)

Ingredients, %	Corn	Barley	Rolled oats	Rice
Cereal	37.15	36.92	42.16	39.68
Dried whey	22.00	22.00	22.00	22.00
Soybean meal, 48%	10.00	10.00	10.00	10.00
Spray-dried animal plasma[a]	8.00	8.00	8.00	8.00
Soy protein concentrate[b]	5.00	5.00	5.00	5.00
Fish meal	4.11	2.34	0.47	4.67
Soybean oil	3.93	5.51	1.79	1.00
Lactose	7.58	7.58	7.58	7.58
Limestone	0.84	0.85	0.99	0.75
Dicalcium phosphate	0.67	0.68	0.69	0.70
Mineral premix[c]	0.35	0.35	0.35	0.35
Vitamin premix[d]	0.20	0.20	0.20	0.20
Lysine-HCl	0.06	0.09	0.12	0.02
DL-Methionine	0.11	0.14	0.14	0.09
L-Threonine	0.01	0.02	0.03	0.01
Calculated composition				
ME, Mcal/kg	3.52	3.52	3.52	3.52
SID lysine, %	1.45	1.45	1.45	1.45
Ca, %	0.90	0.90	0.90	0.90
Available P, %	0.55	0.55	0.55	0.55
Lactose, %	21.00	21.00	21.00	21.00

[a]APC 920, American Proteins Corporation, Ankeny, IA.
[b]Soycomil, Archer Daniels Midland Company, Decatur, IL.
[c]Provided as milligrams per kilogram of diet: sodium chloride, 3,000; zinc, 100 from zinc oxide; iron, 90 from iron sulfate; manganese, 20 from manganese oxide; copper, 8 from copper sulfate; iodine, 0.35 from calcium iodide; selenium, 0.30 from sodium selenite.
[d]Provided per kilogram of diet: retinyl acetate, 2,273 μg; cholecalciferol, 17 μg; DL-α-tocopheryl acetate, 88 mg; menadione sodium bisulfate complex, 4 mg; niacin, 33 mg; D-Ca-pantothenate, 24 mg; riboflavin, 9 mg; vitamin B_{12}, 35 μg; choline chloride, 324 mg.

Table 2. Growth performance of nursery pigs fed different cereal grains (Exp. 1)

Item	Dietary treatments				SEM
	Corn	Barley	Rolled oats	Rice	
Day 0 to 42					
ADG, g	331[ab]	307[c]	323[b]	337[a]	4.6
ADFI, g	495[a]	462[b]	489[a]	504[a]	7.9
G:F	668[a]	666[a]	663[a]	669[a]	8.0

[abc]Means within a row with different superscripts differ ($P < 0.05$).

Table 3. Effects of feeding rice on weaned pig performance (Exp. 2)

Item	Dietary treatments				SEM
	Corn	Rice1	Rice2	Rice4	
Day 0 to 7					
ADG, g	136	126	135	130	5.5
ADFI, g	152	142	145	145	5.6
G:F	878	852	887	854	23.9
Day 0 to 14					
ADG, g	194	195	192	184	5.8
ADFI, g	223	225	219	215	5.3
G:F	869	862	877	855	17.8
Day 0 to 28					
ADG, g	261	264	263	270	8.3
ADFI, g	365	366	360	361	9.4
G:F	753	757	769	775	10.9
Day 0 to 42					
ADG, g	307	315	318	307	6.2
ADFI, g	455	459	468	446	9.1
G:F	741	746	750	747	9.6

Table 4. Effects of substituting rice for corn in phase-1 diet on performance of weaned pigs (Exp. 3)

Items	Replacement level,%				SEM
	Corn	Rice50	Rice75	Rice100	
Day 0 to 7					
ADG, g	114	107	120	123	7.3
ADFI, g	156	147	153	154	5.1
G:F	713	710	768	778	30.0
Day 0 to 42					
ADG, g	388	386	384	389	10.7
ADFI, g	598	594	592	596	16.7
G:F	649	650	649	653	4.5

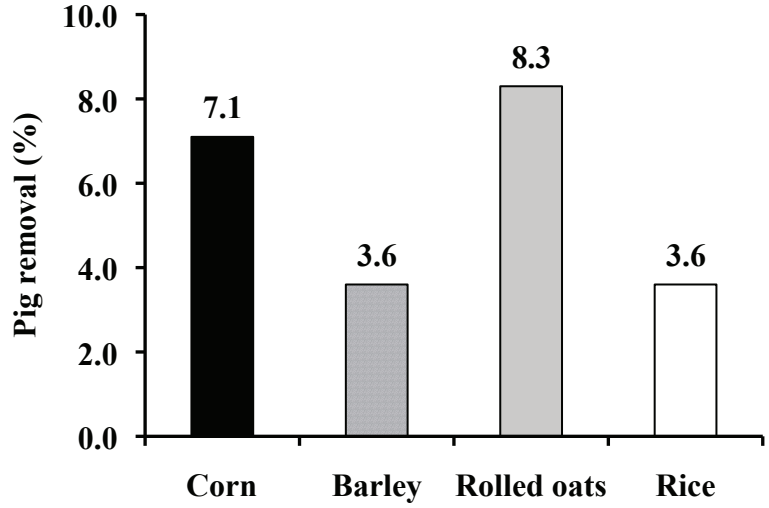

Figure 1. Removal rates of pig fed different cereal diets.

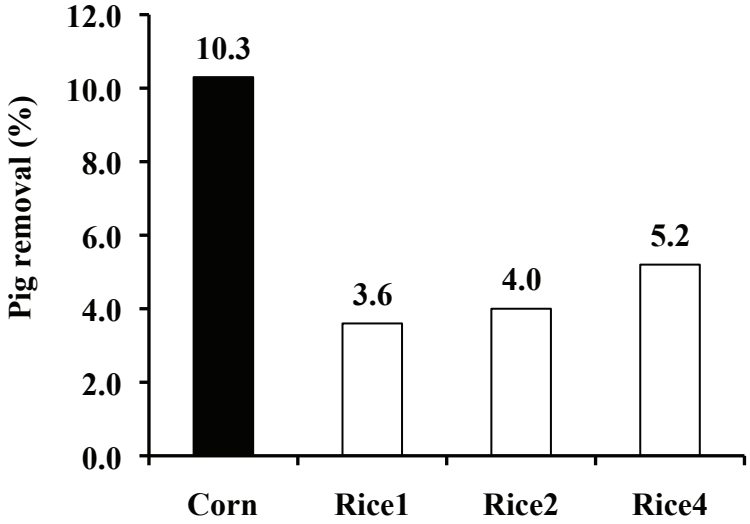

Figure 2. Removal rates of pig fed corn for 6 weeks and rice for 1, 2, and 4 weeks post-weaning.

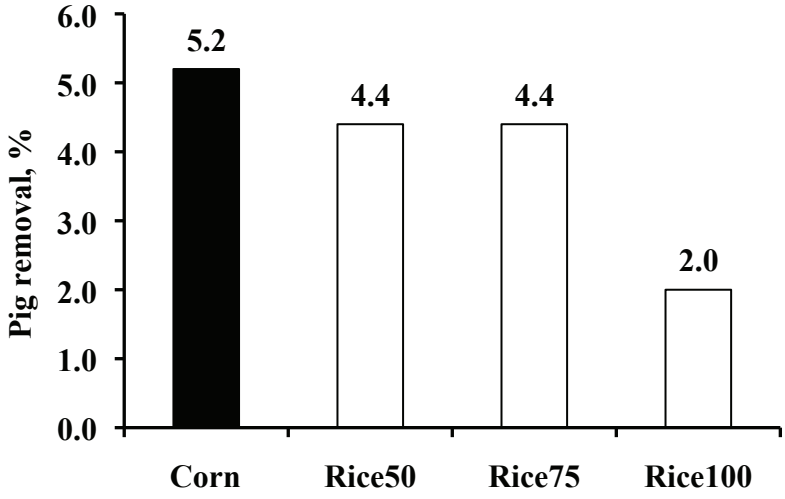

Figure 3. Removal rates of pig fed diets with 0, 50, 75, and 100% replacement of corn with rice for one week post-weaning.

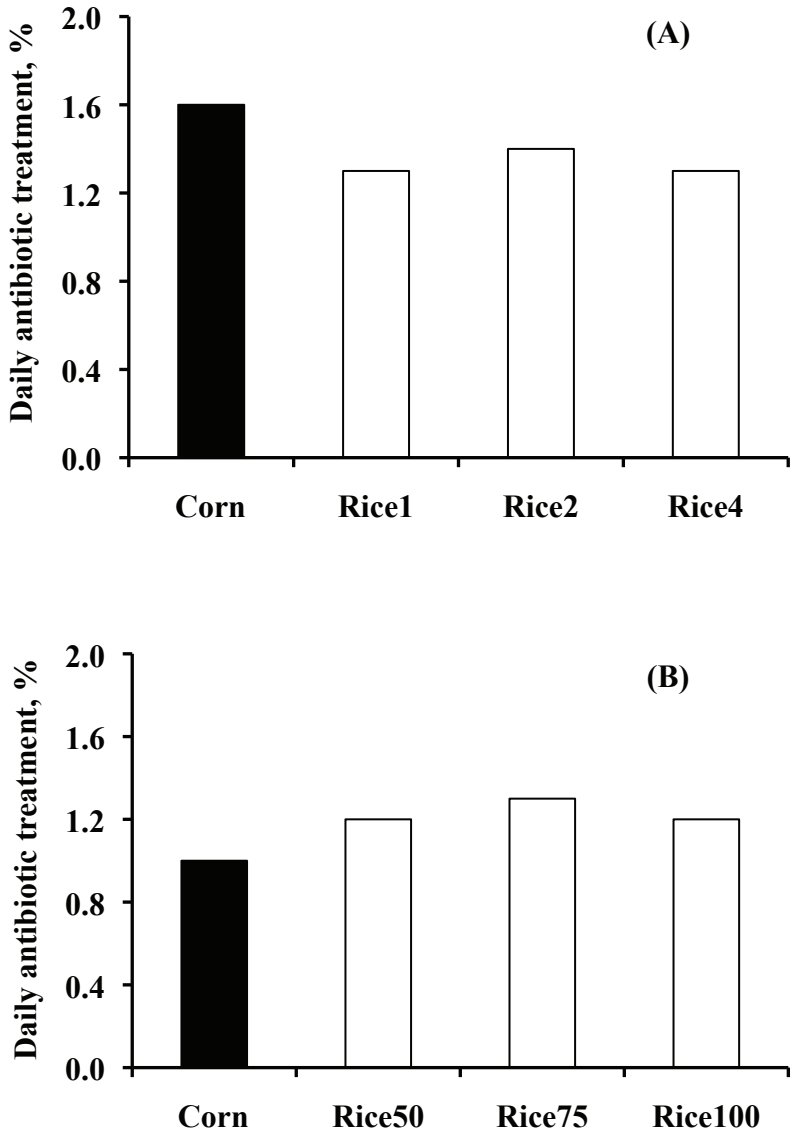

Figure 4. The number of antibiotic treatment in pigs fed corn for 6 weeks and rice for 1, 2, and 4 weeks post-weaning (A) and in pigs fed diets with 0, 50, 75, and 100% replacement of corn with rice for one week post-weaning (B).

Feeding the Reproductive Gilt and Sow

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Summary

The genetic potential of our modern lactating sow has changed a great deal over the last twenty years. In addition, the challenges in the swine industry are requiring nutritionists, veterinarians, and producers to maximize performance and reduce costs. The focus of this proceeding is to revisit some of the known information on production and highlight some of the recent nutrition research that has been conducted to aid in a better understanding of how we can reduce sow farrow to wean feed costs and improve animal performance and longevity.

Introduction

Feeding programs of the growing and lactating reproductive female tend to be overlooked compared to that of feeding the grow/finish pig. However, with the rise in feed costs, every area of pig production should be evaluated. Methods to provide efficiency and maximize reproductive performance must be evaluated and carefully reviewed to fit each system. However, there are some basic guidelines that can be used to start improving performance.

