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Contents

Commercialization and Consolidation of the Swine Industry in China

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Summary

Commercialization and consolidation of the swine industry in China has progressed rapidly similar to that experienced in the United States. Once the restrictions of the Great Leap Forward and the Cultural Revolution were eliminated, individual Chinese by the millions started to grow pigs for food and family income. With the decollectivization across China, swine production grew dramatically, rising to almost 678,000,000, or over 6 times the production in the United States. With industrial growth and job opportunity, the farmers made a choice of working in factories or staying on the farm, increasing food productivity, and adapting technology somewhat similar to the decisions in the United States.

Introduction

China is the most populous country in the world with an excess of 1.3 billion people. Food sufficiency is an ongoing concern for China. Table 1 presents some of the obvious challenges for a country of this size and population. In contrast, the United States is 2.3% larger in area and has 24.4% more arable land on which to produce food, while China has 428% more people to feed than does the United States. Various efforts have been implemented to conserve food adequacy for an entire year.

The status of the swine industry in China is best understood by positioning this important food source within Chinese agriculture and among other food and feed sources. China produces more than half of the swine in the world. For reasons attributed to drought and political decisions (Great Leap Forward), China suffered through the great famine of 1958 to 1962 that resulted in estimates of 42 million premature deaths during that period (DiKotter, 2010). Food productivity remained a serious problem for more than a decade and is attributed to the manifestation of the Cultural Revolution (MacFarquhar and Schoenhals, 2006).

Decollectivization was reinstated at the end of 1970's and eventually productivity and food availability began to recover (Worden, Savada, and Nolan, 1987). The data in Figure 1 clearly documents the extreme variability in productivity increases for a broad cross section of agriculture (China Statistical Yearbook of 1997, Beijing). There was little change in per capita production of any plant crop except fruit from 1951 through 1978 at which time the benefits of privatization and economic reforms began to allow some growth. Animal products, particularly aquatic and pork, along with fruit have had outstanding recoveries since 1980 with a 7-fold increase by 1997. Most interesting to note is that grain production, in contrast, had only marginal increases over that period. Oil bearing crops, mainly soybeans that provide much of the protein for poultry and swine, had limited increases, but did at least double over the 20-year period. With minimal increases in corn and soybean production through 1997, the question remains: "what made up the remainder of the animal diets to support the tremendous increases in pork production beyond these two energy and protein sources that allowed such growth in swine production?"

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There is a most interesting graph (Figure 2) which shows the National GDP (Gross Domestic Product) for all of China over the period of 1952 to 2005. This graph closely parallels the per capita productivity graph for select crops of agriculture that experienced excellent growth (Figure 1). There was virtually no change in GDP from 1952 through 1985 in either graph. However, from 1985 to 2005 there was the meteoric rise in National GDP and per capita production of select crops, particularly meat, seafood, and fresh fruits. Most of agriculture had much less growth and, most interesting, there were very small increases in grain over the entire 57-year period of 1952 through 2005.

Worldwide, there is a close correlation between National GDP and Meat Consumption (Speedy 2003) (Figure 3). China is experiencing a major cultural change that is markedly influencing food-animal production and the feed industry. It is well documented worldwide, as the economy of a country advances, measured as growth of GDP, there is a great increase in demand for meat and milk in the human diet. As economy of people increases, there is desire and money to provide better nutrition for their families. That results in increased consumption of meat and milk. That demand is increasingly obvious in China.

An answer to the question about why dramatic increases in pork and little or no increase in grain production, is suggested in part from the data in Table 2, which reports that in China, as recent as 2004, producers that slaughtered 9 pigs or less constituted 94% of all pig producers. Those producers accounted for 52.8% of total pig production. Over 99% of producers marketed less than 100 pigs per farm and accounted for 80% of hogs marketed. China had about as many producers as the United States had pigs marketed. A high percent of those pigs consumed garbage and human food waste. One estimate is that the garbage and other human nonconsumable components could be as high as 60 million metric tons (Informa Economics: China's Growing Appetite for Meats: Implications for World Meat Trade, 2011). As recent as 2004, a majority of swine (40% commercial feed, 60% no commercial feed), poultry (30% commercial feed, 70% no commercial feed), and dairy (30% commercial feed, 70% no commercial feed) received no commercial feed. Enlightened Chinese swine producers openly state that it takes an additional 3 months to grow out garbage-fed pigs and an intermediate increase using

moldy, rat and weevil infested old compromised stored corn.

A study by Rabobank for swine in 2007 showed a dramatic decline down to 42% in backyard production and a predicted decline to 35% by 2011. This is supported by a USDA FAS 2012 study (Figure 4) reporting a 37 increase in feed manufacturing from 2007 through 2011. In addition, the corn import data in Table 3, (USDA FAS 2012) shows the increase of corn importation by China expanding from about 4,000 metric ton to 1,753,000 metric ton between 2005 and 2011. These realities contribute to the disparity between the 7-fold increase in swine production, with minimal changes in the production of corn, soybeans and other grains.

There is considerable variation in the grain drying capabilities by grain producers across China. Some of the grain is dried with gas fired dryers as used in the United States. Unfortunately, smaller acreage corn farmers continue to use solar energy on corn spread out on farm yards and even blocked streets. Although solar energy will remove moisture, it is difficult to reduce moisture to less than 15% or preferably 12% moisture at the time of storage.

The quality of storage bins also is quite variable in China from excellent tight bins that avoid rodents, weevil, molds, and moisture to older less secure bins that allow contamination and nutrient loss during storage and support mold growth. For these reasons, mold toxin binders are extensively used across China. Jayas (2011) has reported that China loses about 50 million metric ton out of a crop of over 500 million metric ton of grain in storage losses annually.

There is an additional quality concern for Chinese based corn. China has maintained a program from the time of the great famine under the National Grain Strategic Reserves which requires long term storage of a percentage of the corn. This results in a calculated quantity of corn being stored for 2 to 3 years with expected compromise in nutritional value.

The eventuality is that this corn will be used in swine and poultry diets, which further compromises the nutritional quality and value of this corn. It appears that China accepts the reality that they will be required to import corn to meet their national needs for corn. This will minimize or eliminate the expense and quality compromise of storing corn for 2 to 3 years. Incidentally, China maintains a similar national live pig and pork reserve program to minimize populace unrest because of "high" pork

prices, which disregards the added cost of such reserves, particularly continually maintaining live animals. This too may be diminished as more pork is imported into China.

In essence there are cumulative reasons for reduced value of domestic corn compared to corn imported from United States and Brazil, the countries most able to provide corn for China.

Table 4 shows the increased reliance by China on corn imports over the past 7 years, from 3,975 metric tons in 2005 to more than 1,572,293 metric tons each of the past 2 years with 95% of the past 2 years coming from the United States. Last year China imported 52 million metric tons of soybeans, half of which came from the US. The main use of the corn and resulting soybean meal is swine and poultry diets.

The Ministry of Agriculture in China has more than 14,000 feed companies registered in China. Most of the feed companies recognized as excellent are less than 20 years old. During the period of rapid increases in pig production, a predominance of feed companies were owned by the government. That percentage is dropping rapidly. By the late 1980's the percentage of government owned feed mills had fallen to 60% and by 1997 the percentage had fallen to 37%.   Today the percentage would be in the low teens. Most of the former government owned feed mills were purchased by existing feed companies. Swine producers applaud these changes for reasons of product quality and attention to production issues.

Nutrition expertise ranges from limited knowledge to research substantiated nutrient standards comparable to those in use in the United States. The desks of feed companies and swine producers have the same journals, text books, and Extension publications that many of you have available and have written. Feed processing equipment and feed mill design are similar to what is used in the United States. Least Cost Formulation software and Herdsmen Record Program software are used routinely. Management practices are similar to our efforts, although biosecurity receives a much greater priority in the United States.

Over the past decade, a large number of large scale swine production units have been constructed. Many are vastly different than what would be practical, efficient, biosecure, and environmentally controlled. Following the self expression design of some of these early units, the units currently being constructed are increasingly similar to units that have evolved in the United States. Building companies from the United States are now building units under contract to Chinese swine production companies. The range of latitudes of swine production spans much the same area in United States and China.

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Table 1. Comparisons between USA and China.

	USA	China	Note
Area in sq km	9,809,386	9,556,100	2.3% larger in USA
Arable land in sq km	1,766,670	1,420,036	24.4% greater in USA
Percent arable land	18.01	14.86	
Coastline, km	12,380	9,010	37.4% longer in USA
Countries sharing border	2	17	
Population	313,847,465	1,343,239,923	428% larger in China
Swine production annually	107 million	678 million	533.6% greater in China

CIA, The World Factbook 2012 and US Pork Board

Table 2. The producers in China and USA, 2004

Producers in China, 2004 China Yearbook of Agr				
Slaughtered	No. of Farms	% of Share	Total Slaughtered (1,000)	% of Share
1~9	101,963,901	94.483	347,731	52.867
10~49	4,815,474	4.462	120,945	18.388
50~99	851,429	0.789	58,999	8.970
100~499	249,016	0.231	59,639	9.067
500~2,999	33,844	0.031	36,477	5.546
3,000~9,999	3,388	0.003139	17,420	2.648
10,000~49,999	911	0.000844	14,181	2.156
above 50,000	30	0.000028	2,358	0.359
Total	107,917,993	100.00	657,750	100.00

Producers in US, 2004 Study by Pork Board			
Number Marketed	Number of Operations	% of Operations	% of Market Share
Under 1,000	59,950	85.48	1
1,000 ~ 2,999	6,630	9.45	8
3,000 ~ 4,999	950	1.35	4
5,000 ~ 9,999	1,526	2.18	9
10,000 ~ 49,999	915	1.30	19
50,000 ~ 499,999	134	0.19	19
500,000+	25	0.04	40
Total	70,130	100.00	100

Table 3. Worldwide China importation of corn

Year	2005	2006	2007	2008	2009	2010	2011
Amount, MT	3,975	65,216	35,198	49,173	83,582	1,572,393	1,752,737
Percent from US						94.3	95.7

USDA-FAS, 2012

Figure 1   Per capita production indexes for selected agricultural products (1952 = 100)

China Statistical Yearbook – Agriculture 1997
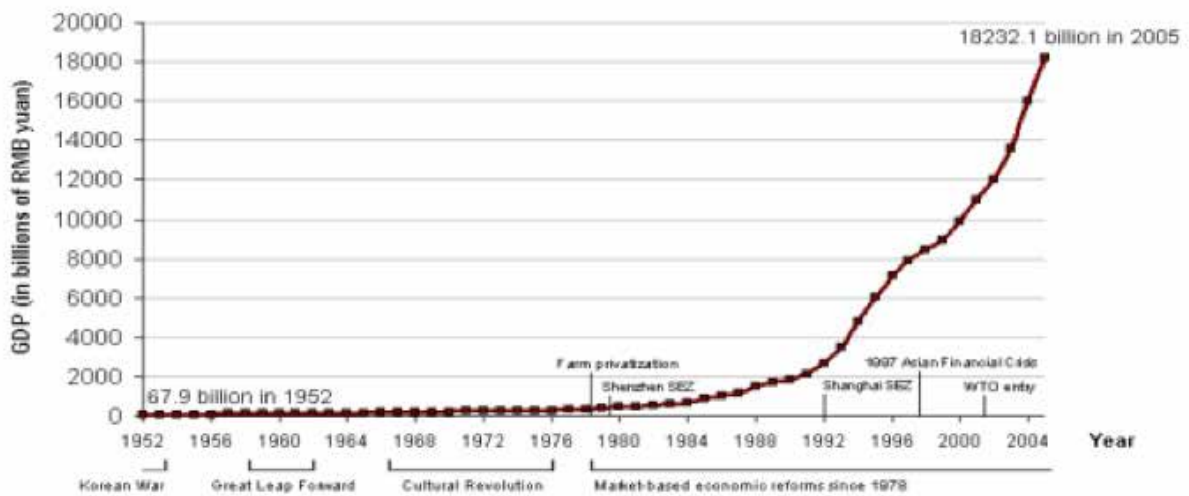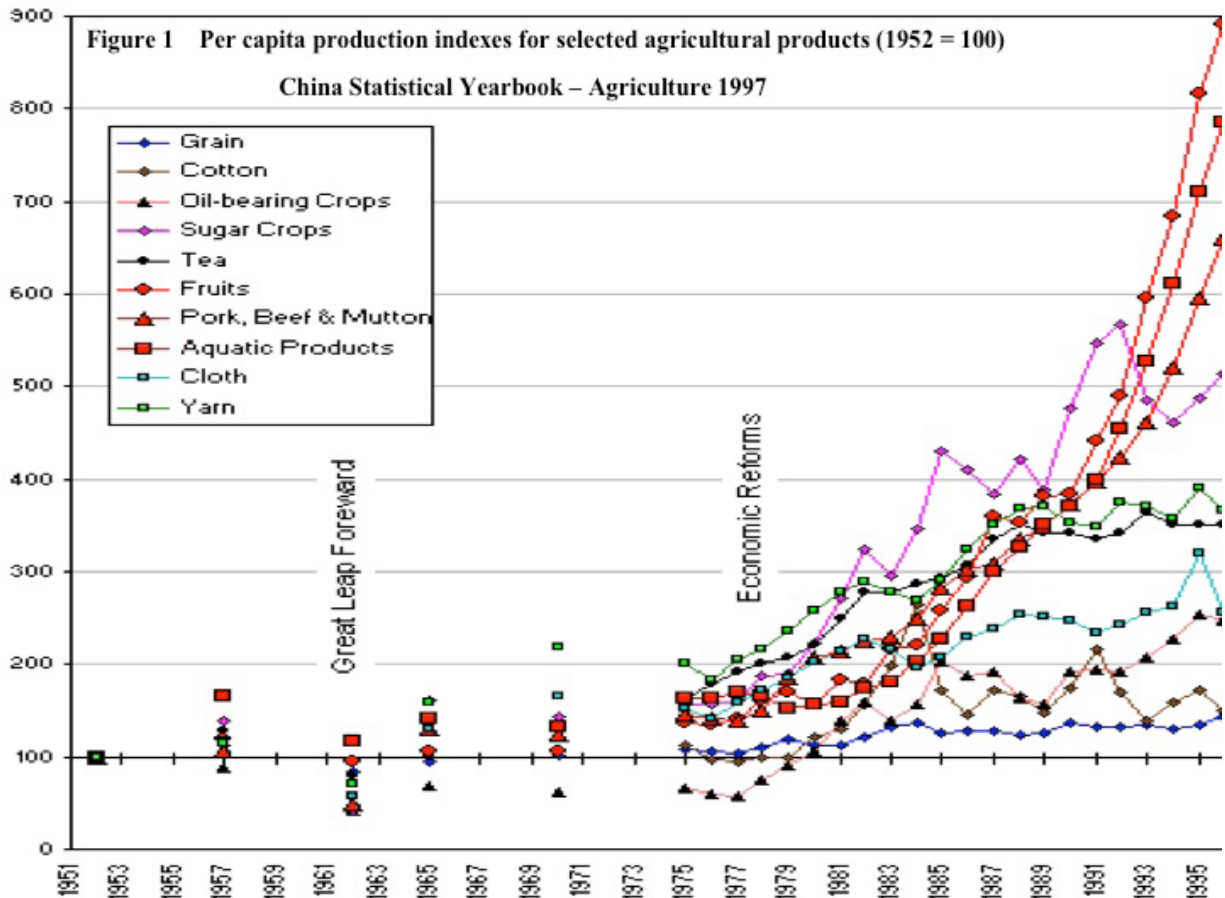
Wikipedia