Gilt Development

Whether replacement stock is received as iso-weans or as animals close to breeding, producers should focus on receiving high health, good structured females. Proper care should be given upon receipt of replacement stock with a thorough evaluation of each animal. Fresh feed and water should be made available at the time of receipt and careful monitoring should be performed for the first week for any signs of illness. The producer should work closely with their local veterinarian to ensure that all vaccinations should be given in a timely manner during development, as well as, during the female's reproductive life.

Gilt growth should be controlled and managed carefully. It is important to allow the animals to grow and mature, but not to become overly fat. A female that develops a high degree of backfat (over 16 mm of backfat) will be less likely to milk and eat during lactation. Large structured females have higher levels of maintenance, and thus, require additional amounts of feed during gestation. This higher feed intake results in additional cost to the producer. In addition, the larger a sow is, the more weight is place on her hips and legs during periods of standing, which can result in early culling for soundness. Selection for size should be made based on the need for a sound female with good tissue cover over her back with some definition over the shoulders and ham regions.

During gilt development, proper space and nutrient requirements are high priority. Females during the period pre-breed (68-168 kg) require higher levels of calcium and phosphorus than the conventional market pig at this weight. The expected requirement for calcium should be .75% and .4% for available phosphorus (NRC, 1998). In addition, space requirements should be higher to reduce structure and physical complications which affect the longevity of a female in the herd. Ideally, producers should target .28 m^2 in the grower, .56 m^2 in the late grower, 1.11 m^2 in the early finisher, and 1.39 m^2 in late finisher and gilt heat checking pens.

Once a gilt is found in heat, she should be moved into an area in which she can be fed a controlled amount of feed to prevent her from gaining too much weight before breeding. Ideally, an animal should be bred after her second heat. If she is a small female and needs additional time for maturity, it may be necessary to wait for a third heat to breed. Animals

should be bred at 136 kgs with an expected 181.8 kgs weight going into the farrowing barn as a bred gilt.

Diet composition during this development period can range from corn and soybean meal to a diet with alternative ingredients. Caution should be made when using certain by-products or grain ingredients that may contain high levels of mycotoxins. Mycotoxins, like zearalenone, have the potential to create estrogenic-like effects on animals when consumed. This can lead to cystic ovaries, swollen vulvas (false heats), or a change in the period in which maturity would normally occur. If a diet is to be fed with these mycotoxins, binders should be added to reduce these negative effects. In addition, during the gilt development phase, special attention should be made to following veterinary guidelines for vaccinations and antibiotics needed to keep the replacement females healthy. Antibiotics should be fed only as needed and limited as much as possible and should be fed according to a veterinarian's recommendation.

Gestation

Gestation feeding has two objectives. The first objective is to provide nutrients in early gestation to recover body stores lost during lactation and the second objective is to provide enough nutrients to maintain pregnancy and support the growth of the developing fetus. Standard gestation programs can be conducted in two different methods: Feed to Condition or Set Feeding.

A "Feed to Condition" program has the best opportunity to get sows back into condition quickly; however, this program requires constant evaluation of animals and repeated adjustments to feed boxes or hand feeding programs. In the "Feed to Condition" program, sows can be fed 2.2 – 2.7 kgs of feed per day for the first 30 days after the first 72 hours post-breeding and then reduce the feed amounts until day 90, when feed should be increased by 2 additional pounds per day to provide for rapid fetal growth.

The other method of feeding in gestation is considered "Set Feeding". In this program, 72 hours after the breeding is completed, animals are placed on a set amount of feed based on size and body condition that is slightly above maintenance. The feeding amount is then increased at 90 days gestation until farrowing to allow for fetal growth demands.

Both systems require trained people that can identify proper body condition and can detect when an animal is too thin or getting too fat by mid-gestation. The target of both programs is to bring a female into farrowing with a body condition score of 3 (5 point scale) with about 12-14 mm of backfat in a mature female (Table 1). By keeping the body condition at this level, sow body size stays within an acceptable range and the nursing female will consume high amounts of lactation feed.

Pregnant females should be fed according to the NRC requirements with special attention being made to energy, crude protein, calcium and phosphorus levels.

Srichana et al. (2007) determined nitrogen retention levels of gestating females during various phases of pregnancy. Gestating females from days 40-50 and 70-80 required 13 g of SID lysine per day (Tables 2 & 3). Between days 90-100, gestating females had maximum nitrogen retention when fed 17 g of SID lysine per day (Table 4).

Lactation

Lactation feed intake is critical for piglet performance and for subsequent farrowing performance. First lactation females tend to consume half to one kilogram less of feed a day in lactation compared to older parity sows. The first parity female also requires a higher percent lysine diet compared to the older females. This higher percent lysine requirement is needed due to the reduction of feed intake combined with the fact that the young female is still growing. In research conducted by Srichana et al. (2007) and Greiner et al. (2009), females that consume 5.5 kg a day require approximately 62 grams of TID lysine a day (Table 5). Older parity females require a similar amount of lysine, but because they consume more feed, the older female can be fed a lower percent of lysine in the diet based on feed intake.

Caution needs to be made on farms that feed the same level of lysine to all lactating females. The younger parity female cannot consume large amounts of feed and this reduced feed intake will not allow her to reach the desired level of 62 grams of lysine per day. Data suggests that there is a strong relationship between days to wean to estrus and the amount of lysine consumed. One recommendation is to develop a separate diet for the gilt compared to the rest of the herd that contains a higher lysine level to adjust for the reduction in feed intake.

The feeding levels of other amino acids or the addition of crystalline amino acids during lactation and gestation have also been evaluated. Boyd et al. (1999) demonstrated that feeding a corn-soy diet with a valine:lysine ratio greater the 1.0 did not improve litter gain or sow performance. Srichana et al. (2007) demonstrated that feeding six pounds of crystalline lysine to first parity gilts did not reduce reproductive performance or piglet litter weight gain. Gilts fed 1% arginine during gestation and lactation had an increased in leukocyte cell up-regulation, which should enhance immune function(Mateo et al., 2007).

Feeding programs during lactation are also important in achieving maximum performance. Feeding programs should be designed to maximize intake without creating a significant drop in feed intake during the first five days of lactation. Current feeding programs practice in the Midwest of the United States place females on ad-libitum feeding 48 to 72 hours post-farrow (Table 6). In research conducted by Innovative Swine Solutions, data demonstrated that some sows in lactation can consume 7 kgs per day when allowed ad-libitum access to feed. By improving feed intake, producers should be able to achieve a feed intake over 5.2 kg per day in gilts and 6 kg per day in sows. The high feed intake results in first parity females gaining weight during lactation instead of losing weight.

By preventing weight loss and ensuring adequate lysine intake, the lactating female will be set up for better subsequent performance. Vinsky et al. (2006) demonstrated that a restriction in feed intake in lactation resulted in lower embryo survivability rate by 30 days of breeding. In addition, higher feed intakes in lactation allow for maximum milk production and heavier piglets at weaning. A pig that weighs .5 kg heavier at weaning will go to market 7 days earlier, which results in more pigs through a finisher a year and a reduction of costs per pig marketed.

In addition to having improved piglet performance and higher quality oocytes, the better intake will allow for the percent of lysine to be lowered while still achieving the goal of 62 g of lysine per day. After weaning, females should be allowed maximum feed intake post-wean until the time of breeding to improve sow fertility and also reduce wean to estrus.

Feedstuff considerations

One primary focus of feeding the reproductive female at any point during her life cycle is to ensure that she has access to fresh feed and water. Water should never be limiting and should have low salt content. High salt levels reduce feed intakes and increases the incidence of piglet scours. At any time when water is restrictive, feed intake will also be reduced. In addition, during lactation, the female should have free access to feed at all times.

Most North American producers have fed corn and soybeans to the growing gilt and the lactating female in the past. However, in 2008, the rise in corn and summer fat prices, created a need to alter current diet formulations. Research conducted by Song et al. (2007) and Greiner et al. (2007) indicates feeding levels of up to 30% dry distiller's grain with solubles (DDGs) can be of value to a lactating sow. Both studies indicate that as long as the lactating female is fed 10-20% DDGs during gestation, she will not refuse the higher level of DDGs during lactation.

The reduction of corn in the diets; however, does require some crystalline amino acid supplementation and a reduction of fat levels. This can provide a large cost savings during periods of high feed costs. In addition, it appears that DDGs provide the added value of a fibrous product to the sow by reducing constipation and adding in sow weight gain.

If the use of DDGs is not available or the concern of mycotoxins or inconsistent nutrient levels is present, producers certainly can look to other alternatives during lactation. Srichana et al. (2007) demonstrated that producers can use up to six pounds of lysine with supplementation of threonine and methionine in sow diets to reduce feed costs and still have consistent piglet performance.

Other feedstuffs, such as wheat, rye, and barley, can be fed to sows. However, caution should be made when using these feedstuffs just as with DDGs. These feedstuffs can contain levels of toxins that can significantly reduce performance. Producers should have their feedstuffs routinely evaluated for vomitoxins, aflatoxins, and zearalenone. Commerical mold binders are available to reduce the negative effects associated with these toxins (vomiting, prolapses, spraddled legged piglets, etc); however, no product on the market currently can reduce all toxins associated with these feedstuffs.

Dietary additives

During periods of high summer heat and humidity, it is imperative that the producer work with his/her nutritionist to maximize nutrients in each pound of feed. Currently, there are a number of products that promote feed intake and encourage good levels of feed intake during the summer. Products such as plasma protein can provide good appetite stimulation. The use of a product with plasma protein may also have other benefits such as improved health and immune function.

In addition to feed additives to improve feed intake, there are also products to improve gut health. Products that provide *Lactobacillus*, organic acids, or yeast cultures are designed to reduce the negative bacteria in the gut through an increase in gut pH and also to increase intestinal immunity. These products are especially beneficial when herds have a high degree of pre-wean piglet scours. In order to get the maximum benefit of the intestinal health products, the additives should be fed in both gestation and lactation.

Other diet additives that can be used that may not show immediate effects would be organic minerals. The feeding of organic minerals should provide added value through the reduction of lameness and improved hoof quality. This will allow herds to maintain animals for longer periods of time in the herd and improved animal longevity.

The feeding of the growing gilt and lactating sow can be a challenge. However, with a good nutrition program and good production implementation onto the farms, the successful feeding of the female can be achieved. Additionally, with the work of a veterinarian, good nutrition and health will result in a reduced culling percent and improved piglet performance.

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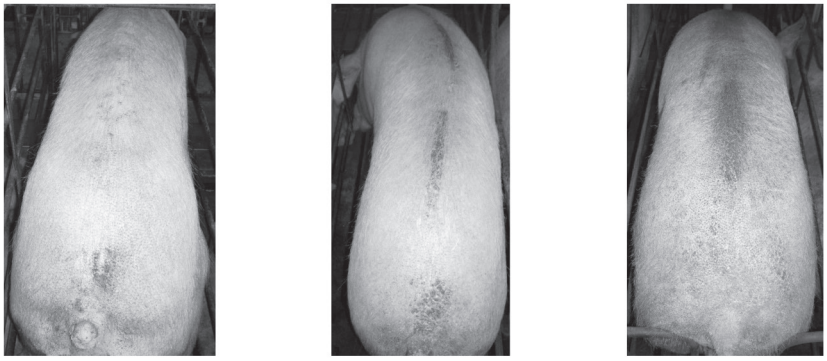
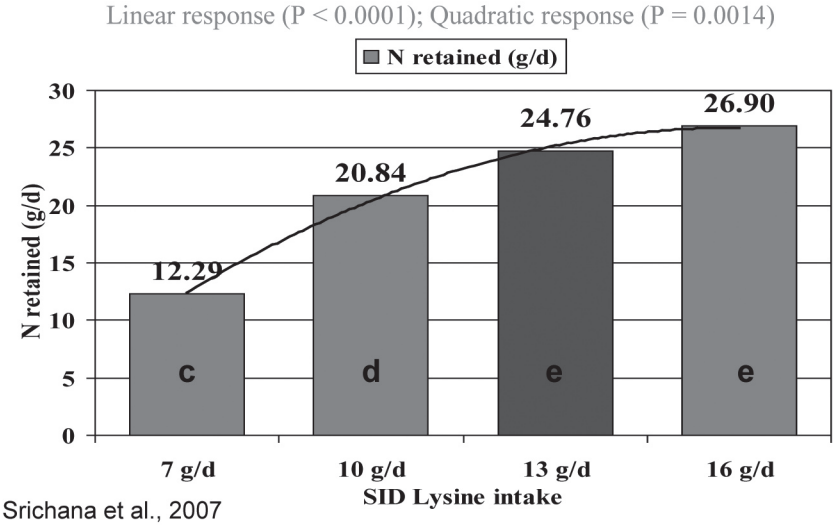
Table 1. Body Condition



BCS – 2	BCS – 3	BCS – 4
Slightly thin	Ideal Condition	Too heavy

Table 2. Determination of lysine retention from Day 40-50 of gestation.

Effect of dietary lysine on Nitrogen retention in early gestation (d 40-50)[a]

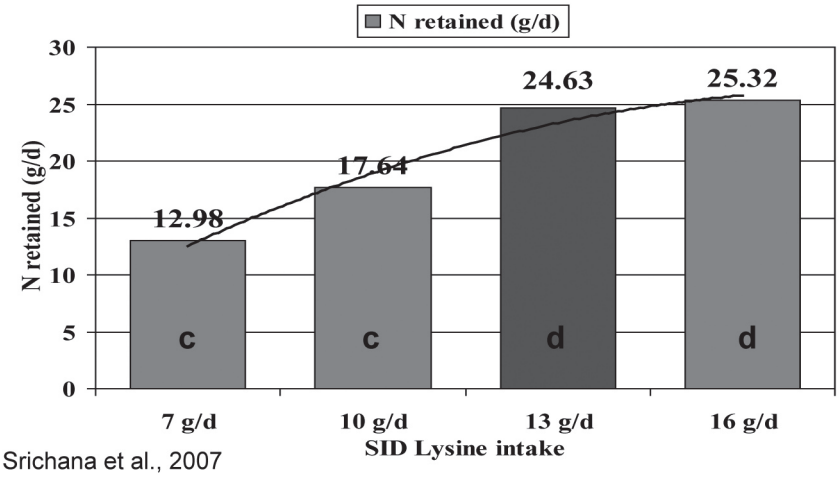


Srichana et al., 2007

Table 3. Determination of lysine retention from Day 40-50 of gestation.

Effect of dietary lysine on Nitrogen retention in mid gestation (d 70-80)[a]

Linear response (P < 0.0001); Quadratic response (P = 0.1216)

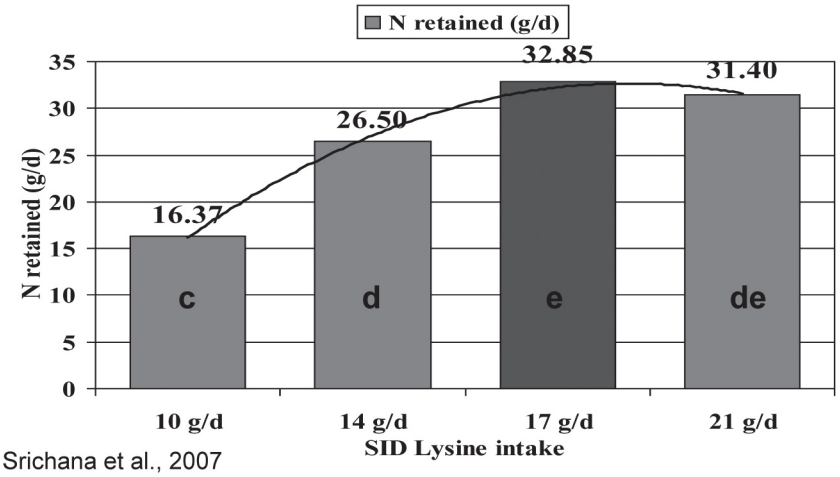


Srichana et al., 2007

Table 4. Determination of lysine retention from day 90-100 of gestation.

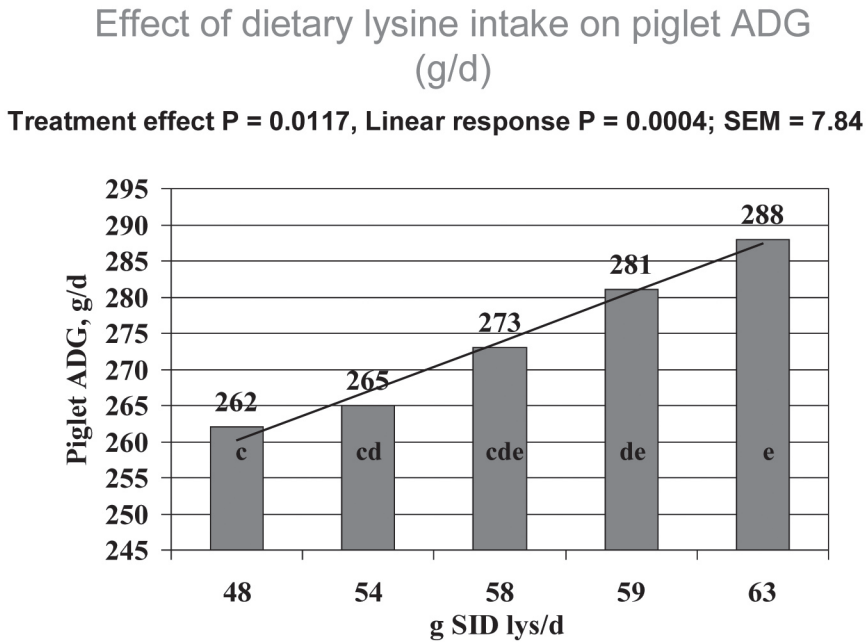
Effect of dietary lysine on Nitrogen retention in late gestation (d 90-100)[a]

Linear response (P < 0.0001); Quadratic response (P < 0.0001)



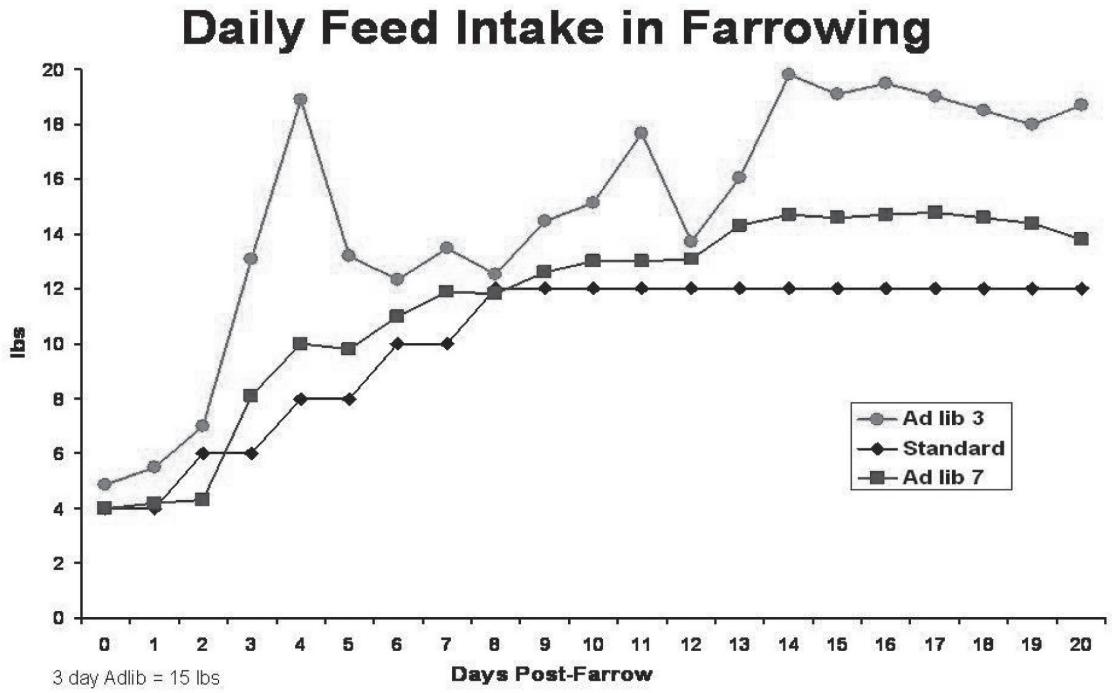
Srichana et al., 2007

Table 5. Effect of SID Lysine levels on first parity piglet litter gain.



Srichana et al., 2007

Table 6. Lactation Feed Intake Programs. Demonstration of different methods of feeding during lactation and total feed intake.



3 day Adlib = 15 lbs

Standard = 10.6 lbs

7 day Ad Lib = 11.5 lbs

Benefits of Mannan Oligosaccharides (MOS) For Sows and Weanling Pigs[1]

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Summary

A MOS-containing product was evaluated with regard to its potential to improve sow performance. Follow-on performance of pigs from those sows into the nursery was also evaluated. The inclusion of the product had no effect on litter size, as would be expected, but it did positively affect pig birth weight, weaning weight, and subsequent end-of-nursery weight. An increase in birth weight of 180 grams in the live born pigs ($P < 0.05$) translated into 780 grams ($P < 0.05$) at weaning which then became 1260 grams ($P < 0.01$) by the end of the nursery phase. There were numerical increases in nutrient content of milk and immunoglobulin levels in colostrum and milk but neither of these was statistically significant to definitively explain the mechanisms whereby the clearly significant increase in pig weight was obtained. However, the numerical improvements were often in excess of 10%, thus the concept of increased nutrient content of milk or increased immunoglobulin content contributing to improved piglet performance is not disproved. There was no indication in this study of an improvement in growth rate in the nursery of the pigs due to the MOS being fed to either the sows or the pigs but there was a trend ($P < 0.06$) for a reduced feed/gain ratio in those nursery pigs that came from MOS-fed sows. The facilities and pigs were very clean and performance was good; whether performance may have been affected to a greater extent in a dirtier environment or in pigs that were health-challenged can not be determined from these results. In conclusion, a MOS-containing product for sows has potential to improve lactation performance.

Introduction

Mannan oligosaccharides (MOS) are complex sugars which consist mainly of mannose. The mannan functions as a ligand for type 1 fimbria, a specific attachment structure of pathogenic bacteria such as E. coli and salmonellae. When bacteria recognize the mannan on intestinal cells, they bind to the cell and then colonize the intestine which can subsequently lead to disease (Newman, 1994). When bacteria recognize and bind with the mannan units of dietary MOS, those bacteria will be flushed out of the intestine instead of attaching and colonizing the intestinal wall. Obviously, then, this could potentially improve gut health and well-being. Dietary MOS supplementation has been studied relative to improving the growth performance and immunity of weanling animals (LeMieux et al., 2003; Miguel et al., 2004) and relative to aspects of reproductive performance of sows (Maxwell et al., 2003; Newman and Newman, 2001).

The aim of this experiment was to determine the effect of supplying MOS to sow diets on reproductive performance and milk composition and, then, on the subsequent growth performance of piglets fed with or without MOS in the nursery.

[1] Presented September 10, 2009 at the 2009 Midwest Swine Nutrition conference, Indianapolis, IN.

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Experimental procedures

A total of 24 Yorkshire or Landrace × Yorkshire sows with an average parity of 1.63 ± 0.92 were assigned to 2 dietary treatments, including: 1) a control diet that met NRC (1998) nutrient requirements and 2) the control diet with a MOS product [0.2% for both gestation and lactation diets]. A modified yeast culture feed additive containing MOS (Celmanax®; Vi-COR, Mason City IA) was the product used in this experiment.

Sows were allotted to treatment based on parity, breed and breeding weight and kept in individual gestation stalls. Individual floor feeding at a level of 1.8 kg/d was maintained throughout gestation with water available from water nipples on an ad libitum basis. The experiment started 14 days before the expected farrowing date, or approximately day 102 of gestation. On approximately d 108 of gestation, sows were moved to a temperature-controlled farrowing facility and placed in farrowing crates. Diets were changed to lactation diets and were fed at a level of 1.8 kg/d until farrowing and were fed ad libitum after farrowing. Gestation room temperature and farrowing/lactation room temperature and humidity were recorded daily.