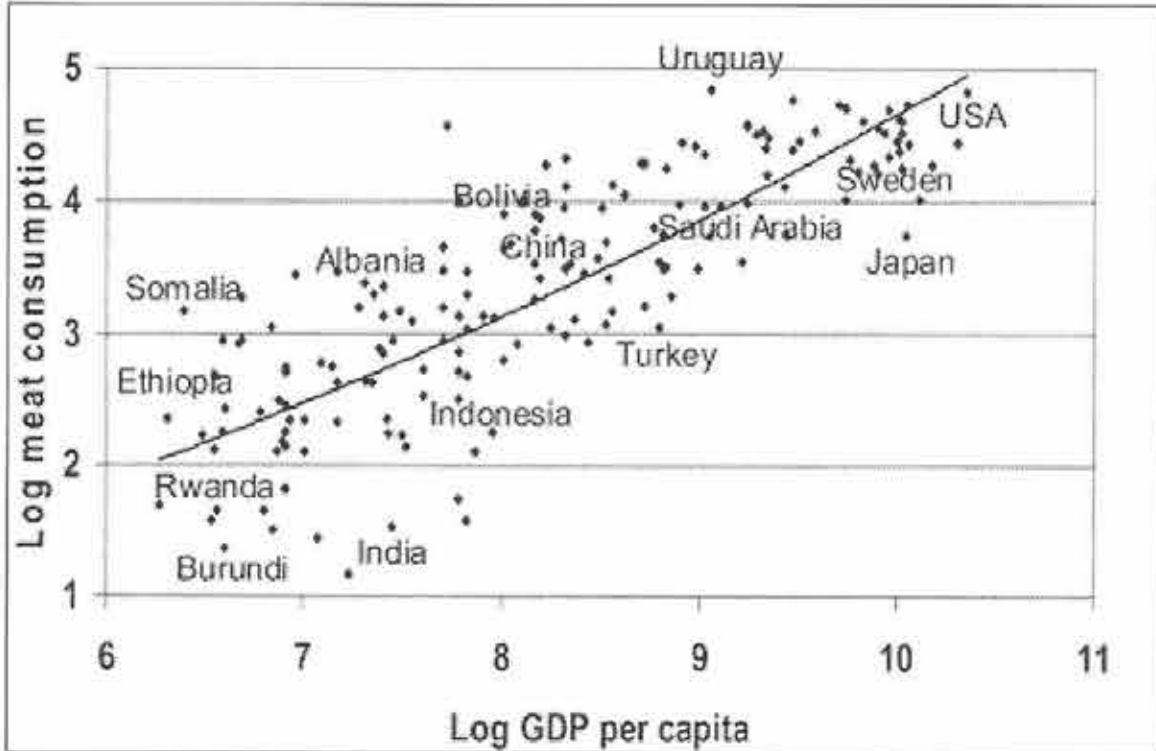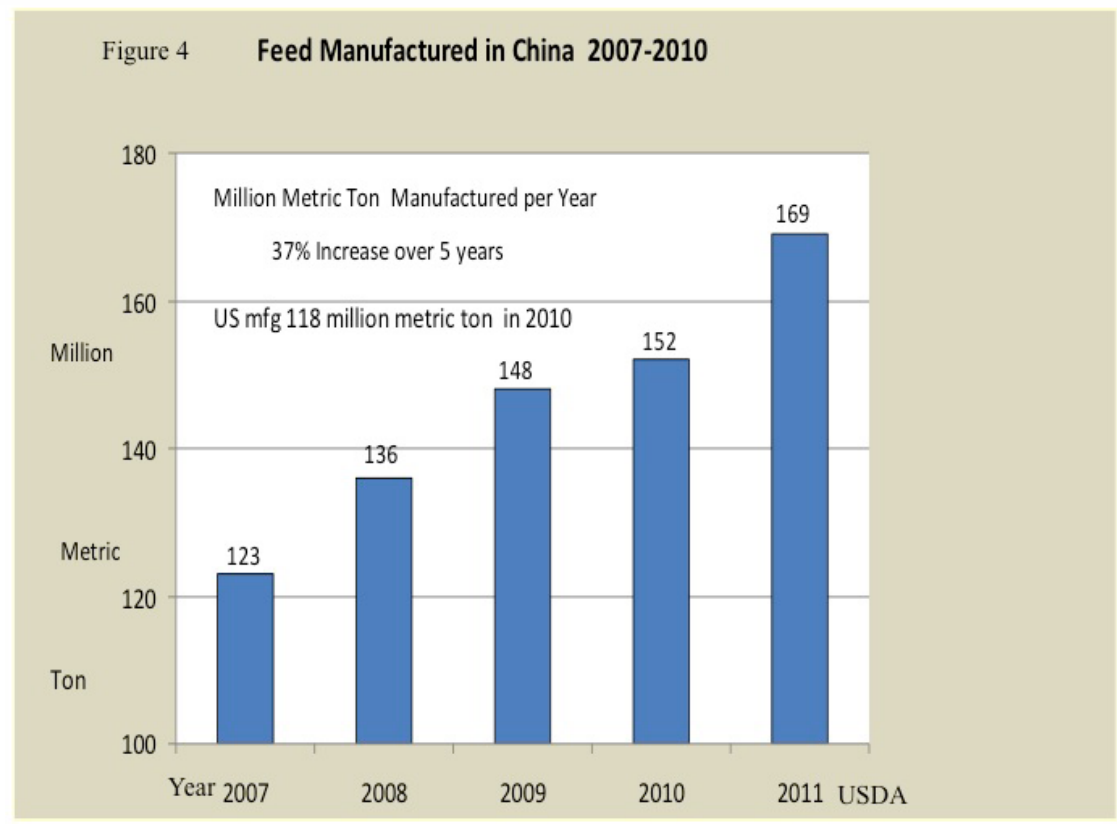- GDP has been virtually flat from WWII through 1984.
- GDP remained below 1000 x 10⁹ RMB until 1985.
- Since 1985, there has been a meteoric rise in GDP

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Figure 3. Correlation Between GDP and Meat Consumptioin, 2003

A. Speedy, 2003

Figure 4   **Feed Manufactured in China 2007-2010**

Million Metric Ton Manufactured per Year

37% Increase over 5 years

US mfg 118 million metric ton in 2010

Nutritional Value of Animal Proteins Fed to Pigs

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Summary

*The most commonly used animal proteins in the swine feed industry are meat and bone meal and fish meal, which have a relatively high concentration of amino acids (**AA**) and also are excellent sources of digestible Ca and P. The concentration of bones in these products is reflected in the concentration of ash and the digestibility of P in fish meal and meat and bone meal is negatively correlated with the concentration of ash in the products. By-products of the poultry industry include chicken meal, poultry by product meal, and AV-E digest, which are often included in diets fed to weanling pigs, because these ingredients contribute to an increase in performance of newly weaned pigs. Hydrolyzed feather meal is also a by-product of the poultry industry that may be used in diets fed to growing finishing pigs. Hydrolyzed intestinal proteins have become available during recent years and are now often included as AA sources in dies fed to weanling pigs. Blood products, either ring dried, drum dried, or spray dried, are also valuable sources of AA, and the spray dried blood products have excellent digestibility values for AA and P. Co-products of the dairy industry include dried whey powder and whey permeate. Unlike other feed ingredients of animal origin, whey powder and whey permeate are not rich in AA and they are primarily used in diets fed to weanling pigs as sources of lactose. However, whey powder and whey permeate also provide P with an excellent digestibility.*

Introduction

Feed ingredients of animal origin have been used in diets fed to pigs as a source of AA, minerals, and vitamins from the earliest days of commercial pig production. However, after production of synthetic forms of all vitamins became possible and it was discovered that inorganic minerals and plant sources of proteins can cover the requirements of pigs for AA, Ca, and P, use of animal proteins no longer was a prerequisite for successful pig production. Animal proteins are, therefore, mainly used in diets fed to newly weaned pigs, who do not tolerate large quantities of soybean meal in the diets. However, many animal proteins may also be used in diets fed to older pigs, where they may supply easily digestible sources of AA, Ca, and P.

Historically, meat and bone meal and fish meal have been the most used animal proteins, but many other animal proteins are produced as by-products or co-products of the human food industry. Recently, several new products have become available as a result of difficulties for other industries in eliminating by-products in a cost-effective way. However, the increases in the costs of feed ingredients that have taken place during recent years make processing of by-products from other industries more economical, which has resulted in several new products entering the marketplace. It is the objective of this contribution to provide an update on energy and nutrient digestibility of the feed ingredients of animal origin that are available to the feed industry.

Fish Meal

Fish meal is an animal protein that is used in diets fed to weanling pigs because of its high digestibility and favorable AA composition (Kim and Easter, 2001). However, quality of fish meal may vary according to the processing methods and

the type of fish used to produce the meal (Stoner et al., 1990; Kim and Easter, 2001). Fish meal may be produced from whole fish or from a mixture of whole fish and fish by-products from the human food industry. The production of fillets from whole fish for human consumption leaves some soft tissue and the bones, which is not used in the human food industry, but can be used for fish meal production. In the production of fish oil, the oil is extracted using a mechanical extraction process and the partly de-oiled meal is subsequently used for fish meal production (AAFCO, 2011; Cho and Kim, 2011).

Different species of fish such as anchovy, herring, menhaden, and white fish may be used to produce fish meal (NRC, 1998) and the nutritional value of the fish meal depends on the species used to produce the meal as well as the drying temperature (Kim and Easter, 2001). Regardless of the species used, the quantity of bones included in fish meal is indicated by the concentration of ash in the meal. In meals with low concentrations of bones, the ash concentration is around 12%, but if there is a large concentration of bones in the meal, the concentration of ash can exceed 20%. The average concentration of ash in 6 sources of Select Menhaden fish meal that were procured by the University of Illinois from 2008 to 2012 is 19.3 ± 0.89% (Table 1) indicating that this source of fish meal contains relatively large quantities of fish bones. The concentration of CP in fish meal can also be used as a predictor of the amount of bones in the meal because the concentration of CP usually is reduced as the amount of bones in the meal is increased.

The best qualities of fish meal have CP concentrations close to 70%, but other qualities have concentrations of CP between 62 and 65% (Sauvant et al., 2004). The average CP concentration in 9 sources of Select Menhaden fish meal that were procured by the University of Illinois from 2008 to 2012 is 63.4 ± 1.27% (Table 1). Fish meal usually contains 9 – 10% fat, but because fish oil is mostly long-chained unsaturated fatty acids, an antioxidant is usually included in the meal to prevent oxidation of the oil.

Due to the high concentration of fat in fish meal, the apparent total tract digestibility (**ATTD**) of GE is relatively high and concentrations of DE and ME in Select Menhaden fish meal is 3,797 and 3,472 kcal/kg (as fed basis; average of 5 sources; Table 2). Thus concentrations of DE and ME in fish meal are slightly greater than in corn and soybean meal.

Fish meal is a rich source of AA that are relatively well digested by pigs. The average standardized ileal digestibility (**SID**) of indispensable AA is 86.9% and the SID of Lys, Met, Thr, and Trp is 86.1, 87.2, 84.7, and 89.9%, respectively. The concentration of P and Ca in fish meal is relatively high due to the inclusion of bones in the meal (Malde et al., 2009), and the P in fish meal has an average value for the standardized total tract digestibility (**STTD**) of 67.1%. For meat and bone meal, it has been reported that the ATTD of P is reduced as the concentration of ash increases because the digestibility of P from bone is less than the digestibility of P from soft tissue (Hua et al., 2005). It is possible, that increased concentrations of bone in fish meal also results in reduced digestibility of P, but this hypothesis has not been investigated. The calcium in fish bones is, however, well digested and the digestibility by pigs of Ca in fish bones is similar to that in calcium carbonate (Malde et al., 2009).

Fish meal is usually used in diets for weanling pigs because young pigs do not tolerate soybean protein in great quantities. In contrast, animal proteins are well tolerated and 5 to 10% fish meal is often used in diets fed to weanling pigs (Chiba, 2001; Cho and Kim, 2011). The G:F ratio increases linearly if fish meal is included in the diet (Bergstrom et al., 1997), which is likely a result of the relatively high DE and ME in fish meal.

Products of the Dairy Industry

As milk is processed for human consumption, several feed ingredients are produced from the part of the milk that is not used in the human food industry. Casein is a high protein product that is produced from defatted milk via enzyme or acid coagulation (AAFCO, 2011). Casein contains the majority of the proteins in milk and has a favorable AA composition (Table 1) and the AA are easily digested (Table 2) by pigs. However, due to the relatively high cost, casein is usually not used in commercial diets fed to pigs, but casein is often used in synthetic or semisynthetic diets used in research diets fed to pigs.