The sow diets were based primarily on corn and soybean meal and were calculated to contain 3,364 kcal/kg ME, 12.62 % CP, and 0.58% lysine for gestation and 3,408 kcal/kg ME, 17.65 % CP and 1.01% lysine for lactation. Minerals and vitamins were added to meet or exceed NRC (1998). The treatment diets were made by adding the Celmanax product to the basal diet in a replacement for corn.

Sow feed consumption during the lactation period was recorded daily. Sow weights were obtained at breeding, pre-feeding of the treatment diets (gestation d 101–102), pre-farrowing (gestation d 111-113), and within 24 h post-farrowing. The number of pigs born (alive and dead) and the birth weight of each pig were recorded within 24 h of farrowing. In addition, pigs received ear-notches, clipping of needle teeth, and injection with 100 mg Fe as Fe dextran on the same day. Some of the piglets were transferred to other litters within treatment within 3 days after birth to balance the litter size. It should be noted that no transferred piglet died during the experiment. Individual pig weaning weights were also recorded.

Blood samples from the sows were collected by jugular venipuncture at pre-feeding of the treatment diets, pre-farrowing (d111-113 of gestation), early lactation (d 4-6 of lactation) and late lactation (d 15-17 of lactation). Colostrum samples were collected within 24 h of farrowing. Milk samples were collected to represent early lactation (d 4 – 6) and late lactation (d 15 – 17) respectively. Serum samples from five piglets in the mid-birth weight range of each litter were collected by jugular venipuncture during early lactation and late lactation. A similar quantity of serum per piglet (approximately 0.1 mL from each piglet) was pooled together within each litter for analysis.

Total IgA, total IgG, and total IgM were measured in all serum and colostrum/milk whey samples by enzyme-linked immunosorbent assay (ELISA) test (pig IgA/IgG/IgM ELISA Quantitation Kit, Bethyl Laboratories Inc., Montgomery, TX) following the manufacturer's protocol.

A total of 104 weaned piglets were assigned from each litter to 2 diets including: 1) a control diet that met NRC (1998) nutrient requirements and 2) the control diet with MOS product [0.2% for both Phase 1 and Phase 2 diets]. The allotted within litter created a 2 × 2 factorial arrangement with the experimental treatments as: 1) control sow diet with control nursery diet, 2) control sow diet with MOS nursery diet, 3) MOS sow diet with control nursery diet, and 4) MOS sow diet with MOS nursery diet. Each sow treatment was replicated with 7 pens of 3 or 4 weaning pigs with gender balanced within the 2 pens formed from each sow. Animals were allowed ad libitum access to feed and water. Body weight and feed disappearance were recorded weekly for four weeks.

The diets were based primarily on corn and soybean meal which were calculated to contain 3,404 kcal/kg ME, 21.92 % CP and 1.38% lysine for the Phase 1 diet (Wk 1 and 2); and 3,316 kcal/kg ME, 20.80 % CP and 1.21% lysine for the Phase 2 diet (Wk 3 and 4). Minerals and vitamins were added into diet to meet or excess the NRC (1998) requirement. No antibiotic was included in the diets.

All data were analyzed by analysis of variance for a completely randomized design using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC) with pen/sow as the experimental unit. The sow data were also analyzed using lactation length as a covariate; nursery data were analyzed using initial body weight as a covariate.

Results

Sow reproductive performance

The effects of dietary MOS supplementation are shown in Table 1. While lactation feed intake was numerically slightly increased (though not significantly) by feeding MOS in the diet, sows fed MOS lost weight during lactation while sows fed the control diet did not (-7.69 vs. 0.54 kg, $P < 0.01$).

The litter size born was not significantly different between MOS-fed sows and control sows and would not be expected to be different given the initiation of dietary treatments on d 102 of gestation. But the litter weight at birth and at weaning of sows fed MOS was numerically higher than sows fed the control diet (17.41 vs. 15.21 kg at birth; 63.75 vs. 55.17 kg at weaning, $P > 0.10$). When this weight is expressed on an individual pig weight, sows fed MOS had heavier piglets than control sows for total pigs born (1.61 vs. 1.45 kg, $P < 0.10$), pigs born alive (1.65 vs. 1.47 kg, $P < 0.05$), and at weaning (6.95 vs. 6.17 kg, $P < 0.05$). This result is similar to the results presented in a review by Pettigrew et al. (2005) where three studies in which birth and weaning weights were reported all demonstrated that adding MOS to sow diets 2-3 weeks before parturition and through lactation period significantly increased piglet body weight.

It is known that sow weight change during lactation and total litter weights differ due to the length of lactation. Thus, although there is no statistical difference of lactation length between treatments (18.92 vs. 18.36 d, $P > 0.20$), an analysis of covariance was conducted to determine if lactation length was contributing to any degree to the positive responses observed in the MOS-fed sows. After re-analysis of variables that could be affected by lactation length with lactation length as a covariate, similar results are observed with MOS-treated sows still having heaver piglets born live at birth (1.65 vs. 1.47 kg, $P < 0.05$) and at weaning (6.86 vs. 6.27 kg, $P < 0.05$). The body weight distribution of pigs at various times is provided in Figure 1. The graphs demonstrate that the body weight is shifted for the whole population and that the increased body weight is not of just the large pigs.

How are increased body weights of pigs accomplished? This could be done through increased milk production, increased nutrient content of the milk, or increased metabolic efficiency of the piglets. The most likely of these possibilities would be an increase in milk production or increased nutrient concentration. In this study there was no attempt to measure milk production. However, milk samples were obtained and Table 2 shows the protein, fat, and lactose content of the sow milk. There were no significant differences on these milk components between treatments but there was a tendency for a lower lactose content in early lactation milk from MOS-fed sows. The components that might be most likely associated with increased weight gain of the pigs would be fat and protein; while these values are numerically higher in MOS-fed sow milk compared to control sow milk in both early lactation (fat: 8.99 vs. 8.22 %; protein: 5.73 vs. 5.56 %, $P > 0.20$) and late lactation (fat: 8.28 vs. 7.67 %; protein: 4.92 vs. 4.82 %, $P > 0.20$), they were not statistically different.

Colostrum, milk, and serum immunoglobulin levels are presented in Table 3. The immunoglobulin results are much like the milk composition results. MOS treatment was associated with an increase of 10% in IgG level in colostrum but the result was, again, not statistically significant (57.85 vs. 51.54 mg/mL, $P > 0.20$). Colostrum IgA and IgM level and both early and late lactation milk IgA, IgG, IgM were also numerically higher in MOS treatments (many of them more than 10%), but none of them were statistically significant. The review by Pettigrew et al. (2005) reported colostrum and early milk immunoglobulin levels from three studies and showed increased levels in 11 of 12 measures; those which were statistically significant had increases from 13 – 39%. Thus, there is a consistent pattern of immunoglobulin increase but, because of inherent variability in this type of measure, the response has to be relatively large to exhibit statistical significance in a single study. Sow serum immunoglobulin levels had similar results, in general, as the milk samples. There was no difference in piglet serum immunoglobulin in late lactation between treatments.

Nursery Performance

The growth performance during the nursery period of piglets from sows fed with or without MOS is presented in Table 4. Piglets from sows fed MOS were significantly heavier ($P < 0.01$) than those from sows fed the control diet at weaning and at each weekly weight for the entire nursery period. The weekly ADG and ADG of each phase for piglets from sows fed MOS were numerically higher than piglets from control sows (but $P > 0.10$), and with regard

to the total experimental period, the ADG of piglets from MOS-fed sows were significantly higher than that of piglets from control sows (444 vs. 405 g, $P < 0.05$). There was no significant difference for ADFI and feed:gain ratio among sow treatments in each week, each phase, nor the entire experimental period. The MOS supplementation of starter feed had no significant effect on ADG, ADFI or feed/gain ratio, nor were there interactions between sow and pig treatments.

It is known that the growth performance during the nursery period is usually affected by the initial BW of pigs entering the nursery. Thus, the positive responses observed in total trial ADG and in the weekly body weights of pigs from MOS-fed sows may have been the result of the heavier initial weight of those pigs entering the nursery. To correct for this, Table 5 shows the results for the nursery period with initial BW as the covariate. The main effects of the covariate analysis are that the statistically significant difference between treatments for pig body weight at the various time points are now absent, the total trial ADG improvement is now absent, and an improvement in feed/gain ($P = 0.055$) in pigs from MOS-fed sows for the total trial period is now introduced. All of these changes are logical. The change in P-value for body weight at later time points would naturally flow from the use of initial body weight as a covariate. The improvement in feed/gain for the total trial is logical because pigs from MOS-fed sows had similar feed/gain in Table 4 (even though they were heavier pigs), so on a common weight basis in Table 5, the feed/gain should be better. All of these statements on the nursery performance basically can be reduced to say that the nursery effects observed in Table 4 were due to the initial body weight of the pigs in this nursery trial and not to the diets fed during the nursery period.

The question must then be asked whether the allotment of pigs to the nursery was done correctly and whether that allotment accurately represented the pigs coming from the farrowing house. To assess this, if the weaning weight is examined from Table 1, it can be seen that pigs from MOS-fed sows were 780 g heavier at weaning while the initial body weight difference in the nursery was 765 g, thus the allotment into the nursery did represent the weaning weights. Mean values in the two tables (Table 1 and Table 4) are not identical because all pigs were not used in the nursery; some pigs were not used because gender balance going into the nursery pens was an allotment criterion. Thus a litter with 5 barrows and 3 gilts would only have used 4 barrows and 2 gilts in the nursery phase (being split into pens of 2 barrows and 1gilt each).

In summation, the inclusion of MOS (as the product Celmanax®) in diets for sows and nursery pigs in this study demonstrated clear improvements in reproductive performance (heavier pigs at all time points) but did not demonstrate clear value in nursery diets. However, pigs from MOS-fed sows performed better in the nursery because of the increased body weight they had at the end of the lactation period.

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Table 1. The effect of dietary MOS supplementation on reproductive performance in sows

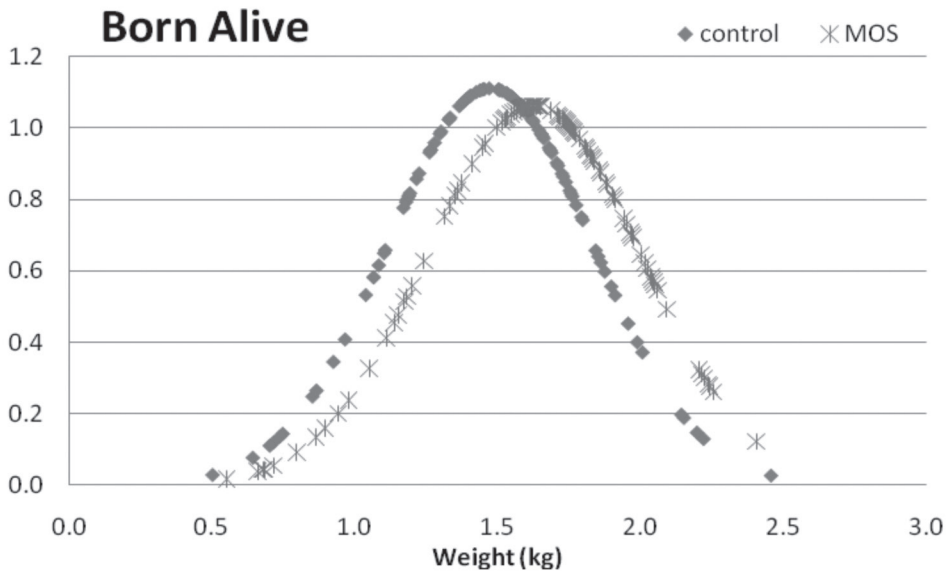
	Control	MOS	SEM	*P*-value
n	11	13		
Average parity	1.82	1.46		
Length (d)				
Lactation	18.36	18.92	0.50	0.437
Days to rebreed[1]	4.33	4.69	0.18	0.170
Weight change (kg)[2]				
D 101 - postfarrow	5.66	5.59	1.46	0.975
Lactation	0.54	-7.69	1.95	0.007
Lactation feed intake (kg)				
Total	95.75	100.91	5.18	0.562
ADFI	5.21	5.31	0.28	0.804
Litter size				
Total	10.45	10.92	0.99	0.740
Alive	9.36	9.85	0.96	0.726
Post-transfer[3]	10.00	9.85	0.63	0.866
Weaning	9.00	9.15	0.48	0.822
Litter weight (kg)				
Total	15.21	17.41	1.47	0.301
Alive	13.80	16.01	1.41	0.281
Post-transfer[3]	15.20	16.08	1.04	0.555
Weaning	55.17	63.75	3.98	0.142
Average piglet weight (kg)				
Total	1.45	1.61	0.06	0.084
Alive	1.47	1.65	0.06	0.044
Post-transfer[3]	1.52	1.64	0.05	0.131
Weaning	6.17	6.95	0.24	0.033

[1] Control: n = 9; MOS: n = 12.

[2] Gestation weight change is the weight difference between breeding and post-farrowing; D 101-postfarrow is the weight difference between the day before sow was fed the experimental diet and post-farrowing; Lactation weight change is the weight difference between post-farrowing and weaning.

[3] Pigs were transferred into Control litters from non-experimental sows to increase litter size to near 10 pigs (non-experimental sows would have received the same diet as the Control sows), pigs were transferred within the MOS treatment to balance litter size among sows in that treatment but no new pigs were brought into the litters.

Figure 1. Body weight distribution of pigs at various times.



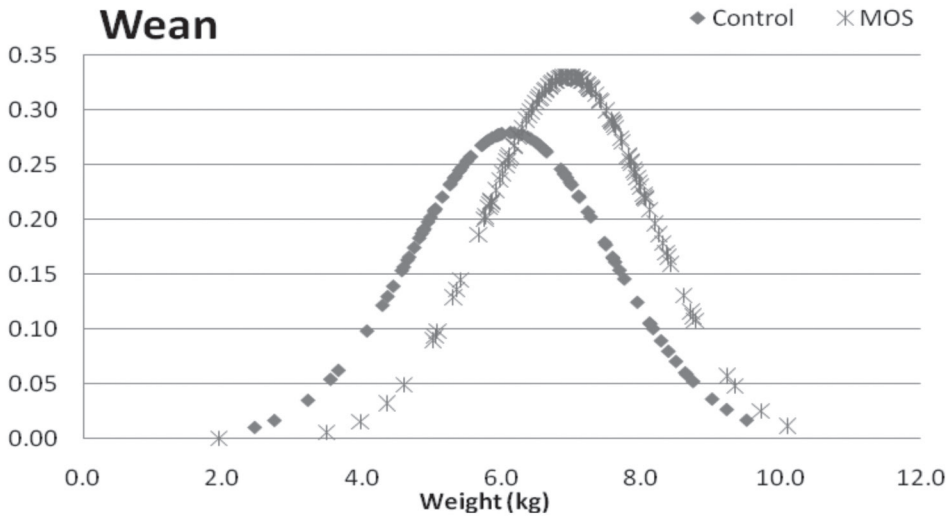


Table 2. The effect of dietary MOS supplementation on sow milk composition (%)[1]

	Control	MOS	SEM	*P*-value
Early lactation				
n	10	13		
Fat	8.22	8.99	0.55	0.337
Protein	5.56	5.73	0.21	0.582
Lactose	5.84	5.54	0.12	0.098
Late lactation				
n	11	13		
Fat	7.67	8.28	0.35	0.229
Protein	4.82	4.92	0.17	0.676
Lactose	5.90	5.85	0.14	0.791

[1]Early lactation milk samples were obtained on D 4-6 of lactation; late lactation milk samples were obtained on D 15-17 of lactation.

Table 3. The effect of dietary MOS supplementation on milk and serum immunoglobulin level (mg/mL)[1].

	Control	MOS	SEM	*P*-value
Pre-farrow sow serum				
n	11	12		
IgA	1.18	1.20	0.12	0.918
IgG	13.80	14.51	1.13	0.658
IgM	6.80	8.55	0.74	0.111
Colostrum				
n	8	7		
IgA	11.22	12.31	1.59	0.638
IgG	51.54	57.85	5.93	0.465
IgM	3.70	3.77	0.45	0.913
Early lactation milk				
n	10	13		
IgA	4.80	5.54	0.53	0.332
IgG	0.60	0.72	0.12	0.478
IgM	1.90	2.30	0.25	0.282
Late lactation milk				
n	11	13		
IgA	3.44	4.10	0.41	0.272
IgG	0.20	0.26	0.03	0.126
IgM	1.02	1.26	0.13	0.201
Late lactation sow serum				
n	10	13		
IgA[2]	0.88	1.04	0.10	0.295
IgG	15.84	15.75	0.99	0.951
IgM	3.80	5.21	0.45	0.037
Late lactation pooled piglets serum				
n	11	13		
IgA	0.17	0.16	0.04	0.826
IgG	8.30	7.89	0.77	0.713
IgM	0.43	0.47	0.04	0.498

[1] Pre-farrow serum samples were obtained on the D 101 – 102 of gestation; post-farrow serum samples and colostrums samples were obtained within 24 h of farrowing; early lactation milk samples were obtained on D 4-6 of lactation; late lactation milk samples, sow serum samples and piglet serum samples were obtained on D 15-17 of lactation.

[2] Control: n = 9; MOS: n = 12.

Table 4. Effects of dietary MOS supplementation on growth performance of weaned pigs.

Treatments[1]						*P*-value		
Sow:	Control		MOS		SEM	Sow	Pig	Sow × Pig
Pig:	Control	MOS	Control	MOS				
Body weight (kg)								
Week 0	6.49 [b]	6.52 [ab]	7.27 [a]	7.27 [a]	0.26	0.007	0.932	0.950
Week 2	9.95 [ab]	9.67 [b]	10.99 [a]	11.06 [a]	0.40	0.005	0.795	0.669
Week 4	18.28 [ab]	17.41 [b]	19.60 [a]	19.82 [a]	0.64	0.007	0.615	0.403
Average daily gain, ADG (g)[2]								
Phase 1	247.4	224.8	265.8	270.3	20.22	0.127	0.660	0.509
Phase 2	595.0 [xy]	552.8 [y]	615.3 [xy]	626.2 [x]	28.28	0.111	0.585	0.357
Total	421.2 [ab]	388.8 [b]	440.5 [ab]	448.2 [a]	18.72	0.046	0.517	0.295
Average daily feed intake, ADFI (g)[2]								
Phase 1	360.3	356.1	378.0	391.3	21.92	0.240	0.836	0.693
Phase 2	946.5	914.6	979.9	993.9	41.41	0.186	0.830	0.584
Total	653.4	635.4	678.9	692.6	27.87	0.151	0.938	0.575
Feed/gain ratio[2]								
Phase 1	1.48	1.60	1.44	1.48	0.07	0.245	0.245	0.510
Phase 2	1.59	1.67	1.60	1.59	0.04	0.324	0.382	0.227
Total	1.55 [y]	1.64 [x]	1.55 [y]	1.55 [y]	0.03	0.177	0.233	0.203

[abc] Means with the same letter are not significantly different ($P < 0.05$).

[xyz] Means with the same letter are not significantly different ($P < 0.10$).

[1] Pigs from 7 litters of each sow treatment were split into the 2 nursery treatment diets, including the Control diet and the diet with 0.2 % MOS, with 3 or 4 pigs per pen and 7 pens per treatment.

[2] Phase 1 is Week 1 and Week 2 postweaning; Phase 2 is Week 3 and Week 4 postweaning.

Table 5. Effects of dietary MOS supplementation on growth performance of weaned pigs with initial BW as covariate.

Treatments[1]						*P*-value		
Sow:	Control		MOS		SEM	Sow	Pig	Sow x Pig
Pig:	Control	MOS	Control	MOS				
Body weight (kg)								
Week 0	6.89	6.89	6.89	6.89				
Week 2	10.38	10.06	10.58	10.64	0.30	0.261	0.660	0.518
Week 4	18.87	17.95	19.04	19.25	0.54	0.239	0.499	0.287
Average daily gain, ADG (g)[2]								
Phase 1	249.7	226.9	263.6	268.1	21.52	0.265	0.662	0.515
Phase 2	606.6	563.3	604.3	615.1	29.12	0.454	0.565	0.343
Total	428.1	395.1	434.0	441.6	19.40	0.240	0.501	0.285
Average daily feed intake, ADFI (g)[2]								
Phase 1	367.1	362.3	371.5	384.8	22.92	0.606	0.849	0.684
Phase 2	973.5	938.9	954.4	968.0	40.13	0.912	0.788	0.537
Total	670.3	650.6	663.0	676.4	27.39	0.766	0.906	0.534
Feed/gain ratio[2]								
Phase 1	1.49 [xy]	1.62 [x]	1.42 [y]	1.46 [xy]	0.07	0.166	0.254	0.520
Phase 2	1.60 [xy]	1.68 [x]	1.59 [y]	1.57 [y]	0.04	0.149	0.389	0.229
Total	1.57 [ab]	1.65 [a]	1.53 [b]	1.53 [b]	0.03	0.055	0.231	0.198

[abc] Means with the same letter are not significantly different according to LSMEAN with covariate as initial weight ($P < 0.05$).

[xyz] Means with the same letter are not significantly different according to LSMEAN with covariate as initial weight ($P < 0.10$).

[1] Pigs from 7 litters of each sow treatment were split into the 2 nursery treatment diets, including the Control diet and the diet with 0.2% MOS, with 3 or 4 pigs per pen and 7 pens per treatment.

[2] Phase 1 is Week 1 and Week 2 postweaning; Phase 2 is Week 3 and Week 4 postweaning.

The Controversy between Natural and Synthetic Vitamin E – New Discoveries

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Summary

Swine cannot synthesize vitamin E. Although the green foliage of pasture provided a source of α-tocopherol, it was not until pigs were moved to confinements that a supplemental source for vitamin E became recognized by the NRC (1973). Since that time vitamin E has been shown to enhance the immune system and specific reproductive disorders, enhance reproductive performance, increase the colostrum and milk α-tocopherol supply to the nursing pig, prevent the vitamin E deficiency post weaning (a critical stage in the young pig), increase tissue α-tocopherol concentration, enhances pork quality by reducing oxidative products, reduces discoloration and extends shelf life of processed pork products and does not appear to be toxic even when supplemented at excessive levels. During the last 30 years there has been a scientific debate over whether natural or synthetic vitamin E is superior to the other. The rat fetal resorption test demonstrated that natural was superior by a 1.36 ratio. Synthetic vitamin E is manufactured having several chemical forms which differ in bioavailability, thus the major reason why synthetic vitamin E was poorer on a mg / mg basis. However, recent research has shown that the 1.36 ratio underestimates the relative bioequivalence of the natural vitamin E form. Past and current research was used to calculate the bioequivalence of the 2 vitamin E forms in this presentation. In general, swine of all productive phases seem to utilize both forms of vitamin E but the natural source of vitamin E is more effective.

Introduction

Within the fat soluble vitamin group there are compounds having similar chemical structures that possess the same general function (i.e., antioxidants). This group of fat soluble compounds is termed vitamin E. One group of compounds within vitamin E is termed tocopherol and is made up of a chromanol ring and a phytyl side chain. There are 4 natural tocopherol molecules (alpha [α], beta [β], gamma [γ], or delta [δ]). The difference among the molecules is the number of methyl groups on the chromanol ring. Alpha (α)-tocopherol has 3 methyl groups on the chromanol ring, while the others have either one (delta (δ)-tocopherol) or two (beta (β) and gamma (γ)-tocopherol) methyl groups. All possess a wide range of biological activities with α-tocopherol recognized as possessing the highest vitamin E activity in animals. Synthetic α-tocopherol is manufactured and sold as vitamin E, however, unlike other synthetic vitamins, synthetic α-tocopherol is not completely identical in structure to natural α-tocopherol. Natural α-tocopherol is comprised of one molecule (RRR-α-tocopherol); while synthetic vitamin E is a racemic (rac) mixture of 8 isomers (all-rac-α-tocopherol), of which one of the isomers is identical to RRR-alpha-tocopherol. The "RRR" notation is in reference to the positions of the 3 methyl groups on the chiral carbons on the phytyl side chain of the tocopherol structure. Since there are 3 chiral carbons on the side chain, the production of synthetic vitamin E yields a racemic mixture of 8 possible locations for the methyl groups (i.e., RRR, RRS, RSR, RSS, SSS, SSR, SRS, and SRR-α tocopherol). The older terminology for natural α tocopherol is "d-α-tocopherol" while synthetic vitamin E is called "d,l-α-tocopherol". The United States Pharmacopeia (USP; 1999) has published the International Unit (I.U.) value for the 2 sources of vitamin E in an attempt to equate the 2 sources. Using rat fetal resorption studies, natural source is recognized to possess approximately 36% greater biological activity than an equal weight of synthetic.