Whey is a co-product of the cheese manufacturing industry and if dried can be used in diets fed to weanling pigs as a source of lactose. Whey powder contains 65-70% lactose, 13-15% CP, and up to 15% ash. However, the proteins in whey powder may be extracted to produce whey protein concentration, which is used in the human

food industry. The resulting de-proteinized whey is called whey permeate and contains 80 to 85% lactose and 5 to 15% ash (Nessmith et al., 1997b). If the ash is removed from whey permeate, a low-ash whey permeate, which contains 85-90% lactose, is produced (Kim et al., 2012).

The digestibility of energy in whey powder and whey permeate is greater than in a corn-soybean meal diet (Kim et al., 2012). The concentration of DE and ME in whey powder is greater than in whey permeate, but low-ash whey permeate has a concentration of DE and ME that is similar to that of whey powder (Table 2; Kim et al., 2012). The STTD of P in whey powder is not different from the STTD of P in whey permeate and the STTD of P in both of these ingredients is greater than 90% (Table 2).

Whey powder is an effective source of lactose in diets for weanling pigs (Cera et al., 1988), and whey powder supports weight gain of weanling pigs to the same extend as lactose (Mahan, 1993). However, whey permeate is as effective as a source of lactose as whey powder and may also be used in diets fed to weanling pigs (Nessmith et al., 1997a; Naranjo et al., 2010). Inclusion of 25% whey powder in a corn-soybean meal diet fed to weanling pigs increases weight gain during the initial 21 d post-weaning (Lepine et al., 1991) and it is common to include between 15 and 20% lactose in diets fed to pigs during the initial 2 weeks post weaning. The response to lactose is reduced in the later stages of the post-weaning period, and the optimum inclusion of lactose in week 3 and 4 post-weaning is 7.5% (Cromwell et al., 2008).

By-Products of the Poultry Industry

Chicken Meal and Poultry Byproduct Meal

Chicken meal (**CM**) and poultry by product meal (**PBM**) are protein ingredients that have a concentration of AA that is similar to that of fish meal (Table 3; Keegan et al., 2004). Poultry by-product meal is produced from the offal of carcasses of slaughtered poultry and includes feet, necks, undeveloped eggs, and intestines (AAFCO, 2011). Chicken meal is prepared from clean flesh and skin of chickens without or with bone derived from the whole carcass of poultry (AAFCO, 2011). However, the quality of CM and PBM depends on the quality of the rendered parts that are used in the production (Dong et al., 1993).

Chicken meal and PBM are often used in diets for pets and pigs as replacements for fish meal (Yamka et al., 2003; Keegan et al., 2004; Zier et al., 2004). Pigs fed diets containing PBM from d 0 to 28 post-weaning have growth performance that is not different from that of pigs fed fish meal, blood meal, and spray dried protein plasma (Keegan et al., 2004; Zier et al., 2004). However, the high concentration of ash in PBM may impact growth performance of pigs (Keegan et al., 2004).

The concentration of most nutrients is similar in CM and PBM (Table 3), but PBM contains more fat and more GE than CM. Chicken meal also contains more ash than PBM, which indicates that more bones are added to CM than to PBM. The ATTD of GE is similar for CM and PBM (Table 4), but the DE and ME are greater in PBM than in CM. In contrast, the SID of most indispensable AA in CM and PBM are not different.

AV-E Digest

AV-E digest is a protein ingredient that is produced from extruded egg albumins, enzymatically hydrolyzed whole spent hens, and soybean meal (**SBM**), which is used as a carrier. AV-E digest is used mainly to replace fish meal in weanling pig diets. There is limited information related to the palatability of this ingredient and no data on growth performance of pigs fed diets containing AV-E-Digest have been published.

The GE and CP concentration in AV-E digest is slightly less than in CM and PBM, but there is more ash and AEE in AV-E digest than in CM and PBM (Table 3). This is probably due to a greater addition of bones to AV-E digest. The use of SBM as a carrier increases the absorption of fat in the final product (Myer et al., 2004) and aids in improving the flowability of the product. The DE and ME in AV-E digest are slightly less than in CM and PBM (Table 4). The SID of most indispensable AA are greater in AV-E digest compared with CM and PBM, which may be a result of the SBM that is included in the product because the SID of AA in SBM is greater than in PBM and CM.

Feather Meal

Fresh poultry feathers are collected from the poultry processing industry. Cleaned feathers may be processed by steam to hydrolyze the keratins in the feathers, which increases the digestibility of AA in the feathers (van Heugten and van Kempen, 2002; Apple et al., 2003). Poultry blood may or may not be added to the hydrolyzed feather before they are dried.

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Hydrolyzed feather meal with added blood contain more AA and less fat than if no blood is added to the feathers, but the concentration of gross energy and most nutrients other than AA and fat in feather meal without blood is similar to that in feather meal with blood (Table 3). The concentration of P and Ca is less in hydrolyzed feather meal than in most other animal proteins because feather meal does not contain bones.

The DE and ME in feather meal without blood are greater than in feather meal with blood (Table 4), which is likely due to the greater concentration of acid hydrolyzed ether extract (**AEE**) in feather meal without blood. The ATTD and STTD of P are also greater in feather meal without blood than in feather meal with blood, which is difficult to explain because P digestibility in blood products is relatively high (Almeida and Stein, 2011). There is, however, very little P in avian blood meal so the addition of blood to hydrolyzed feather meal may not contribute to any measurable differences in the meal. The SID of indispensable AA is also slightly greater in feather meal without blood than in feather meal with blood, which indicates that the addition of blood did not improve the digestibility of AA in feather meal. It is possible that the reason for this observation is that if blood is added to the feather meals, more heating is needed in the drying process, which may result in reduced AA digestibility in the feather meal with blood. However, the variation in energy and nutrient digestibility among sources of hydrolyzed feather meal is relatively high (Wang and Parsons, 1997), and the variation among sources is greater than the effects of adding blood to the meals. It is possible that these differences are a result of differences in processing procedures because each facility uses a unique setting for steam pressure and time of hydrolysis when feather meal is hydrolyzed (Moritz and Latshaw, 2001). There is, however, no information about the exact impact of specific processing procedures on nutrient and energy digestibility in hydrolyzed feather meal, but the variability among sources is the biggest concern in terms of utilizing feather meal in diets fed to swine.

Pigs fed a corn-SBM diet with an inclusion of 8% feather meal have growth performance that is not different from that of pigs fed a corn-SBM diet without feather meal (van Heugten and van Kempen, 2002). However, inclusion of 10 or 20% feather meal in diets fed to growing-finishing pigs may result in reduced feed intake and average gain (Ssu et al., 2004). Inclusion of up to 9% hydrolyzed feather meal in diets fed to finishing pigs from 67 kg to market does not result in any change of carcass composition or feed conversion, but may reduce average daily gain (Chiba et al., 1996).

Intestinal Co-Products and Meat Meals

PEP 2+ and PEP50

PEP2+ and PEP50 are produced from hydrolyzed porcine intestinal mucosa that is left after heparin has been extracted from the intestines. During production of PEP2+, dried fermentation biomass, which is a by-product of the production of synthetic Lys, is mixed with hydrolyzed intestinal mucosa, and enzymatically treated, low-antigen SBM is used as a carrier. In contrast, in the production of PEP50, conventional SBM is mixed with intestinal mucosa to enhance fat absorption and faster drying of the product.

Both PEP2+ and PEP50 are high protein products that may be used as replacements for fish meal in diets fed to weanling pigs. Inclusion rates of up to 6% of each product in phase 2 diets do not negatively influence pig growth performance (Myers et al., 2011).

The concentrations of CP and most AA are slightly less in PEP2+ and PEP50 than in fish meal, but the concentration of Lys is greater in PEP2+ than in PEP50, which is likely a result of the dried fermentation biomass that is included in PEP2+. The concentration of ash is also less, but the concentration of GE is greater, in PEP2+ and PEP50 than in fish meal (Table 5). The DE and ME in PEP2+ and PEP50 are comparable with that of most other animal protein sources (Table 6), but the STTD of P in PEP2+ and PEP50 is relatively high compared with the STTD of P in most other feed ingredients, which partly offsets the lower concentration of P in these ingredients compared with fish meal. The SID of AA in PEP2+ and PEP50 is similar to the SID of AA in fish meal.

DPS 50 RD

A product called DPS 50RD is produced from enzymatically hydrolyzed porcine mucosa and small intestines that have been roller-dried after heparin has been extracted. The concentration of AA in DPS 50RD is relatively high (Table 5) and the SID of most indispensable AA is greater in DPS 50RD than in most other animal proteins with the

exception of PEP2+ and PEP50 (Table 6). It has been indicated that DPS50 may replace soybean meal, fish meal, whey powder, or blood cells in diets fed to weanling pigs without negatively impacting pig growth performance (Zimmerman and Sparks, 1996; Lindeman et al., 2000). A carry over effect of DPS50 on performance of pigs during 2 to 3 weeks after feeding of DPS 50RD was discontinued has been suggested (Zimmerman and Sparks, 1996), but this effect has not been verified in subsequent experiments.

Meat and Bone Meal

In the animal slaughter industry, processing of animals to obtain products for human consumption leaves parts of animals that can be used to produce meat and bone meal (**MBM**). This product consists of rendered products from mammal tissues that is finely ground and dried to obtain a meal. Meat and bone meal contains bones from the animals, but hair, hoofs, blood, horns, rumen contents, and manure are not included in MBM (AAFCO, 2011). Meat and bone meal may replace inorganic P in diets fed to pigs without negatively affecting growth performance or bone structure (Traylor et al. (2005), and MBM can contribute up to 30% of the CP needed in diets fed to pigs (Hendriks et al., 2002).

Some variability among sources of MBM has been reported due to differences in the origin and quality of the raw materials used to produce MBM. However, most producers of MBM blend products to market MBM that contains either 50% CP or 56% CP. The concentration of CP, acid hydrolyzed ether extract, and GE is similar to that in many other animal proteins, but the concentrations of ash, P, and Ca are greater than in most other ingredients due to the inclusion of animal bones in the product. The concentration of DE and ME in MBM is less than in corn and soybean meal (Olukosi and Adeola, 2009) and there is a negative correlation between the concentration of ash in MBM and the ME of the product (Olukosi and Adeola, 2009). The concentration of ash in MBM is largely a consequence of the concentration of bone in the product. As the concentration of bone is increased, the concentration of not only ash, but also Ca and P is increased in MBM.

There is, however, a negative correlation between the concentration of ash in MBM and the STTD of (Sulabo and Stein, 2013) because the digestibility of P in soft tissue is greater than in bone tissue (Jongbloed and Kemme, 1990). Nevertheless, the average STTD of P in MBM (68.8%; Table 6) is close to that in fish meal and MBM is, therefore, a rich source of digestible P. The ATTD of Ca in MBM varies from 53 to 81% and the average ATTD in MBM (65%) is close to the average ATTD of Ca in fish meal and in calcium carbonate (Sulabo and Stein, 2013).

Blood Products

Ring Dried or Drum Dried Blood Meals

Avian, porcine, and bovine blood meal are produced from clean and fresh avian, porcine, or bovine blood exclusive of all extraneous materials such as hair, stomach contents, and intestinal contents (AAFCO, 2011). To produce dried blood meal, the fresh blood is decanted, cooked, dried, and ground (Bellaver, 2005). The nutritional value of blood meal varies according to the processing procedures used and specifically, the drying procedure influences the digestibility of AA in blood meal (Moughan et al., 1999; Pearson et al., 1999). Historically, blood meals have been ring dried or drum dried and these procedures are still widely used in the industry.

The energy and nutrient composition of avian, porcine, and bovine blood meal are similar with the exception that bovine blood has a reduced concentration of Ile compared with avian blood meal (Table 7). The ATTD of P is less in avian blood meal than in porcine blood meal, but this is mainly due to the reduced concentration of P in avian blood meal compared with porcine blood meal. Therefore, when values for STTD of P are calculated, no difference between the 2 ingredients is observed (Table 8; Almeida and Stein, 2011). The average SID of most indispensable AA in avian blood meal is also similar to the SID of indispensable AA in porcine blood meal, but the SID of most indispensable AA in bovine blood meal is greater than in the avian and porcine meals (Table 8).

Spray Dried Blood Products

Spray drying of blood meal is accomplished by spraying blood into a draft of warm and dry air (AAFCO, 2011). The procedure usually leads to blood products with a high nutrient digestibility and the particle size of the blood is reduced, which contributes to an increase in the nutritional value of

blood products (FEDNA, 2010). Spray dried blood products are used in weanling pig diets due to the high digestibility of nutrients in these ingredients (Grinstead et al., 2000).

Whole fresh blood may be spray dried to produce spray dried blood meal (**SDBM**). Because of the low temperature used in the drying procedure compared with ring drying or drum drying, SDBM has a greater SID of AA than blood meal that has not been spray dried (Table 8; Moughan et al., 1999). Spray dried blood meal may be included at 6% in diets fed to pigs from d 7 to 28 post-weaning to maximize growth performance, but after d 21, the use of SDBM is not critical for increasing growth performance of pigs (Kats et al., 1994).

Blood may be centrifuged before drying to separate plasma and blood cells. Each of the 2 streams are subsequently spray dried and spray dried plasma protein (**SDPP)** and spray dried blood cells (**SDBC**) are produced (AAFCO, 2011). The dried products are sometimes granulated to improve handling characteristics.

The concentrations of CP and AA are greater in SDBC than in SDPP, whereas the concentration of ash, Ca, and P are greater in SDPP than in SDBC. The P in SDPP is 100% digestible (Bunzen et al., 2008; Almeida and Stein, 2011), which is likely a result of the fact that no cell membranes are present in SDPP. The SID of AA is similar in SDPP and SDBC, but the concentration of Met and Ile is low in both ingredients. However, the SID of Ile is less in SDBC than in SDPP, which indicates that addition of synthetic Ile, may be needed when SDBC is included in the diets.