In order to prevent oxidation of either natural or synthetic sources, an acetyl group must be attached to the active site on the hydroxyl group on the chromanol ring. This stabilizes the product until the acetyl group is hydrolyzed in the intestinal tract prior to absorption. The stability of the natural acetate appears to be equal to the stability of the synthetic acetate in complete feeds or supplements. The 4 primary commercial sources of vitamin E with the recognized I.U. activity for each are: RRR-α-tocopherol (1.49 I.U. per mg), RRR-α-tocopheryl acetate (1.36 I.U. per mg), all-rac α-tocopherol (1.1 I.U. per mg), and all-rac α-tocopheryl acetate (1.00 I.U. per mg). Recent research with humans and other livestock has questioned the relative biological activity of the natural and synthetic vitamin E sources and most researchers contend that the natural vitamin E has more biological activity than the 1.36 conversion ratio that is accepted by the USP (Institute of Medicine, 2000).

This review follows the review of Stuart and Kane (2004), but enlarges upon their summary in bringing forth new research and further supports the call for a review of the current equivalence of natural and synthetic vitamin E for humans and animals. Since vitamin E is not synthesized by the animal, it must rely on a supplemental source of the vitamin and thus an accuracy of biological potency of these sources becomes very important. This paper will only review swine research and will separate categories by production phase, explains why vitamin E is necessary in today's swine feeds, and that the current use of the 1.36 conversion ratio of synthetic to natural vitamin E is outdated.

Reproducing Sow

The need for supplemental vitamin E was not included in the early editions of the NRC (1973) because animals were generally housed on pasture and received an ample supply of vitamin E. The consumption of lush green forages provides a large supply of vitamin E (RRR- or d-α-*tocopherol*) to the sow and ultimately to her progeny (Table 1; Mutetikka and Mahan, 1993). Once animals were housed in confinement, however, the vitamin E/selenium deficiency began to emerge in commercial herds. Concurrent at that time was the prevalent parturition disease known as MMA (mastitis, metritis, agalactia) and unless sows were immediately treated, lactation performance was tremendously lowered and rebreeding was difficult. Synthetic vitamin E fed at high levels was found to increase litter size (Table 2), reduce MMA, and increase the vitamin E status of gestating and lactating sows and their progeny at birth through weaning (Malm et al., 1976; Mahan, 1991, 1994). Natural vitamin E was subsequently found to accomplish the same production points, but when equal I.U. of natural and synthetic vitamin E were compared, a greater vitamin E status of the sow, colostrum, milk, and pig at birth and weaning was achieved with the natural source (Mahan et al., 2000; Lauridsen et al., 2002). In a 3 parity study evaluating both natural and synthetic vitamin E, the natural vitamin E source clearly had greater sow serum, liver, colostrum, and milk tocopherol concentrations (Table 3). When the conversion of natural to synthetic was calculated on a mg basis (assuming the synthetic ratio at 1.36) the mg *d* ÷ mg *d,l tocopherol* results demonstrated that the sow had average equivalence of 1.61 in the serum and a 1.89 ratio in her liver but sows colostrum and milk had an average equivalence of 1.58. This indicates both were substantially above the officially recognized 1.36 conversion ratio.

In Figure 1, it is also clear that the sow does not transfer much α-tocopherol to the developing fetus. This is understandable as fat soluble products do not readily cross the placenta. Supplemental vitamin E ranged from 0 to 66 IU per kg feed, and although neonatal liver tocopherol concentrations are low, the data in Table 4 demonstrate there was a small increase in liver α-tocopherol and was greater when the natural form was fed to the sow. When the equivalence between the 2 sources is calculated for the neonatal pig liver it was 1.90. Figure 1 also shows the greater increase in vitamin E status in the nursing pig. This concentration of α-tocopherol in the liver of the young pig at weaning is critical as it represents the pig at the onset of starter period and its vitamin E status is completely based on what was consumed in the milk. Both vitamin E source and level resulted in weanling pig livers with increased α-tocopherol concentrations, but the greater differences occurred when the natural source of vitamin E was fed. Table 4 shows the calculated equivalence of the 2 sources with weanling pig liver having an equivalence of 2.16 when the 33 IU diets were fed to sows. The data in Table 4 also show that the equivalence was somewhat lower when higher dietary levels of vitamin E were fed. This possibly indicates that the efficiency of α-tocopherol usage is greater at lower dietary vitamin E intakes.

Weanling Pigs

It is clear thus far that the vitamin E status of the weaned pig is completely dependent upon what the sow transfers through her colostrum and milk and the subsequent consumption by the pig. As sows age their vitamin E status declines and although young gilts may have not had any reproductive or disease problems associated with vitamin E, it might occur with older sows. There are two aspects with the weanling pig that makes it a critical period for vitamin E nutrition. The first is the pig's rapid growth rate and thus its supply of stored vitamin E rapidly declines. If the vitamin E status of the pig was initially low at weaning or there are some other complications that interfere with vitamin E absorption or utilization, the deficiency onset will be quickly realized. The second point is that because the digestive enzymes have not yet matured, one of the enzymes secreted by the pancreases necessary for the hydrolysis of the ester linkages (i.e., acetate) from the tocopheryl molecule is low in the young pig and could reduce its absorption. The absorption of tocopherol was found to be lower than at later age (Hendemann and Jensen, 2001). Although the pig has a low esterase enzyme supply, it is probably adequate to supply an ample release of tocopherol as will be denoted later.

It was a common practice on many swine farms to inject vitamin E and Se into weaned pigs to prevent the deficiency onset. Although today that practice is reduced because of our greater knowledge on how to supplement the diets of sows and weaned pigs with both vitamin E and Se, there are occasions where injections become necessary. It was also a common practice to inject both vitamin E and Se together and commercial products were available to do that. We recently conducted an experiment where a natural source of vitamin E (Vital E) was injected in the weaned pig at 300 IU (i.e., 221 mg d-α- tocopherol) and the same product but with 1 mg of Se injected at the same site in another set of pigs. We bled the pigs at approximately 2 hour intervals (later times were spread out) to evaluate how long these nutrients were effective as measured by blood analysis. The results in Figure 2 show a peak in α-tocopherol approximately 12 hours post injection but within 48 hours most of the vitamin E had been dissipated or stored in body tissue. When Se was injected at the same time and site along with vitamin E, the same general trend occurred, but the α-tocopherol concentration was lower at each measurement period, except at 6 hr post injection. These results indicate that because of the pro-oxidant activity of Na selenite (the source of Se) had oxidized some of the vitamin E making the tocopherol less available.

Because injections are labor intensive and expensive there was clearly a need for supplemental vitamin E in the diets of weanling pigs. Although studies have been done with synthetic vitamin E (Moreira et al., 2002), that study showed the same general trend for tocopherol as when the natural source of vitamin E was fed. Serum and tissue concentration of α-tocopherol were greater when the natural vitamin E was fed. In the natural vitamin E study there was a decline in α-tocopherol in pigs that did not receive supplemental vitamin E (Figure 3). This indicates the need for supplementation at the early post weaning stage is not easily met by supplementing the diet of weaned pigs. It is now recognized that an average serum or plasma concentration of 2 μg/mL should be considered the minimum to prevent a deficiency. During the initial week post-weaning serum tocopherol concentrations declined in all treatment groups but increased sooner and was greater when 300 IU was provided.

Because of the low serum tocopherol and the inappetance of the young pig during the initial week post weaning, providing tocopherol in the drinking water may be a better way to ensure that all pigs received a minimum dosage as all pigs drink even when they don't eat feed. The results in Figure 4 demonstrate that 100 IU (74 mg) of natural vitamin E was sufficient to maintain the 2.0 μg/mL serum α-tocopherol concentration that should protect the pig from a deficiency. The question brought up earlier was whether the young pig had the digestive esterase activity to hydrolyze the acetate from tocopheryl acetate in the water for it to be effectively absorbed. When *d-α-tocopheryl acetate* or *dl- α-tocopheryl acetate* were both put in the drinking water and evaluated for the next 24 hours, it is evident in Figure 5 that both forms could be effectively absorbed and this absorption occurred within a few hours of providing it in the water supply.

Another question comes up in regarding tocopherol absorption relates to its fat soluble nature. Several commercial diets do not contain fat but the question arises whether the presence of fat in the weanling pig diet enhances or diminishes the absorption of vitamin E. A study conducted by Moreira and Mahan (2002) demonstrated that dietary

fat increased serum tocopherol concentrations in the weaned pig (Figure 6). A report by Specht et al. (2003) demonstrated in Figure 7 that when natural or synthetic vitamin E was emulsified making the products miscible in water (similar to that in the digestive tract) that absorption was greater and was greater during the initial week post weaning when both products were emulsified.

Grower-Finisher Pig

The growing pig has a need for vitamin E as does the other production phases. However, with the rapid grow rate of various tissues and their high metabolic rates, α-tocopherol can be easily destroyed by oxidative reactions within the tissue or prior to its deposition. Certain feeds or feed processing methods (e.g., high-moisture grains, soft fats, ground feed) can also destroy the natural vitamin E that is indigenous in the various grains. Because supplemental dietary sources of vitamin E (natural or synthetic) are stabilized with acetate until it is removed from the vitamin E molecule by the digestive esterase enzyme, none of the supplemental forms are destroyed in the feed. Studies conducted with growing pigs have demonstrated that all tissue incorporate vitamin E. Figure 8 demonstrated that the concentration of α-tocopherol in loin muscle increased and was greater as the dietary level of either form increased but there was a consistently greater amount of α-tocopherol retained when the natural form was provided. This experiment was conducted using the IU as the dietary variable and had the amount of mg "d" vs mg "dl" been compared the differences would have been even greater.

There are 2 current studies that have investigated the equivalence ratio of natural vs. synthetic vitamin E. The first study presented in Figure 9 clearly demonstrated that the ratio of α-tocopherol in the heart muscle was approximately 2.64 and the kidney approximately 2.2 (Yang et al., 2009). Other tissues were evaluated and they demonstrated the same general trend. These results show that the 1.36 ratio currently in use by the feed industry and NRC (1998) underestimates the relative value of natural vitamin E. It would seem that the current equivalence value is outdated.

The second trial conducted with grower finisher swine was done at the University of Illinois (Boler et al., 2009). Their study involved feeding 200 IU natural vitamin E and comparing it to the same level of synthetic vitamin E. The results demonstrated when the same dietary IU levels of both sources were compared, the pigs fed the natural vitamin E at the same dietary IU level of synthetic had pork chops less oxidative damage (Figure 10), that ground pork had less oxidative damage (Figure 11), and the rate of discoloration was less (Figure 12) when the natural form of the vitamin was fed.

Some vitamins can accumulate in tissue and if fed in amounts that greatly exceed the pig's requirement are often times quite toxic, resulting in reduced performance, and other side effects. An experiment conducted testing levels of natural vitamin E from 0 to 2700 IU. There was no adverse effect on pig performance. When tissues were examined, the tocopherol concentrations increased in a linear manner to 2700 IU vitamin E/kg diet (Figure 13).

Conclusions

Although it is well recognized that there is a need for vitamin E, the supplementation at all production phases of swine is essential. There are several ways that this vitamin can be provided and the mode of providing it may vary for the production phases. Pigs on pasture probably have no further need for supplementation of the vitamin, whereas those fed in confinement need a supplemental form of vitamin E. Natural and synthetic vitamin E are available for the feed and animal industries, with natural sources generally being more costly. Although cost per unit of active product should be the guiding rule on which one to use, it is important to recognize that the current I.U. method used to equate their value appears to be in error and needs to be corrected to more accurately reflect its equivalent value. It would appear on the basis of these data that a ratio natural to synthetic vitamin E of 1.75 to 2.25 may be more reasonable than the current ratio of 1.36.

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Table 1. Vitamin E status of lactating sows and litters when fed a non vitamin E C-SBM diet in confinement or pasture.

	C-SBM diet (no Vitamin E)			
Tocopherol In tissue	Confinement	Legume pasture	SEM	P value
Sow serum (g/mL)	0.46	0.87	0.16*	0.05
Sow milk (g/mL)	0.28	0.54	0.14*	0.05
Litter serum (g/mL)	0.72	1.18	0.09*	0.05
Litter liver (g/g)	0.85	2.36	0.28*	0.05

Source: Mutetikka and Mahan, 1993

Table 2. Effect of Vitamin E (synthetic) on Sow Reproduction.

	Vitamin E, IU/kg			
Experiment 1	0	16	33	66
Pigs/Litter, no.	9.8	10.9	11.2	10.0
Colostrum Vitamin E (g/mL)	2.72	4.34	7.75	7.01
Milk Vitamin E (g/mL)	0.44	0.77	1.29	1.67

	Vitamin E, IU/kg		
Experiment 2	22	44	66
Pigs/Litter, no.	11.9	12.0	12.3

Source: Mahan, 1991, 1994

Table 3. Effect of Natural and Synthetic Vitamin E on Sow □-Tocopherol Contents.[1]

Item	Vitamin E Source				P value	Ratio
	Synthetic	Responses	Natural	Responses		
mg:	45	per mg	33.1	per mg	(N vs S)	(mg "d"/mg "dl")[2]
No. sows	76		78		-	-
Serum tocopherol, µg/mL						
Breeding	2.36	0.052	2.83	0.085	0.01	1.63
Weaning	1.99	0.044	2.20	0.060	0.01	1.50
Sow liver tocopherol, µg/g	5.28	0.117	7.30	0.221	0.10	1.89
Colostrum tocopherol, µg/mL	21.53	0.478	25.02	0.756	0.01	1.58
Milk tocopherol, µg/mL	3.11	0.069	3.62	0.110	0.01	1.59

Source: Mahan et al. (2000)

[1]An average of 30 and 60 IU of both vitamin E sources (i.e. 45 IU). This is equivalent to

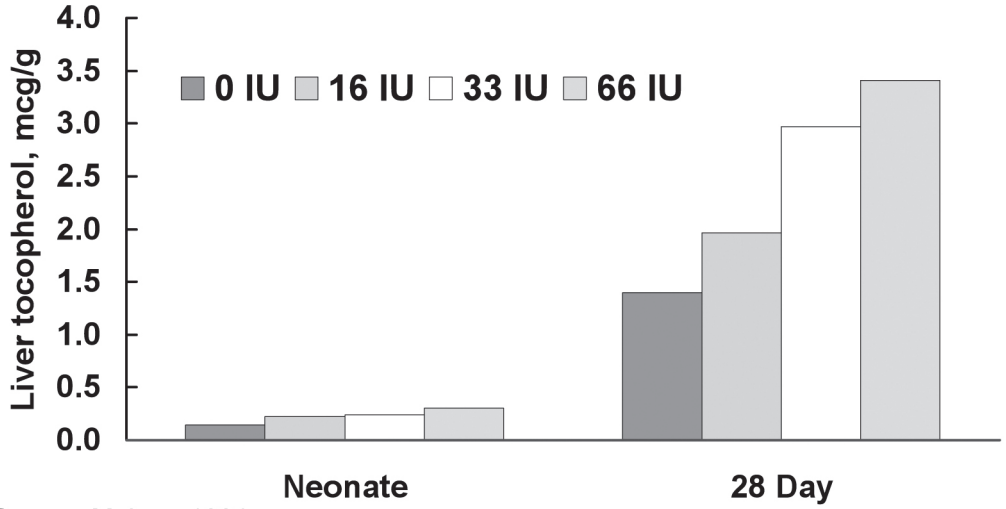
[2]The ratio of d to dl forms is based on a mg not IU basis and represents the equivalence ratio. The conventional ratio is 1.36.

Table 4. Natural or synthetic vitamin E fed to the sow on neonatal and weanling pig tocopherol status.[1]

Item	Natural (d)				Synthetic (dl)				SEM	Ratio (mg "d"/mg "dl")	
	33 IU	Responses	66 IU	Responses	33 IU	Responses	66 IU	Responses		33 IU	66 IU
mg:	24.3	per mg	48.5	per mg	33	per mg	66	per mg			
Neonatal pigs											
Liver tocopherol, µg/g	0.46	0.019	0.51	0.011	0.34	0.010	0.42	0.006	0.06	1.90	1.83
Weaned pigs											
Liver tocopherol, µg/g	6.15	0.253	6.54	0.135	3.85	0.117	4.74	0.072	0.71	2.16	1.88
Serum tocopherol, µg/mL	4.16	0.171	5.12	0.106	3.68	0.112	4.53	0.069	0.25	1.53	1.53

[1]Source: Mahan et al., 2000

Figure 1. Effect of Sow Dietary Vitamin E on Neonate and Weaning Pig Liver Tocopherol



Source: Mahan, 1991

Figure 2. Serum α-tocopherol post injection of Vitamin E and Se

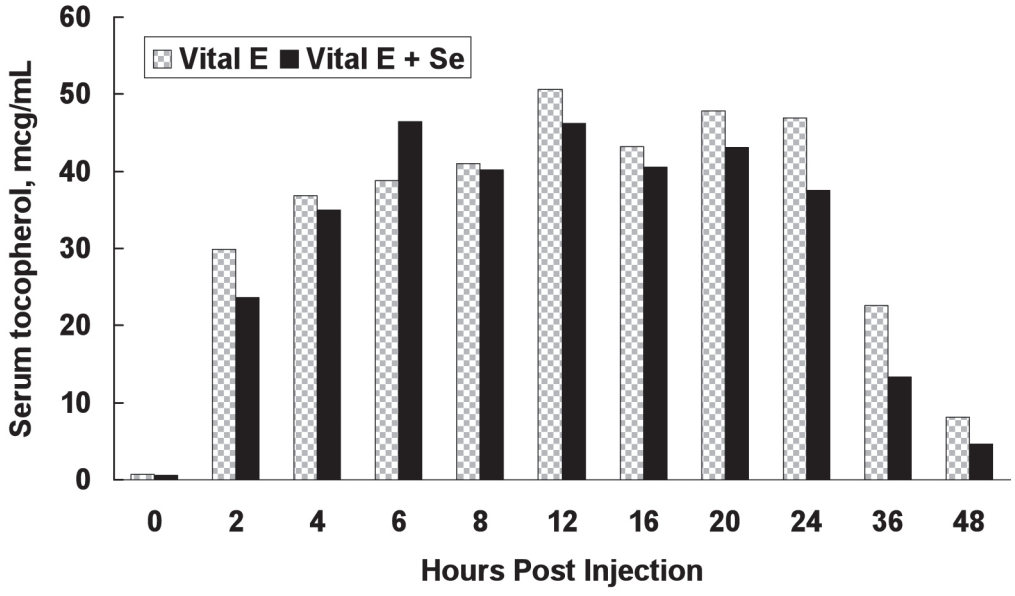


Figure 3. Effect of Dietary Natural Vitamin E on Serum Tocopherol

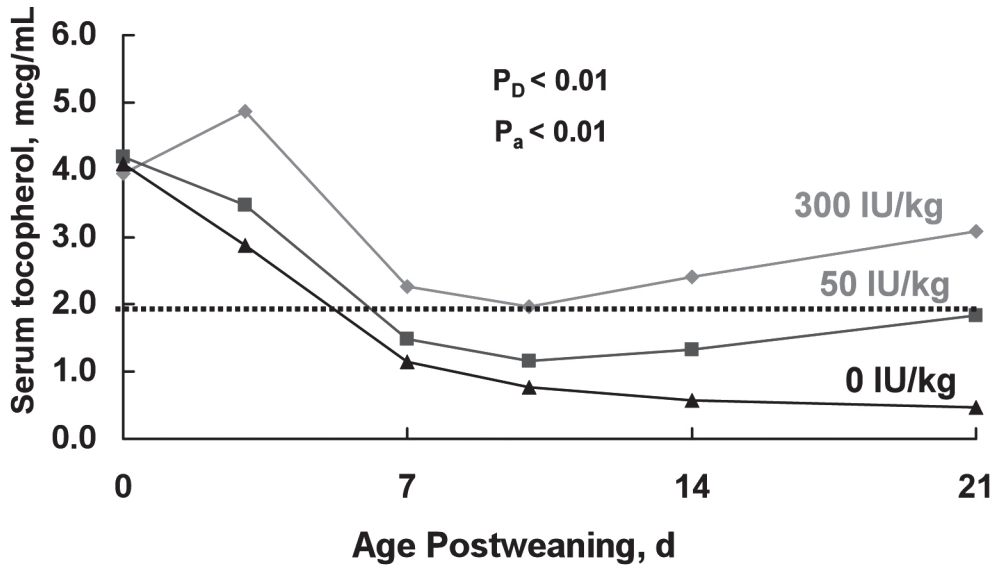


Figure 4. Effect of Supplemental Vitamin E in the Drinking Water on Serum Tocopherol

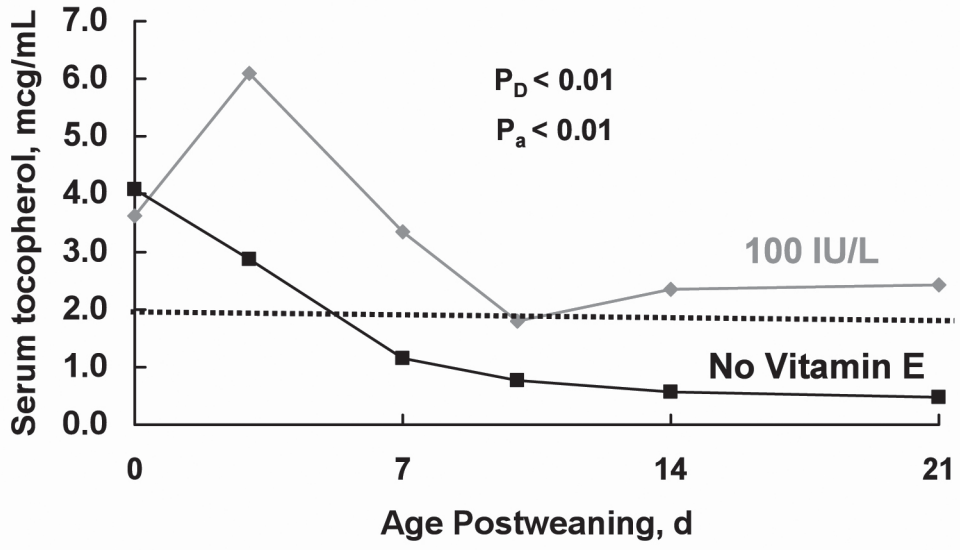


Figure 5. Effectiveness of α Tocopherol Absorption upon supplying Vitamin E in the drinking water (100 IU/L)