Spray dried plasma protein is commonly used in phase 1 and phase 2 diets (0 to 7 and 7 to 14 d, post-weaning, respectively) fed to weanling pigs because this ingredient stimulates feed intake (Ermer et al., 1994). Inclusion of up to 6% SDPP in diets fed to weanling pigs increases ADG and ADFI and the positive effect is more noticeable in week 1 and 2 post-weaning than in subsequent weeks (Van Dijk et al., 2001). Inclusion of 6% SDBC in diets feed to growing pigs may decrease G:F, but inclusion of 5% SDBC supports growth performance that is similar to that of the control diet (Kerr et al., 2004).

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Table 1. Analyzed nutrient composition of fish meal and milk products, as-fed basis

Item	Fish meal	Casein	Whey powder	Whey permeate	Whey permeate, low ash
GE, kcal/kg	4,423	4,586	3,6,20	3,426	3,657
DM, %	91.5	91.8	90.0	97.6	98.4
CP, %	63.4	86.8	13.4	4.3	3.0
Ash, %	19.3	4.4	11.6	9.0	1.7
AEE[1], %	9.0	0.1	-	0.8	-
P, %	3.1	0.7	0.6	0.6	0.1
Ca, %	5.2	0	0.5	0.4	0.1
Lactose, %	-	-	66.0	76.1	88.8
Indispensable, AA %					
Arg	3.66	2.84	0.26	-	-
His	1.40	3.65	0.21	-	-
Ile	2.56	3.22	0.65	-	-
Leu	4.32	9.58	1.11	-	-
Lys	4.76	7.47	0.93	-	-
Met	1.68	1.96	0.15	-	-
Phe	2.39	5.01	0.35	-	-
Thr	2.40	3.65	0.68	-	-
Trp	0.61	1.19	0.23	-	-
Val	3.01	6.73	0.62	-	-
Dispensable, AA %					
Ala	3.82	4.36	0.52	-	-
Asp	5.40	7.27	1.09	-	-
Cys	0.50	0.46	0.22	-	-
Glu	7.73	14.51	1.81	-	-
Gly	4.44	2.54	0.21	-	-
Pro	2.82	6.95	0.59	-	-
Ser	2.04	4.17	0.43	-	-
Tyr	1.89	3.76	0.26	-	-
Total AA	55.41	89.30	10.32	-	-

[1]AEE = acid hydrolyzed ether extract.

Table 2. Concentration of DE and ME and the apparent total tract digestibility (ATTD) of energy and P, the standardized total tract digestibility (STTD) of P, and the standardized ileal digestibility (SID) of CP and AA in fish meal and milk products.

Item	Fish meal	Casein	Whey powder	Whey permeate	Whey permeate, low ash
Energy					
ATTD of GE, %	86.3	-	-	-	-
DE, kcal/kg	3,797	-	3,494	3,177	3,626
ME, kcal/kg	3,472	-	3,317	3,009	3,537
Phosphorus					
ATTD of P, %	63.4	-	84.3	86.1	55.9
STTD of P[1], %	67.1	-	91.2	93.1	91.8
SID of CP and AA[2], %					
CP	84.1	98.4	-	-	-
Indispensable AA					
Arg	92.1	99.7	-	-	-
His	86.2	97.0	-	-	-
Ile	86.9	96.6	-	-	-
Leu	87.3	98.2	-	-	-
Lys	86.1	98.1	-	-	-
Met	87.2	98.5	-	-	-
Phe	85.7	98.7	-	-	-
Thr	84.7	94.1	-	-	-
Trp	89.9	96.2	-	-	-
Val	85.4	97.2	-	-	-
Mean	86.9	97.5	-	-	-
Dispensable AA					
Ala	85.8	96.1	-	-	-
Asp	78.7	95.4	-	-	-
Cys	77.7	92.7	-	-	-
Glu	86.2	95.4	-	-	-
Gly	90.7	103.0	-	-	-
Pro	106.1	112.9	-	-	-
Ser	84.2	94.4	-	-	-
Tyr	85.4	98.0	-	-	-
Mean	86.9	98.5	-	-	-
All AA	86.9	97.9	-	-	-

[1] Values for STTD were calculated by correcting values for ATTD for basal endogenous loss of P.

[2] Values for SID were calculated by correcting the values for AID for basal ileal endogenous losses.

Table 3. Analyzed nutrient composition of chicken meal (CM), poultry by-product meal (PBM), AV-E digest, and feather meal without and with blood, as-fed basis

Item	CM	PBM	AV-E digest	Feather meal without blood	Feather meal with blood
GE, kcal/kg	4,907	5,226	4,783	5,529	5,422
DM, %	96.8	94.8	93.8	92.0	93.5
CP, %	66.0	62.3	49.5	81.2	82.2
Ash, %	14.2	11.3	14.6	1.8	1.9
AEE[1], %	11.0	14.3	15.8	9.4	7.0
P, %	2.4	1.9	1.8	0.2	0.3
Ca, %	4.4	2.7	3.3	0.5	0.5
Indispensable, AA %					
Arg	4.05	4.05	3.19	5.63	5.53
His	1.25	1.32	1.05	0.70	1.27
Ile	2.43	2.35	2.03	3.79	3.85
Leu	4.27	4.25	3.49	6.63	7.07
Lys	3.49	3.96	2.90	1.83	2.68
Met	1.09	1.26	0.76	0.55	0.66
Phe	2.42	2.41	2.17	3.96	4.14
Thr	2.27	2.37	1.76	3.69	3.76
Trp	0.58	0.60	0.43	0.45	0.56
Val	3.15	2.92	2.45	6.13	6.25
Dispensable, AA %					
Ala	3.78	3.92	2.77	3.75	4.07
Asp	4.67	4.84	4.24	5.21	5.61
Cys	0.96	0.59	0.75	4.09	3.74
Glu	7.56	7.68	6.59	8.48	8.51
Gly	5.56	5.63	3.93	6.34	5.88
Pro	4.06	3.52	2.98	7.87	7.16
Ser	2.65	2.38	1.74	8.48	7.53
Tyr	1.92	2.08	1.69	2.23	2.47
Total AA	56.16	56.13	44.92	79.79	80.71

[1]AEE = acid hydrolyzed ether extract.

Table 4. Concentration of digestible and metabolizable energy, apparent total tract digestibility (ATTD) of energy and P, standardized total tract digestibility (STTD) of P, and standardized ileal digestibility (SID) of CP and AA in chicken meal (CM), poultry by-product meal (PBM), AV-E digest, and feather meal without and with blood, as-fed basis

Item	CM	PBM	AV-E digest	Feather meal without blood	Feather meal with blood
Energy					
ATTD of GE, %	89.2	87.9	92.6	-	-
DE, kcal/kg	4,161	4,805	4,145	5,194	4,752
ME, kcal/kg	3,694	4,348	3,235	4,947	4,446
Phosphorus					
ATTD of P, %	-	-	-	82.5	73.3
STTD of P[1], %	-	-	-	96.9	80.0
SID of CP and AA[2], %					
CP	67.4	72.1	75.8	69.6	66.3
Indispensable AA					
Arg	79.1	81.8	86.0	82.1	79.6
His	62.8	67.4	75.0	64.9	58.2
Ile	65.8	67.9	79.6	80.9	79.1
Leu	65.2	68.6	79.7	75.8	71.1
Lys	60.5	68.9	77.1	56.4	65.3
Met	74.9	75.2	84.2	67.4	67.5
Phe	64.7	68.0	75.6	78.5	73.8
Thr	63.3	67.1	76.1	68.4	65.6
Trp	69.7	72.7	91.2	80.4	80.1
Val	63.5	70.0	74.5	77.6	73.0
Mean	67.0	70.9	79.5	72.9	70.9
Dispensable AA					
Ala	69.7	73.5	80.2	71.8	68.3
Asp	48.2	53.1	66.6	47.6	46.2
Cys	55.4	55.6	48.9	58.6	54.4
Glu	64.9	72.3	68.8	65.5	62.6
Gly	67.1	70.5	71.1	71.5	69.3
Pro	76.3	89.2	79.6	64.9	60.7
Ser	71.1	73.2	75.9	76.5	72.9
Tyr	66.3	72.1	78.3	71.8	70.0
Mean	64.9	69.9	71.2	66.0	63.0
All AA	66.1	70.5	76.0	70.0	67.6

[1] Values for STTD were calculated by correcting values for ATTD for basal endogenous loss of P.

[2] Values for SID were calculated by correcting the values for AID for basal ileal endogenous losses.

Table 5. Analyzed nutrient composition of PEP2+, PEP50, DPS 50RD, and meat and bone meal (MBM), as-fed basis

Item	Peptone P2+	Peptone P50	DPS 50 RD	MBM
GE, kcal/kg	4,934	4,630	-	4,143
DM, %	95.2	94.7	-	95.5
CP, %	59.5	53.6	49.7	52.8
Ash, %	12.0	10.1	-	26.5
AEE[1], %	13.1	7.4	-	13.1
P, %	0.8	0.7	-	4.2
Ca, %	-	-	-	8.6
NDF, %	2.5	5.8	-	-
ADF, %	1.4	3.6	-	-
Indispensable, AA %				
Arg	3.47	3.13	2.36	3.61
His	1.35	1.19	0.98	1.04
Ile	2.62	2.21	1.98	1.57
Leu	4.52	3.82	3.56	3.32
Lys	4.86	3.59	3.21	2.99
Met	1.09	0.80	0.86	0.75
Phe	2.48	2.23	1.90	1.85
Thr	2.27	1.81	1.85	1.72
Trp	0.49	0.47	0.30	0.35
Val	3.22	2.63	2.52	2.33
Dispensable, AA %				
Ala	3.24	2.47	2.72	3.91
Asp	5.41	4.77	4.03	3.95
Cys	0.71	0.61	1.00	0.45
Glu	7.53	7.09	6.34	6.14
Gly	3.01	2.41	3.34	6.74
Pro	2.67	2.33	2.41	4.07
Ser	1.89	1.67	1.46	1.91
Tyr	2.01	1.62	1.57	1.31
Total AA	52.84	44.85	43.37	48.02

[1]AEE = acid hydrolyzed ether extract.

Table 6. Concentration of digestible and metabolizable energy, apparent total tract digestibility (ATTD) of P, standardized total tract digestibility (STTD) of P, and standardized ileal digestibility (SID) of CP and AA in PEP2+, PEP50, DPS 50RD, and meat and bone meal (MBM), as-fed basis

Item	PEP2+	PEP50	DPS 50 RD	MBM
Energy				
DE, kcal/kg	4,587	4,348	-	-
ME, kcal/kg	4,291	4,122	-	-
Phosphorus				
ATTD of P, %	90.6	68.0	-	65.9
STTD of P[1], %	97.6	76.2	-	68.8
SID of CP and AA[2], %				
CP	78.2	84.1	76.2	84.1
Indispensable AA				
Arg	91.5	95.5	89.4	95.5
His	81.0	87.2	81.5	87.2
Ile	83.3	87.9	84.3	87.9
Leu	84.2	88.6	86.8	88.6
Lys	84.1	87.5	84.2	87.5
Met	83.9	89.1	89.4	89.1
Phe	81.8	87.1	85.5	87.1
Thr	78.1	83.5	81.1	83.5
Trp	95.3	94.1	97.1	94.1
Val	82.8	87.2	83.3	87.2
Mean	84.0	88.3	86.3	88.3
Dispensable AA				
Ala	83.4	88.5	83.6	88.5
Asp	72.4	80.6	81.3	80.6
Cys	43.6	57.5	72.9	57.5
Glu	76.4	78.7	68.4	78.7
Gly	79.7	85.2	74.1	85.2
Pro	144.4	148.4	84.1	148.4
Ser	80.1	87.2	81.3	87.2
Tyr	84.2	88.6	89.1	88.6
Mean	83.0	89.3	79.3	89.3
All AA	83.6	88.8	81.9	88.8

[1] Values for STTD were calculated by correcting values for ATTD for basal endogenous loss of P.

[2] Values for SID were calculated by correcting the values for AID for basal ileal endogenous losses.

Table 7. Analyzed energy, DM, and nutrient composition of avian blood meal, porcine blood meal, bovine blood meal, spray dried plasma protein (SDPP), spray dried blood cells (SDBC), and spray dried blood meal (SDBM), as-fed basis

Item	Avian blood meal	Porcine blood meal	Bovine blood meal	SDPP	SDBC	SDBM
GE, kcal/kg	5,278	5,278	-	4,687	5,302	5,159
DM, %	89.6	90.3	92.7	90.6	93.3	93.5
CP, %	87.7	89.0	95.0	77.3	94.2	93.8
Ash, %	1.80	1.4	-	8.1	2.5	4.2
AEE[1], %	0.4	0.3	-	0.5	0.1	0.1
P, %	0.3	0.7	-	1.3	0.8	-
Ca, %	0.1	0.3	-	0.1	0.3	-
Indispensable, AA %						
Arg	4.52	4.10	3.27	4.42	3.61	3.54
His	5.03	5.88	5.91	2.52	6.73	5.96
Ile	3.75	2.15	0.42	2.44	0.35	0.62
Leu	9.75	11.06	12.45	7.56	12.79	11.77
Lys	7.61	7.81	8.59	6.99	8.62	7.995
Met	1.02	0.86	1.28	0.87	0.98	0.89
Phe	5.46	5.73	6.81	4.24	6.80	6.215
Thr	4.13	3.39	3.77	4.71	3.51	3.48
Trp	1.38	1.53	1.24	1.45	1.50	1.61
Val	5.92	7.12	8.46	5.22	8.49	7.93
Dispensable, AA %						
Ala	6.58	6.77	7.58	4.04	7.81	7.155
Asp	8.06	9.40	8.75	7.73	10.17	9.53
Cys	1.92	0.71	0.53	1.90	0.52	0.75
Glu	8.29	7.72	6.46	10.55	7.48	7.31
Gly	3.26	3.80	3.69	2.74	4.22	3.945
Pro	3.36	3.30	3.1	4.19	3.25	3.235
Ser	3.30	3.58	3.47	4.53	4.12	3.855
Tyr	2.99	3.03	2.25	3.88	1.93	1.78
Total AA	86.29	87.91	88.03	79.96	92.84	87.57

[1]AEE = acid hydrolyzed ether extract.

Table 8. Apparent total tract digestibility (ATTD) of P, standardized total tract digestibility (STTD) of P, and standardized ileal digestibility (SID) of CP and AA in avian blood meal, porcine blood meal, bovine blood meal, spray dried plasma protein (SDPP), spray dried blood cells (SDBC), and spray dried blood meal (SDBC), as-fed basis

Item	Avian blood meal	Porcine blood meal	Bovine blood meal	SDPP	SDBC	SDBM
Phosphorus						
ATTD of P, %	57.5	76.5	-	91.3	-	-
STTD of P[1], %	86.1	89.7	-	102.8	-	-
SID of CP and AA[2], %						
CP	70.4	68.9	81.7	96.0	92.3	93.8
Arg	75.6	70.2	88.1	97.4	98.5	96.9
His	68.6	77.5	92.2	94.3	98.3	98.5
Ile	67.2	33.6	71.9	93.5	58.3	86.6
Leu	67.0	76.1	91.6	94.5	97.7	97.9
Lys	74.0	78.6	90.5	94.2	97.6	98.0
Met	74.0	70.1	84.3	94.0	96.0	96.7
Phe	67.3	76.4	91.4	94.5	97.8	98.0
Thr	71.7	68.6	88.2	92.7	95.9	96.9
Trp	69.3	77.0	89.6	94.1	95.2	97.2
Val	66.5	76.0	91.2	93.3	97.7	97.8
Mean	70.1	70.3	87.3	94.4	93.2	96.2
Ala	68.8	75.5	90.9	93.4	99.8	98.1
Asp	69.1	74.3	90.0	91.4	97.7	98.2
Cys	65.0	55.1	87.2	91.2	84.5	95.3
Glu	69.4	71.5	87.4	91.5	93.6	98.3
Gly	79.2	66.1	81.3	90.2	100.6	97.4
Pro	103.7	28.7	-	105.5	97.0	152.4
Ser	72.2	70.9	86.4	93.4	96.8	97.0
Tyr	-	-	88.5	89.2	88.0	90.2
Mean	65.9	55.3	87.4	93.2	94.7	103.3
All AA	68.4	64.0	87.4	93.9	93.9	99.2

[1] Values for STTD were calculated by correcting values for ATTD for basal endogenous loss of P.

[2] Values for SID were calculated by correcting values for AID for basal ileal endogenous losses.

Lipids, Fatty Acids, and More

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Summary

    Energy is the most expensive nutritional component in livestock diets. Lipids are concentrated energy sources and are known to affect growth, feed efficiency, feed dust, and diet palatability. The majority of research studies that have been conducted regarding the biological effects of lipids in livestock feeds have focused mainly on the effects of feeding high quality lipids on animal growth performance in young animals. With increased use of lipids in human foods and the wide array of composition and quality of lipid sources available to the animal industry, it is essential to understand lipid digestion, absorption, composition, and quality factors affecting their utilization. The following proceedings is a summary of recent research by the authors related to measures of lipid quality and on the influence of consuming thermally oxidized lipids on physiological, metabolic, immunological, and growth indices in growing pigs.

Introduction

    World production of vegetable oils, currently approximately 286 billion pounds annually, has grown dramatically over the last 20 years, with the main oils being palm oil (30% of the world's vegetable oil production), soybean oil (28%), rapeseed/canola oil (15%), and sunflower oil (9%); with other vegetable oils accounting for less than 20% of the market (Figure 1)**.** Production of palm oil is largely in Indonesia (approximately 44% of the world's production) and Malaysia (40%), while the production of soybean oil is largely in the US (35%), Brazil (30%), and Argentina (20%). Consumption of edible vegetable oils is dominated by its use in the food industry (approximately 80% of the total use), but its growth has also been stimulated by industrial uses, such as for biodiesel production. Worldwide consumption of vegetable oils has largely been driven by economic and population expansion in developing countries such as India, Pakistan, China, North Africa and the Middle East, but also in other parts of the world (EU, US, Brazil, etc.) for new and existing industrial applications.

    Although smaller in magnitude, fats obtained from the rendering industry also play an economically important part in the livestock industry. In the US,

fats from the rendering industry are approximately 11 billion pounds annually and include: inedible tallow (36% of US rendered fats), edible tallow (17%), poultry fat (11%), and lard (3%). In addition, yellow grease (i.e., recycled vegetable oils from restaurants) is also considered part of the rendering industry, and provides a substantial quantity of lipids (14%) to the animal industry. Animal fats can also be utilized in the production of biodiesel thereby affecting product availability and cost for use in animal feeds.

Lipid Classification

    Lipids are a group of structurally diverse, water-insoluble, organic-solvent-soluble organic compounds. Lipids have hydrocarbon chains or rings as a major part of their structure, with the primary types of hydrocarbons being fatty acids and steroids. Fatty acids are linear, aliphatic monocarboxylic acids [$R\text{-}(CH_2)_nCOO\text{-}$], and almost always have an even number of carbons. Unsaturated fatty acids may contain one or more cis double bonds with essentially no conjugated double bonds compounds being found, except for conjugated linoleic acid. In addition, there are very few 'trans' fats in nature, but some trans fats can be generated due to the hydrogenation process, such as in the rumen or from industrial processing,

whereupon trans fats have a higher melting point and behave more like a saturated fat. A general description of common fatty acids is listed Table 1.

In the body, lipids are stored as triglycerides, having one, two, or three different fatty acids esterified to glycerol, as depicted in Figure 2. At room temperature, saturated fatty acids tend to be solids (fats) while unsaturated fatty acids tend to be liquids (oils); likewise, long chain fatty acids tend to be solids while short chain fatty acids tend to be liquids. In the body, membrane lipids differ from storage lipids in that they have only two hydrocarbon chains and one polar head group, which have a high affinity for water. Membrane lipids are commonly called phosphoglycerides (or phospholipids), with the main phosphoglycerides being phosphatidyl-choline, -ethanolamine, -serine, and –inositol. Sphingosine and cholesterol are also membrane lipids. When phospholipids are dispersed in water, structures formed include micelles (aggregates in with the hydrocarbon chains coalesce in the center, with the polar head groups on the surface), lipid monolayers (polar head groups in the surface of the water with the hydrocarbon chains projecting upward), and lipid bilayers (a double layer of phospholipids with the hydrocarbon chains aligned and projecting inward, and the polar groups forming the interface with water on both sides of the bilayer), (Figure 3). Esters of fatty alcohols, commonly with a chain length of 8 or longer, are considered a wax.

Lipid Digestion and Absorption

In animals, lipid consumption occurs mostly in the form of triglycerides from plant or animal sources whereupon the process of digestion and absorption is essentially the process of converting dietary triglycerides to chylomicrons in the body. Although lingual lipase (salivary lipase or pregastric lipase) may partially digest dietary lipids (specific for the C_3 linkage), lipids are primarily acted upon by pancreatic lipase which hydrolyzes the triglyceride into fatty acids (primarily the C_1 and C_3 ester linkages) and bile salts (stabilize the mixed micelle emulsion) such that the resultant mixed micelles are small enough to entry into the intermicrovillous space of the intestinal mucosa cells. Subsequent absorption of fatty acids and monoglycerides (largely C_2 monoglycerides) into the intestinal mucosa cell occurs by diffusion into the cell where the fatty acids and the monoglycerides are carried to the

endoplastimic reticulum where they are reformed into triglycerides, and in conjunction with cholesterol and protein, form a chylomicron which enters into the lymphatic system for subsequent metabolism (Figure 4). An 'average' chylomicron is composed of 87% triglycerides, 9% phospholipids, 2% cholesterol, and 2% protein. Bile salts are largely reabsorbed in the lower ileum and transported back to the liver for reutilization in the lipid digestion process.

Lipids in Animal Produciton

Supplemental fats and oils are commonly added to swine diets to increase energy density of the diet, but may also reduce dust, supply fat soluble vitamins and essential fatty acids, and may improve diet palatability. Composition of lipids utilized in the livestock industry varies widely, with some common lipids and their fatty acid composition listed in Table 2. Most recently, oil extracted from dry-mill ethanol plants has become available to the livestock industry. Although little data are available, a recent 'in-house' analysis of crude corn oil obtained from an ethanol plant suggest that its relative fatty acid composition differs little from refined corn oil, however, concentrations of unsaponifiables and free fatty acids appear to be slightly elevated compared to its refined counterpart (Table 3).

Fats and oils have generally been considered to be a highly digestible energy source (Babatunde et al., 1968; Cera et al., 1988a,b; 1989a; 1990; Li et al., 1990; Jones et al., 1992; Jorgensen et al., 2000). However, their source and level may also affect nitrogen digestibility and retention, and amino acid absorption (Lowrey et al., 1962; Cera et al., 1988b, 1989a,b; Li et al., 1990; Li and Sauer, 1994; Jorgensen and Fernandez, 2000). In addition, the apparent digestibility of various lipids in nursery pigs has been shown to increase with age (Hamilton and McDonald, 1969; Frobish et al., 1970) with digestibility of the lower digestible animal fat sources (lard and tallow) increasing to a greater extent with age compared to digestibility of vegetable oils (Cera et al., 1988a,b; 1989a, 1990). The NRC (1998) estimates of DE content of various fat sources are based on the classic research by Wiseman et al. (1990) and Powles et al. (1993, 1994, 1995) where DE, kcal/kg = $[(36.898 – (0.005 × FFA, g/kg) – (7.330 × e^{-0.906×U:S}))/4.184]$, ME subsequently calculated as 96% of DE, and NE estimated using an equation that includes ME, ash, and ADF [NE,

kcal/kg = 328 + (0.599 × ME, kcal/kg) – (15 × % ash) – (30 × % ADF)]. For comparative purposes, the prediction of the energy value of lipids for poultry as listed in the poultry NRC (1994) is: ME_n = 8,227 -10,318$^{(-1.1685U:S)}$ as obtained from Ketels and DeGroote (1989) or ME_n = 28,119 – 235.8(C18:1 + C18:2) – 6.4(C16:0) – 310.9(C18:0) + 0.726(IV × FR_1) – 0.0000379 (IV(FR_1 + FFA)) as obtained from Huyghebaert et al. (1985). Even though recent research (Jorgensen and Fernandez, 2000; Kerr et al., 2009; Silva et al., 2009; Anderson et al., 2012) has shown that the DE and ME content of various refined lipids in swine are similar to values reported in the NRC (1998), the effect of quality (free fatty acid level and degree of oxidation) on energy value among fat sources has not been well established.

Lipid Quality

Lipids can be subjected to a wide variety of laboratory tests to define quality or ensure that the lipid product meets specifications according to trade or a buyer's requirements. Some general lipid quality indices are listed in Table 4.

Lipid Peroxidation

Measurement of lipid peroxidation provides useful information to evaluate the degree of peroxidation. However, the assessment regarding the degree of lipid peroxidation may not be valid due to the drawbacks of the method used for characterizing peroxidation and the stage in the peroxidation process when the lipid analysis occurred. Lipid peroxidation is a complex process and is affected by several factors including degree of saturation, temperature, oxygen, heavy metals, undissociated salts, water, and other nonlipidic compounds. Lipid peroxidation is generally considered to consist of three phases: (1) an initiation phase which involves the formation of free lipid radicals and hydroperoxides as primary reaction products, (2) a propagation phase where hydroperoxides formed are decomposed into secondary peroxidation products, and (3) a termination phase involving the formation of tertiary peroxidation products (Gutteridge, 1995; Yong and McEneny, 2001). Lipid hydroperoxides initially formed during the lipid peroxidation process not only have the potential to impact lipid quality, and therefore could affect animal health and performance, but the formation of secondary and tertiary oxidation products (aldehydes, ketones,

alcohols, hydrocarbons, volatile organic acids, and epoxy compounds) often have additional effects on lipid quality and animal productivity. As such, the increase and decrease in the amount of various lipid peroxidation products over time during each of these phases increases the difficulty of accurately measuring and assessing the extent of lipid peroxidation (Morita et al., 1983). Figure 5 represents a general schematic representation of lipid peroxidation depicted in the following figure (Liu, 1997). Unfortunately, there appears to be no single method that seems to adequately describe or predict lipid peroxidation due to the complexity of lipid composition and the phases involved in lipid peroxidation (Kim and LaBella, 1987). Therefore, to accurately analyze the amount of lipid damage caused by peroxidation, it may be advantageous to determine the degree of lipid peroxidation at several time intervals using more than one test, some of which are listed and described in Table 5.

Lipid Quality and Nutritional Value

A recent examination of lipids obtained from a local feed mill showed a range in total MIU from 0.8 to 3.7%, AOM from 8.0 to 332 hours, IV from 66.3 to 84.0 g/100 g lipid, PV from 0.4 to 7.3 mEq/kg, and FFA from 5.8 to 51.6%. Consequently, there appears to be a wide range in composition and quality of lipids being fed to livestock. Unfortunately little is known about each quality indices on the ability of the animal to utilize the lipid source for energy. Leeson et al. (1997) showed no impact of lipid rancidity on turkey performance. In contrast, Cabel et al. (1988) and Dibner et al. (1996) reported decreased broiler performance with an increase in fat rancidity. A similar discrepancy has been noted in swine. Fernández-Dueñas et al. (2008) reported no effect of oxidized canola oil or tallow on pig performance, while (Derouchey et al. (2004) reported that increasing the rancidity of choice white grease (PV of 105 mEq/kg equating to 6.3 mEq/kg diet) decreased feed intake, but fatty acid digestibility was not affected. In addition to supplementing lipids by themselves, various animal and vegetable protein meals (i.e., meat and bone meal, dried distillers grains with soluble) also contain moderate amounts of lipids, and since these feedstuffs are heat processed, the lipids in these products may also be susceptible to oxidation (Song et al., 2011). To date, however, the data is inconclusive on the level of lipid oxidization in these feedstuffs and on subsequent

animal productivity. Carpenter et al. (1966) and L'Estrange et al. (1967) fed growing pigs 10% meat meal with a peroxide value of 210 mEq/kg (resulting in 3.5 mEq/kg diet) and reported no difference in performance compared to pigs fed the same diet containing unoxidized lipids. In contrast, Fernández-Dueñas (2009) and Harrell et al. (2010) reported that diets containing DDGS or oxidized corn oil resulted in depressed pig performance. In light of this confusion, The authors of this paper embarked on an extensive study evaluating the impact of lipid type and oxidation status on pig performance, intestinal integrity, and metabolizable energy concentration. The results (data not shown) will be presented at the end of the oral presentation.