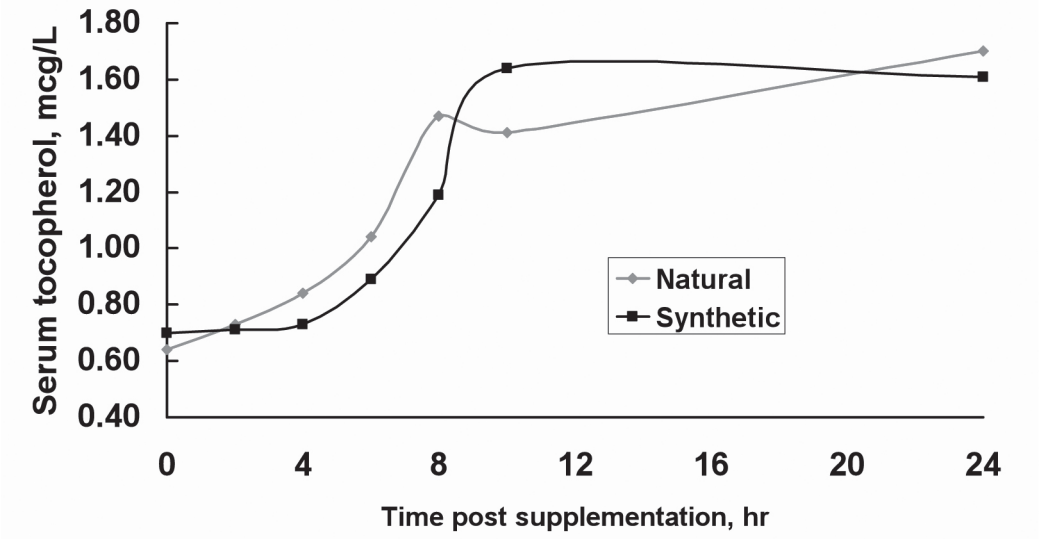


Figure 6. Effect of Dietary Fat and Vitamin E Level on Serum Tocopherol

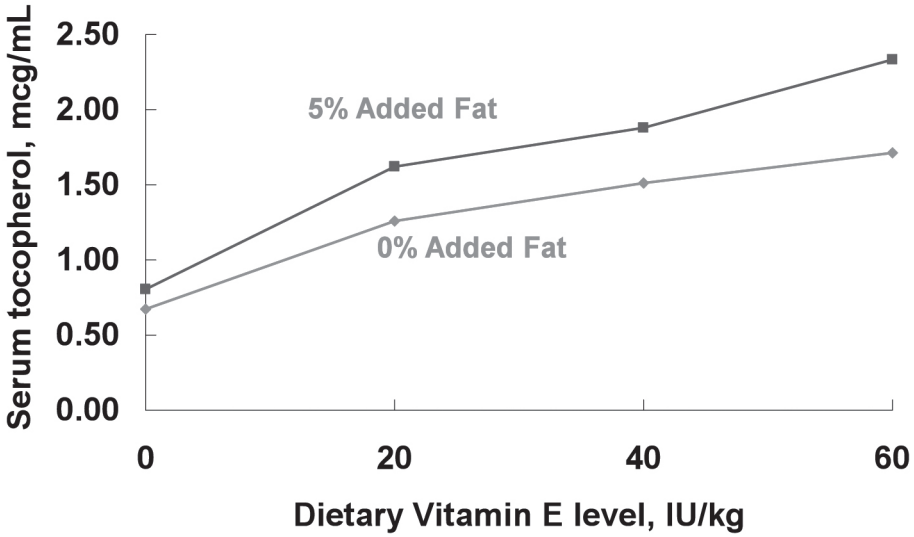


Figure 7. Emulsification of Natural and Synthetic Vitamin E Sources Provided in the Drinking Water on Absorption of Tocopherol

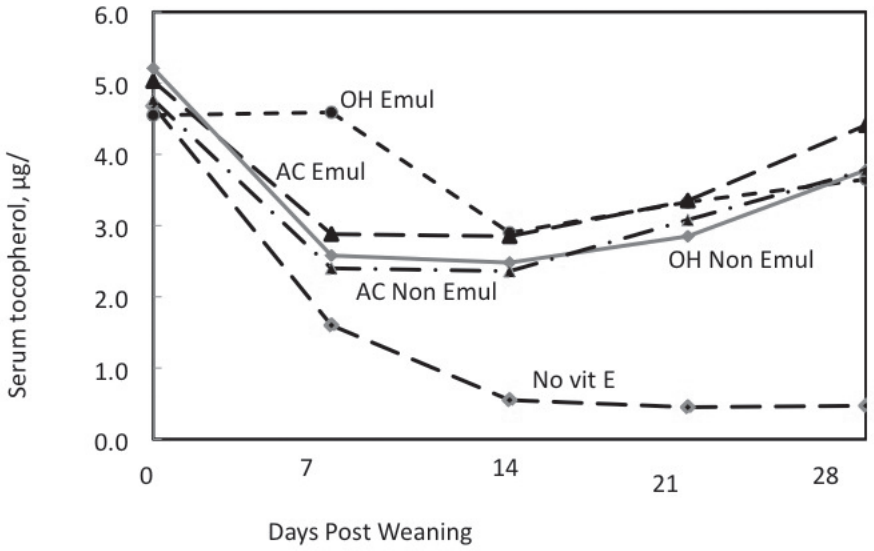


Figure 8. Effect of Natural vs. Synthetic Vitamin E on Loin Tocopherol

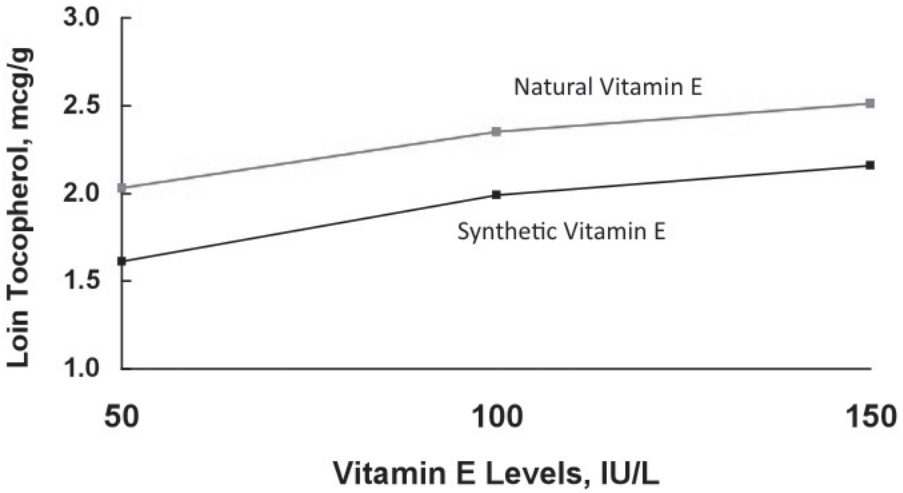
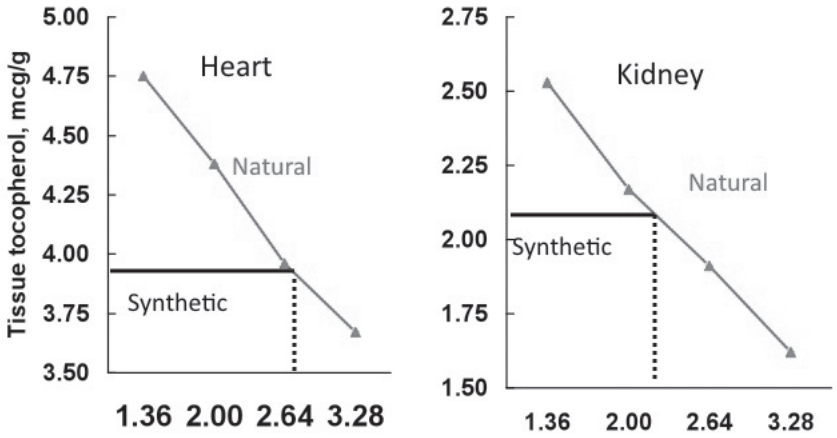


Figure 9. Relationship of Natural to Synthetic Vitamin E

Source: Yang et al. (2009)



Ratio of Natural to Synthetic Vitamin E (normal = 1.36)

Figure 10. Oxidative Products (TBARS) in Pork Chops
Over a 15 Day Retail Display

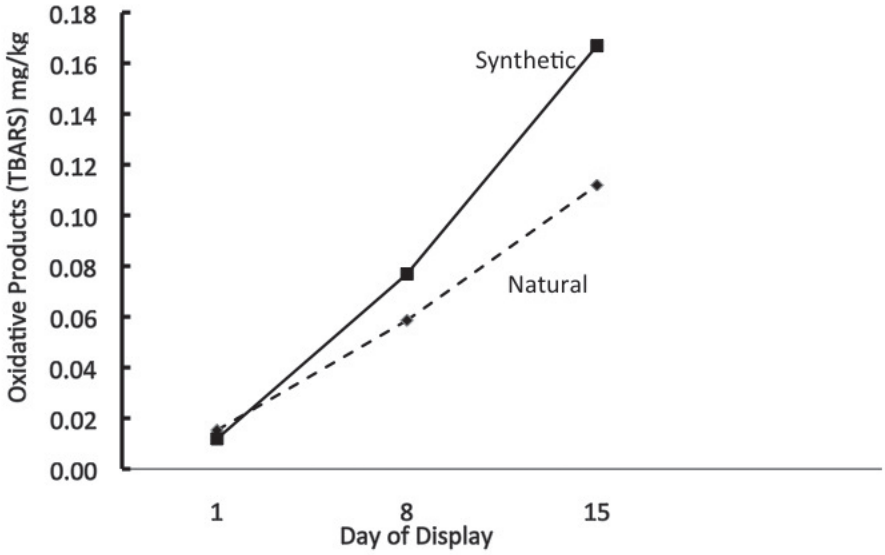


Figure 11 . Oxidative Products (TBARS) in Ground Pork
0ver a 12 Day Retail Display

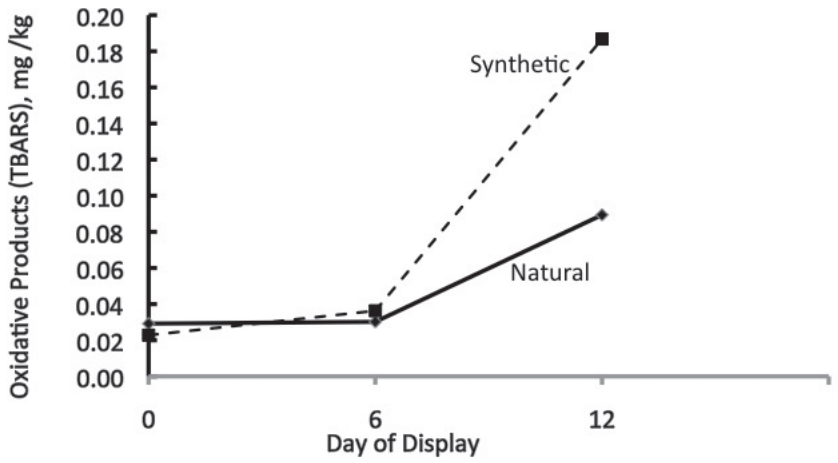


Figure 12. Percent discoloration Over a 5 Day Period in Retail Display

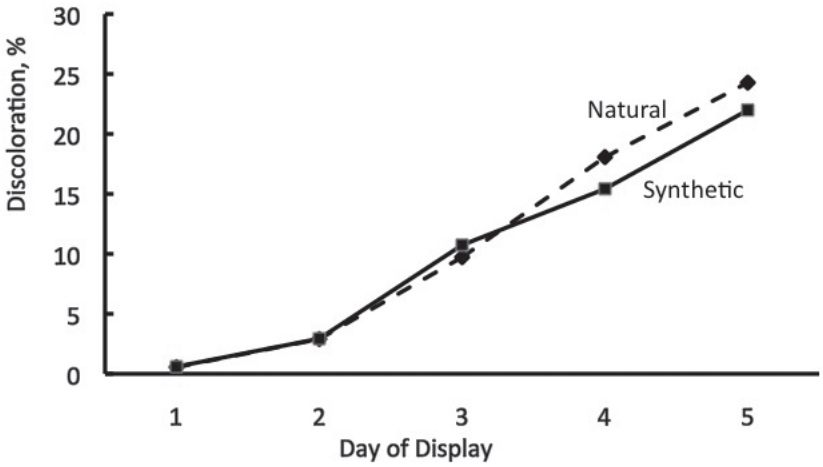


Table 13. Effect of natural α-tocopheryl acetate fed to grower finisher pigs on tissue tocopherol concentrations