In addition to the effect of oxidation on the nutritional value of a lipid, there is also a potential impact of free fatty acid content on lipid digestibility. Brambila and Hill (1966) and Jorgensen and Fernandez (2000) reported that digestibility of free fatty acids is lower than that of triglycerides, which coincides with a lower digestible energy content with increasing levels of free fatty acids (Wiseman and Salvador, 1991; Powles et al., 1994, 1995; Jorgensen and Fernandez, 2000). This appears to be especially true in young pigs as depicted in Figure 6 (Powles et al., 1995). In contrast, Cera et al. (1989b) reported that feeding 8% of a medium-chain FFA did not negatively affect pig performance and DeRouchey et al. (2004) reported that fatty acid digestibility was not affected by free fatty acid level in choice white grease fed to nursery pigs.

Additional factors may also affect lipid digestibility and utilization, being associated with where the lipid products are obtained-human food or agricultural industries. These factors include the concentration and fatty acid composition of mono- and di-glycerides, emulsifying agents/acid oils/soap stocks/free fatty acids, and hydrogenated lipids.

Monoglycerides/Fatty Acid Position: Limited data are available on the effect of specific fatty acids on the C_1, C_2, or C_3 position of glycerol on lipid digestibility. It has been suggested (Bracco, 1994) that the presence of a long-chain saturated fatty acid at the C_1 and C_3 positions of a triglyceride are partially responsible for the poor absorption of cocoa butter. It is thought that long chain-fatty acids on the C_1 and C_3 positions are absorbed less efficiently than long-chain fatty acids bound on the C_2 position, due to their more hydrophobic characteristic. This is supported by Smink et al. (2008) who reported that

randomization of the 16:0 fatty acid to the C_2 position in palm oil had a positive effect on its digestibility in broilers. In swine, the effect of fatty acid position is less clear. Scheeder et al. (2003), reported that fatty acid position had no impact on fatty acid composition of depot fat in growing pigs (suggesting no impact on lipid digestibility), which is supported by Innis et al. (1996) who reported that the fatty acid composition of adipose tissue was only slightly influenced by the triglyceride structure. In contrast, Innis and Dyer (1997) reported that the fatty acid on the C_2 position is conserved during digestion and absorption, and subsequently in its reassembly to chylomicron triglycerides. Location of fatty acids on the C_1 and C_3 position may also be important as long-chain unesterfied fatty acids may have reduced absorption because of a tendency to form insoluble soaps with divalent cations.

Emulsifying Agents: In pigs, lecithin has been shown to have little impact on lipid and energy digestibility or growth performance (Overland et al., 1993ab; Overland et al., 1994; de Souza et al., 1995; Miller et al., 1994). In contrast, lysolecithin has been shown to improve fatty acid digestibility, but had minimal effects on pig performance (Jones et al., 1992). Recently Xing et al. (2004) reported an increase in lipid digestibility in nursery pigs supplemented with 0.05% lysolecithin on d-10, but no effect on energy digestibility. On d-28, however, neither lipid or energy digestibility was affected by lysolecithin supplementation, but there appeared to be was a slight improvement in piglet BW gain.

Free Fatty Acids: As summarized by Wiseman et al. (1998), the presence of free fatty acids has a negative impact on the digestion of fatty acids, more so in young birds>young pigs=old birds>old pigs, and more so in saturated fatty versus unsaturated fatty acids.

Hydrogenation: Hydrogenation of vegetable oils to covert them to semisolid fats is a commonly used practice in the food industry, and as a consequence, the availability of these products to the animal industry has increased. However, the impact on the digestibility of these chemically altered fats must be understood relative to their potential value to the livestock industry. In broilers, free palmitic (C16:0) and steric (C18:0) acids have been reported to be poorly or completely indigestible (Renner and Hill, 1961). This is supported by Dvorin et al. (1998) who reported that in broilers, AME_n was lower in diets containing hydrogenated soybean oil, compared to

the unhydrogenated soybean oil, which the authors suggested was due to a lower fat digestibility, less deposition of PUFA in body lipids, and higher lipogenesis compared to birds fed unhydrogenated soybean oil. Likewise, Kaplan and Greenwood (1998) reported that hydrogenated soybean oil (subsequently high in steric acid, $C18:0$) was largely unavailable to rats compared to hydrogenated coconut oil (high in lauric acid, $C12:0$). In swine, Tullis and Whittemore (1980) suggested that the poor digestibility of hydrogenated tallow was likely due to the high concentration of steric acid ($C18:0$). Most recently, Gatlin et al. (2005) reported that apparent fat digestibility decreased linearly as the amount of fully hydrogenated tallow or choice white grease fat increased, suggesting that the digestibility of fully hydrogenated animal fats is approximately zero.

Antioxidants in Animal Nutrition

Antioxidant chemistry is a complex field of science and is beyond the scope of this presentation. Readers interested in this subject are encouraged to reviews on this topic by Frankel (2007) and Wanasundara and Shahidi, 2005). Addition of antioxidants (i.e., butylated hydroxyanisole, butylated hydroxytoluene, tocopheral, and ethoxyquin) has been evaluated in humans, rodents, and livestock, but their impact on animal physiological and performance parameters has been inconsistent (Fernández-Dueñas, 2009). Dibner et al. (1996) reported reduced feed efficiency in broilers fed oxidized poultry fat compared to birds fed unoxidized poultry fat, with the addition of ethoxyquin improving feed efficiency--regardless of lipid oxidation level. Likewise, supplementation of additional antioxidants improved growth performance in pigs fed diets containing DDGS or oxidized corn oil (Fernández-Dueñas, 2009; Harrell et al., 2010). In contrast, others have shown that supplementation of antioxidants have no effect on growth performance in animals under dietary oxidative stress (Wang et al., 1997; Anjum et al., 2002; Fernández-Dueñas et al., 2008; Song et al., 2012).

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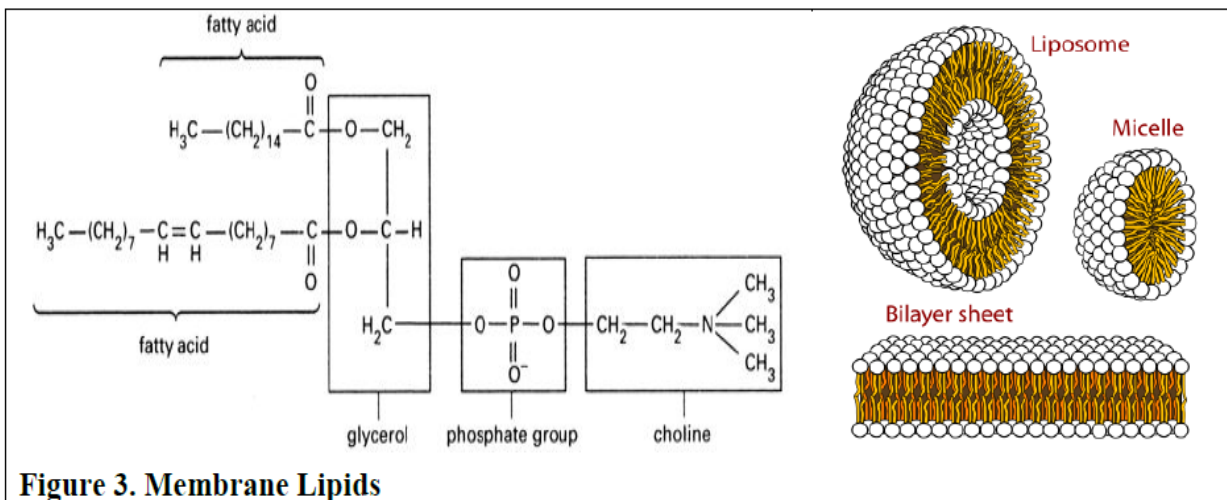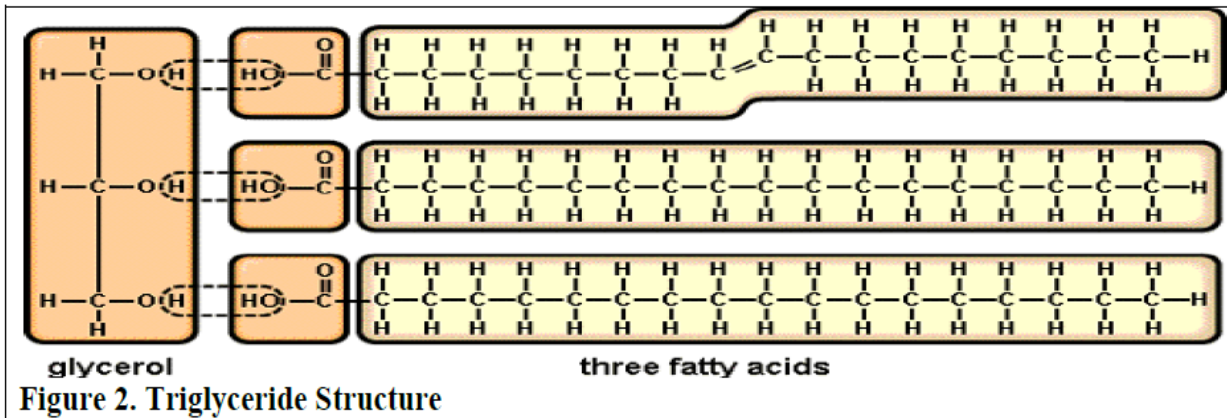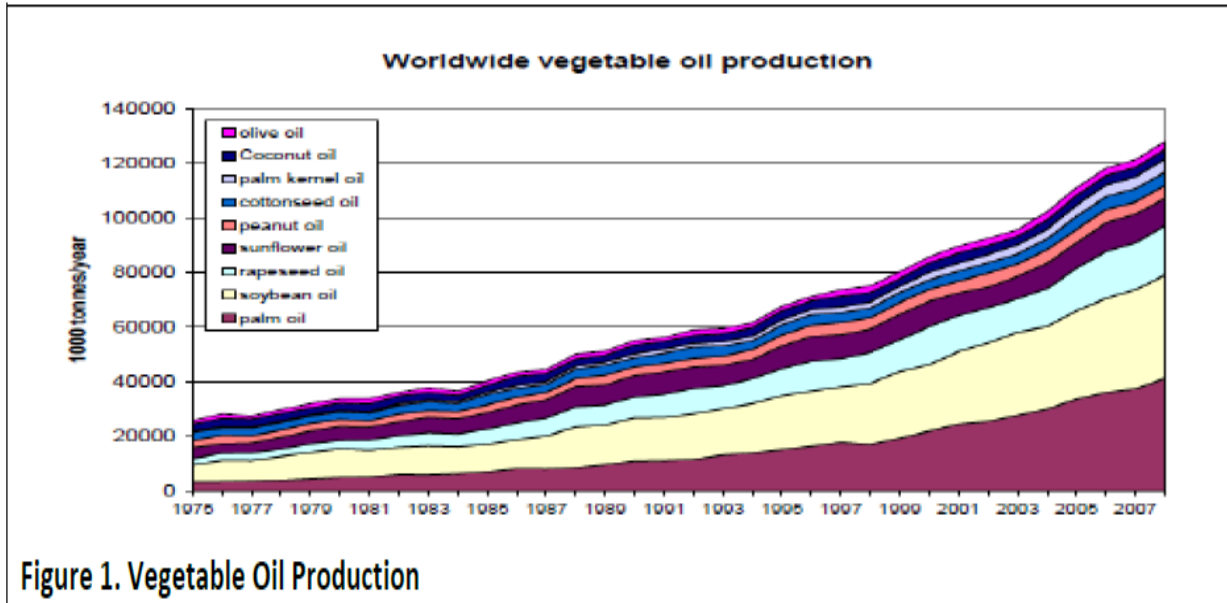
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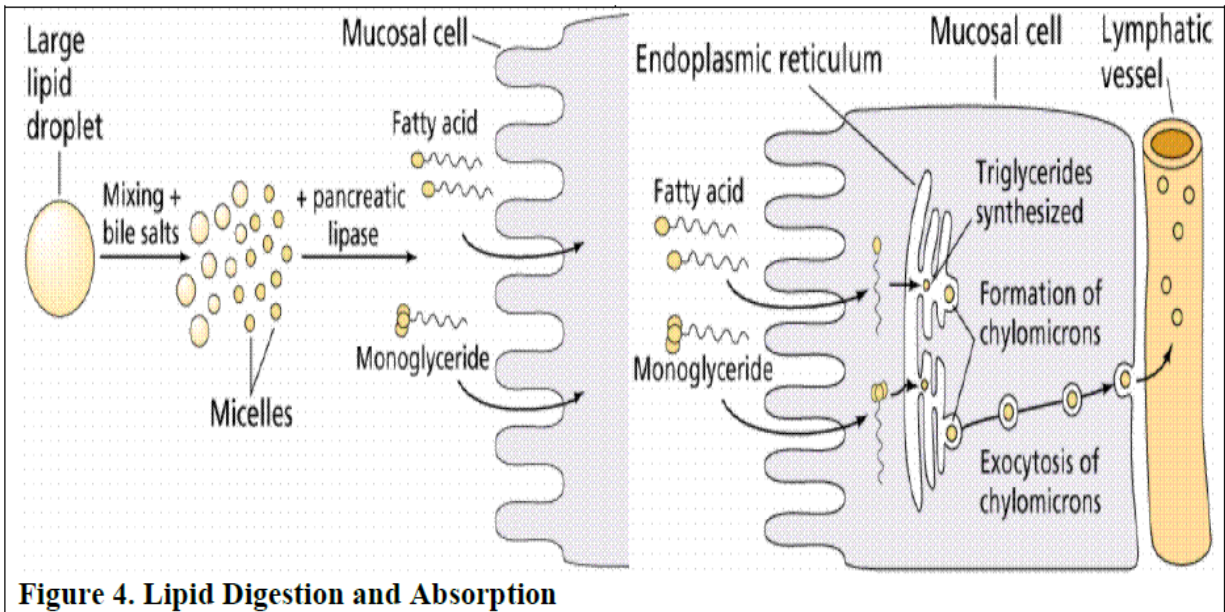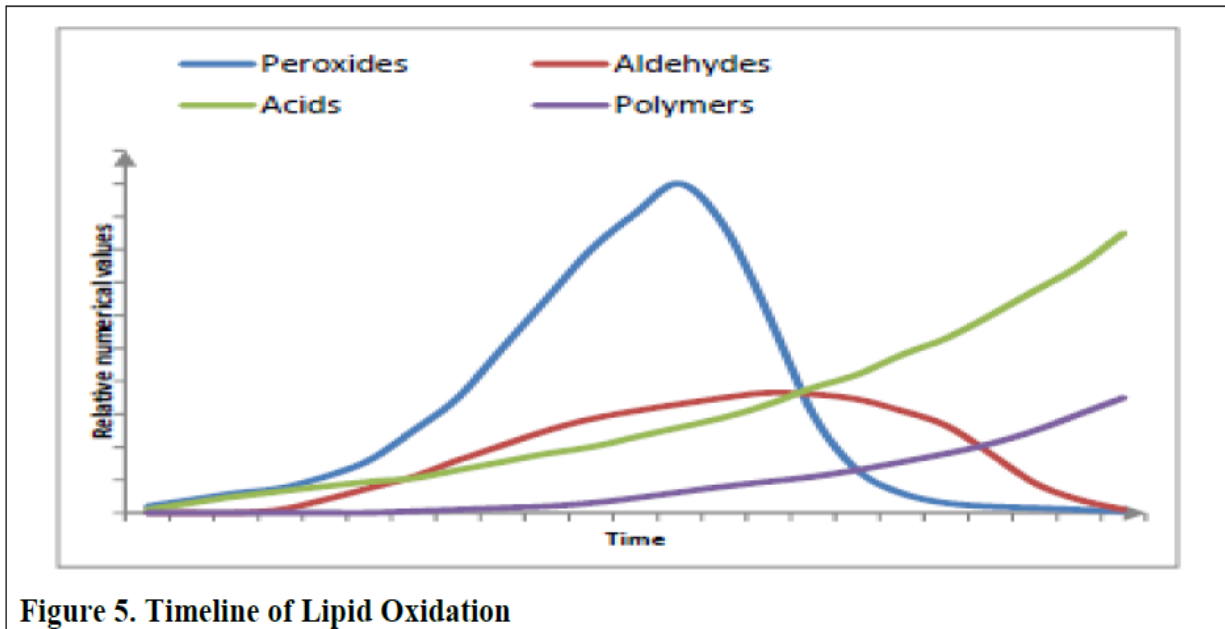
Figure 1. Vegetable Oil Production

Figure 2. Triglyceride Structure

Figure 3. Membrane Lipids

Figure 4. Lipid Digestion and Absorption

Figure 5. Timeline of Lipid Oxidation

Figure 1 Influence of ratio of unsaturated to saturated fatty acids (U/S) on digestible energy (DE) of fats — interaction with age of pig and free fatty acid (FFA) content of fats (—■— young, FFA = 50 g/kg; —▲— young, FFA = 500 g/kg; —×— old, FFA = 50 g/kg; —＊— old, FFA = 500 g/kg).

Figure 2 Influence of free fatty acid (FFA, g/kg fat) content on digestible energy (DE, MJ/kg) of fats — interaction with age of pig and ratio of unsaturated to saturated fatty acids (U/S) of fats (—■— young, US = 1·5; —▲— young, US = 3·5; —×— old, US = 1·5; —＊— old, US = 3·5).
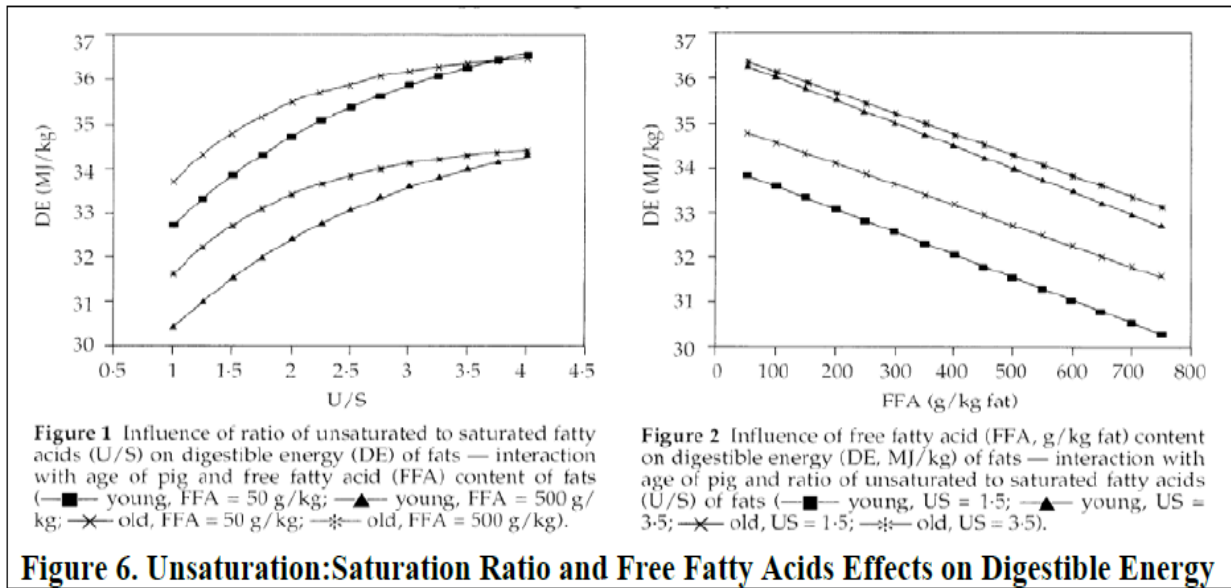
Figure 6. Unsaturation:Saturation Ratio and Free Fatty Acids Effects on Digestible Energy

Table 1. Chemical Names and Descriptions of Common Fatty Acids				
Common name	Carbons	D-bonds	Scientific name	Common source
Butyric	4	0	butanoic acid	butterfat
Caproic	6	0	hexanoic acid	butterfat
Caprylic	8	0	octanoic acid	coconut oil
Capric	10	0	decanoic acid	coconut oil
Lauric	12	0	dodecanoic acid	coconut oil
Myristic	14	0	tetradecanoic acid	palm kernel oil
Palmitic	16	0	hexadecanoic acid	palm oil
Palmitoleic	16	1	9-hexadecenoic acid	animal fats
Stearic	18	0	octadecanoic acid	animal fats
Oleic	18	1	9-octadecenoic acid	olive oil
Ricinoleic	18	1	12-hydroxy-9-octadecenoic acid	castor oil
Vaccenic	18	1	11-octadecenoic acid	butterfat
Linoleic	18	2	9,12-octadecadienoic acid	grape seed oil
α-Linolenic	18	3	9,12,15-octadecatrienoic acid	flaxseed (linseed) oil
γ-Linolenic	18	3	6,9,12-octadecatrienoic acid	borage oil
Arachidic	20	0	eicosanoic acid	peanut oil, fish oil
Gadoleic	20	1	9-eicosenoic acid	fish oil
Arachidonic	20	4	5,8,11,14-eicosatetraenoic acid	liver fats
Eicosapentaenoic	20	5	5,8,11,14,17-eicosapentaenoic acid	fish oil
Behenic	22	0	docosanoic acid	rapeseed oil
Erucic	22	1	13-docosenoic acid	rapeseed oil
Docosahexaenoic	22	6	4,7,10,13,16,19-docosahexaenoic acid	fish oil
Lignoceric	24	0	tetracosanoic acid	some in most fats

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Table 2. Fatty acid composition of various fats and oils utilized in the livestock industry

Source	Caprylic, 8:0	Carpic, 10:0	Lauric, 12:0	Myristic, 14:0	Palmitic, 16:0	Stearic, 18:0	Arachidic, 20:0	Behenic, 22:0	Palmitoleic, 16:1	Oleic, 18:1	Linoleic, 18:2	Linolenic, 18:3
Canola[1]	-	-	-	0.1	4.1	1.8	0.7	0.3	0.3	60.9	21.0	8.8
Coconut	7.1	6.0	47.1	18.5	9.1	2.8	0.1	-	-	6.8	1.9	0.1
Corn	-	-	-	0.1	10.9	2.0	0.4	0.1	0.2	25.4	59.6	1.2
Fish[2]	-	-	0.1	10.8	23.2	4.2	0.4	0.1	11.4	10.6	1.8	1.7
Lard	-	0.1	0.1	1.5	26.0	13.5	0.2	-	3.3	43.9	9.5	0.4
Palm	-	-	0.3	1.1	42.9	4.6	0.3	0.1	0.2	39.3	10.7	0.4
Poultry	-	-	0.1	0.8	25.3	6.5	0.2	-	7.2	37.7	20.6	0.8
Soybean	-	-	-	0.1	10.6	4.0	0.3	0.3	0.1	23.2	53.7	7.6
Tallow	-	-	0.1	3.2	24.3	18.6	0.2	-	3.7	42.6	2.6	0.7
Yellow grease	-	-	0.1	0.6	14.2	6.6	0.4	-	1.0	36.2	35.4	3.8

[1] Canola oil additionally contains: C24:0, 0.2% and C22:1, 0.7%.
[2] Manhaden oil additionally contains: C16:2-4, 4.7%; C18:4, 2.1%; C20:2-4, 3.2%; C20:5, 11.9%; C22:1, 0.2%; and C22:4-6, 9.0%.

Table 3. Composition of crude versus refined corn oil

Corn oil source	Crude fat	Moisture	Insolubles	Unsaponifiables	Free fatty acids	Myristic, 14:0	Palmitic, 16:0	Stearic, 18:0	Palmitoleic, 16:1	Oleic, 18:1	Linoleic, 18:2	Linolenic, 18:3
Crude	99.30	1.99	0.01	10.38	13.22	0.08	12.79	2.04	0.11	28.14	54.27	1.30
Refined	98.90	1.54	ND	7.08	3.65	0.08	13.46	2.10	0.11	27.65	49.16	0.03

Table 4. Lipid Quality Indices	
Color	Quantified relative to the Fat Analysis Committee (FAC) standard, ranging from 1 (light) to 45 (dark).
Fatty acid profile	Relative amounts of individual fatty acids in a sample.
Free fatty acids	Amount of fatty acids not bound to the glycerol backbone in a triglyceride.
Insolubles	Amount of sediment in a sample. For example, fiber, hair, hide, bone, or soil.
Iodine value	Measure of chemical unsaturation, expressed as grams of iodine absorbed by 100 g of fat.
Moisture	Amount of moisture in a sample.
Saponification value	An estimate of the mean molecular weight of the constituent fatty acids in a sample, defined as milligrams of KOH required to saponify 1 g of fat. The higher the SV, the lower the mean chain length.
Titer	The solidification point of the fatty acids, an important characteristic in producing soaps or fatty acids.
Total fatty acids	The total of both free fatty acids and fatty acids combined with glycerol.
Unsaponifiables	A measures of material in the lipid that will not saponify (form a soap) when mixed with caustic soda (NaOH or KOH). Examples include: sterols, hydrocarbons, pigments, fatty alcohols, and vitamins.

Table 5. Lipid Oxidation Indices	
Peroxide value (PV)	Lipid peroxides and hydroperoxides.
p-Anisidine value (AnV)	Measure of the amount of the high molecular weight saturated and unsaturated aldehydes.
Thiobarbituric acid reactive substance concentration (TBARS)	Measure of carbonyl-containing secondary lipid oxidation products formed from the decomposition of hydroperoxides. Developed to detect malondialdehyde, although other carbonyl compounds can also contribute to TBARS values.
Hexanal	A major secondary lipid oxidation product produced from the termination phase during the oxidation of linoleic and other ω-6 fatty acids.
2, 4-decadienal (DDE)	A product derived from peroxidation of linoleic acid.
4-hydroxynonenal (HNE)	An α, β-unsaturated lipophilic aldehyde formed from the peroxidation of polyunsaturated ω-6 fatty acids, such as arachidonic or linoleic acid.
Active oxygen method stability (AOM)	A predictive method where purified air is bubbled through a lipid sample at 97.8°C, and the PV of the lipid is determined at regular intervals to determine the time required to reach a PV of 100 mEq/kg lipid (recorded as h), or the PV of the lipid is determined at a predetermined time endpoint, such as at 20 h (recorded as mEq/kg lipid).
Oxidative stability index (OSI)	A method whereupon air passes through a lipid under a specific temperature, at which point volatile acids decomposed from lipid peroxidation are driven out by the air and subsequently dissolved in water thereby increasing its conductivity. The conductivity of the water is constantly measured, and the OSI value is defined as the hours required for the rate of conductivity to reach a predetermined level.

The Potential of Supplemental Zinc to Enhance the Ractopamine Response in Finishing Pigs

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Summary

Zinc is a nutritionally important trace element that confers function of over 300 proteins including those responsible for DNA and RNA replication, gene transcription and protein synthesis. The objective of this study was to determine the effect of supplemental zinc source, oxide or chelate, in combination with ractopamine on growth performance, carcass characteristics, and foot health in finishing pigs. Dietary treatments contained either 50 ppm supplemental available zinc from ZnO or Zn-amino acid complex (Availa Zinc® (AZ)) d 0-56 and ractopamine (RAC; 7.5 ppm) during d 35-56 of the study. From d 35-56, animals were fed their respective finishing dietary treatments: 1) control (0.70% TID Lys) + ZnO; 2) high lysine (1.00% TID Lys) + ZnO; 3) high lysine + AZ; 4) Diet 2 + RAC; or 5) Diet 3 + RAC. From d 35-56 and overall (d 0-56), for pigs fed RAC (diets 4 and 5) had greater ADG (P < 0.001) and G:F (P < 0.001) than pigs fed non-RAC diets. From d 35-56, pigs fed AZ had 6.13% greater ADG (P = 0.05) and tended to have greater G:F (P < 0.10) than pigs fed ZnO. Pigs fed diet AZ + RAC tended to have greater G:F than pigs fed diet ZnO + RAC (P < 0.10), which was intermediate to pigs fed all other diets. Overall (d 0-56), pigs fed AZ tended to have 2.9% greater ADG (P = 0.06) than pigs fed ZnO. Ractopamine increased (P < 0.01) primal ham weight 5.2% and dissected ham lean weight by 8.4% and percent lean in the ham by 3% (P < 0.01). The results of the present study indicate that supplementation with AZ may partially mitigate some of the adverse foot disorders associated with feeding RAC. Feeding finishing pigs an iso-level of AZ compared to ZnO improved pig ADG and G:F, with a greater improvement in growth and carcass parameters observed when AZ is fed in combination with RAC. More work is needed to clarify if supplemental zinc enhances the RAC response as a signaling factor in the mTOR pathway and muscle synthesis and/or through improved gut health and immune system.

Introduction

With the increasing global population, estimates reports that current food production will be required to double by 2050 (FAO 2009). Increasing efficiency of current feed technologies and development of new technologies will play a critical role in meeting this global food demand. Ractopamine hydrochloride (RAC) is a β1 androgenic agonist and has been shown to increase ADG, G:F, and carcass lean without detrimental effects on pork quality characteristics (Armstrong et al. 2004, Apple et al. 2007).

Zinc is a nutritionally important trace element that confers function in over 300 proteins, including those responsible for DNA and RNA replication, gene transcription, and protein synthesis (Vallee et al. 1999). Nutrition can play a critical role in the

modulation of the immune response (Klasing, 1998 and Kidd, 2004). Zinc has been shown to have a direct influence on the immune system (Kirchgessner et al. 1976) and is required for normal immune function (Dardenne and Back, 1993; Kidd et al. 1996). In the absence of an immune challenge, nursery pigs supplemented with 1500 ppm or 3000 ppm zinc had greater weight gain and feed efficiency than pigs not supplemented with zinc (Mavromichalis et al., 2000). When an antimicrobial antibiotic was omitted from treatment diets, Hill et al., (2001) observed that ADG increased in a quadratic fashion in response to supplemental zinc (0, 1500 or 3000 ppm).

The objective of this study was to determine the effect of supplemental zinc source, oxide or organic on growth performance, carcass characteristics, and foot health in finishing pigs and determine the interaction of zinc source and ractopamine when zinc was included at 50 ppm above the basal 50 ppm supplemental level in the finishing diet.

Experimental Procedures

Animals

Two hundred crossbred [US Duroc x (US York x Chester)] barrows and gilts were initially blocked by BW into 8 blocks with an initial BW of 81.1±0.22 lb. Pairs of blocks (1 and 2, 3 and 4, 5 and 6, 7 and 8) were started on a weekly schedule, starting from heaviest to lightest to provide similar start weights and aid in slaughter at the end of the experiment. Pigs were housed 5 pigs/pen with equal numbers of barrows and gilts within a block. Pigs were housed at the Purdue University Environmental Research Building in 6 x 8 ft pens on totally slatted concrete floors with ad libitum access to a single hole self-feeder and nipple drinker. Rooms were mechanically ventilated and a minimum temperature of 18 to 20 °C was maintained.

Diets

Pigs were assigned to corn-soybean meal based finishing diets containing one of the two supplemental zinc sources (50 ppm), Zinc oxide (ZnO) or Availa Zinc® (AZ). All diets throughout the study contained 50 ppm supplemental available Zn from zinc oxide in the trace mineral premix as the basal level of

Zn. Dietary treatments contained either 50 ppm supplemental available zinc from ZnO or AZ from d 0-56 and with or without ractopamine (RAC; 7.5 ppm) during d 35-56 of the study. At day 35, animals were assigned to their respective finisher 2 diet. Within each block, pens were randomly assigned to 1 of 5 dietary treatments: 1) control (0.70% TID Lys) + ZnO; 2) high lysine (1.00% TID Lys) + ZnO; 3) high lysine + AZ; 4) Diet 2 + RAC; or 5) Diet 3 + RAC. The zinc treatments were initiated 5 weeks prior to the lysine and RAC treatments. All diets (Table 1) were formulated to meet or exceed NRC (1998) nutrient requirements of growing-finishing swine.

Dietary supplemental zinc sources were added to a fine ground corn premix. The Availa-Zinc 100 premix was mixed as 454 g of Availa-Zn with 454 g of finely ground corn to make the 2 lb inclusion per ton of feed. The zinc oxide premix was made by mixing 90 g of zinc oxide with 137 g of soybean protein concentrate and 681 g of fine ground corn to make the 2 lb inclusion per ton of feed. Both of these inclusion rates were calculated to provide 50 ppm (45.4 g/ton) of supplemental available zinc from each source assuming 100% availability for the Availa-Zn 100 source and assuming 72% Zn in the zinc oxide with an estimated 70% availability.

Animal Growth and Performance

All pigs were weighed individually at the start of treatment (d 0), d 14, 35 and the last day of final treatments (d-56, 1 day before slaughter). Pen feed intakes were measured at time of each BW measurement. Pen averages for BW, ADG, ADFI, and G:F of each treatment group were determined for each time period.

Hoof Lesion Scoring

All individual animals slaughtered at the Purdue University Meats Laboratory had their front and rear hooves accessed for the type, number, and severity of cracks and lesions. Lesions were scored as 4 distinct categories: horn cracks (cracks in the horn of the nail), pad cracks (apparent separation of the hoof wall from the nail or separation of the pad itself), ulcers (erosion of the pad tissue), and bruises of the pad and nail. The number and severity (from 0-3 in 0.5 increments) of lesions were determined according to the Zinpro's sow lameness foot scoring guide.

Carcass Characteristics

On day-56, two pigs per pen (one barrow and one gilt) with BW closest to the pen mean were slaughtered at the Purdue meats lab. The remaining three pigs from each pen were slaughtered at a commercial pork processing facility to obtain individual hot carcass weight (HCW) and carcass probe backfat and loin depth. Pigs harvested on Purdue campus had individual live, hot carcass, and leaf fat weights recorded at the time of slaughter. After a 24 h chill (3°C), the right side of each individual carcass was ribbed and allowed exposure to air for 20 minutes to bloom the loin prior to evaluating color, marbling and firmness using NPB standards. Loin muscle area was measured using a dot grid and back fat measurements were taken at the tenth rib, last rib mid-line, and last lumbar mid-line. Fat-free lean percentage was estimated using the equation of Schinckel et al. (1999) which includes HCW, tenth rib backfat, and loin area. Water holding capacity of loin chops was determined from a 1 inch loin chop taken from the 10th rib location of the right carcass (Rasmussen and Stouffer, 1996). Approximately 48 hours after slaughter, hams from the right side of the carcass were dissected. Primal ham weight was recorded and the hams were dissected into skin, muscle, fat and bone tissues. Percent dissected ham lean was calculated by dividing the dissected ham muscle weight by the primal ham weight.

Statistical Analysis

Pen was used as the experimental unit (n = 40) for statistical analysis of all live animals and carcass measurements. Data were analyzed as a complete block design using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC.). A series of orthogonal contrasts were used to assess the effect of added lysine (treatment 1 versus 2), main effect of zinc source (ZnO vs AZ), main effect of RAC and the interaction of RAC and zinc source. Additionally, mean separation tests were performed using Duncan's procedure with $P \leq 0.05$ considered significant and 0.06 to 0.10 considered trends.

Results and Discussion
Growth performance

Supplemental zinc source, ZnO or AZ had no effect on ADG (913 vs 926 g/d), ADFI (2.95 vs 2.97 kg/d), or G:F (0.298 vs 0.299) during the first 35 days of the study (ZnO vs AZ, respectively). During the final three weeks of the finishing period RAC increased ADG ($P < 0.01$) by 27% (Table 2). Pigs fed the normal lysine control diet had greater ($P < 0.01$) ADG and greater daily feed intake ($P < 0.03$) than pigs fed high lysine diets without RAC. Pigs fed AZ had 6.13% greater ADG than pigs fed ZnO ($P < 0.05$). Ractopamine increased G:F ($P < 0.05$) while AZ tended to increase G:F ($P < 0.06$) with pigs receiving AZ and RAC in combination having the greatest G:F.

For the entire 56 day feeding period, RAC increased ADG ($P < 0.01$) while control pigs tended to have greater ($P < 0.09$) ADG than pigs fed high lysine diets without RAC. Availa Zinc® tended to increase total weight gain ($P < 0.06$) and ADG ($P < 0.06$)

Carcass Characteristics

Pigs fed RAC had greater BW ($P < 0.01$) and HCW ($P < 0.01$) than pigs fed diets without RAC. Increased dietary lysine reduced BW ($P < 0.01$) and tended to reduce HCW ($P < 0.06$) when compared to pigs fed the control lysine diet, primarily due to the poorer performance of the high lysine – ZnO fed pigs. Feeding AZ increased BW ($P < 0.01$) and HCW ($P < 0.05$) compared to feeding ZnO. Pigs fed the combination of AZ and RAC had the greatest HCW and pigs fed RAC+ZnO had greater HCW than pigs fed just ZnO. These differences in HCW and LW however did not correspond to any differences in dressing percentage for each of the treatment diets. Feeding RAC increased LMA ($P < 0.001$) but did not affect fat thickness ($P > 0.11$) at the mid line, last rib or at the 10th rib. Calculated percent lean was greater ($P < 0.04$) for RAC fed pigs. Drip loss from loin core samples was not different among any of the treatment groups.

Primal ham weight increased ($P < 0.01$) as a result of feeding RAC and pigs fed RAC and supplemental AZ had the greatest numerical primal ham weights (Table 3). Ractopamine increased ($P < 0.01$) dissected ham lean weight by 8.4%. Percent lean of the ham was increased ($P < 0.01$) and percent skin and fat was reduced ($P < 0.01$) in RAC fed pigs, with the greatest changes in ham lean and fat occurring with the combination of RAC and AZ.

Foot characteristics

Overall condition of the feet was poorer (P <0.01) in pigs fed RAC (Table 4). Ractopamine increased the number (P < 0.01) and severity (P < 0.01) of pad bruises as well as an increase in the number (P < 0.01) and severity (P < 0.02) of horn cracks compared to non-RAC fed pigs. Pigs fed RAC and supplemented with AZ had numerically fewer and less severe horn cracks than pigs fed RAC and supplemented with ZnO. Feeding AZ numerically (P= 0.15) reduced the number of horn cracks and severity of horn cracks. Additionally, pigs receiving supplemental AZ alone (without RAC) had numerically the fewest and least severe horn cracks of all the treatments. Ractopamine increased the incidence (P < 0.01) and severity (P < 0.01) of foot ulcers. The number and severity of foot pad ulcers was greatest in ZnO supplemented pigs fed RAC. The number of foot ulcers was not different between control pigs, pigs fed high lysine diets without RAC and pigs fed RAC supplemented with AZ.

Discussion

The present study was designed to evaluate the effect of supplemental zinc source, oxide or chelate, on growth performance, carcass characteristics, and foot health in finishing pigs. The effect of zinc source and level of inclusion has been studied in weanling pigs in some detail. Hill et al., (2001) reported that ADG and G:F of weanling pigs increased in a quadratic manner in response to increasing amount of supplemental zinc oxide (0, 500, 1000, 2000, or 3000 mg/kg Zn, respectively). In the absence of an antimicrobial agent, Hill et al., (2001) reported a quadratic increase for ADG and G:F when 1500 or 3000 mg/kg Zn from zinc oxide were added to the diet in weanling pigs. Schell and Kornegay (1996) reported no performance benefit to inclusion of 3000 mg/kg of Zn in the diet from feed grade, zinc-methionine, zinc-lysine, or reagent grade zinc sources in weaned pigs from 28 to 42 days of age. Other studies have shown variable response to source and level of inclusion of zinc in weanling pigs (Hahn and Baker, 1993, Fryer et al., 1992, and Wedekind et al., 1994). However, little information on the effect of level and sources of supplemental zinc source on the performance of finishing pigs is available. In the present study, pigs fed AZ had 6.1% greater ADG than pigs supplemented with ZnO during the final 3 weeks of the finishing phase, which agrees with results from Patience et al., (2011a) who reported pigs fed RAC and AZ had greater ADG than RAC with Zn sulfate fed pigs. No differences in feed intake were observed resulting in a tendency for pigs fed AZ to have 5.2% greater G:F than pigs fed ZnO. Patience et al., (2011a) reported that pigs fed organic zinc consumed more feed than pigs fed zinc sulfate when both were fed RAC. Cattle fed 200 mg per head of RAC daily had greater ADG when 360 mg per head of zinc methionine was provided daily than cattle that were only fed RAC (Zinpro Coporation, 2007). In this same study, cattle fed 360 mg/hd/day of zinc methionine also had greater hot carcass weights than cattle only fed RAC. Similarly, pig hot carcass weights were greatest in our study for RAC fed pigs supplemented with 50 ppm organic zinc. More recently, Rambo and co-authors observed that supplementation with either 25 or 50 ppm zinc from ZnO or AZ to high health pigs did not improve the growth performance or carcass composition of finishing pigs fed RAC when compared to pigs fed RAC with no supplemental zinc beyond the 50 ppm that was included in the trace mineral premix (unpublished data, 2012).

According to Woodward (2009) adverse reactions to RAC in swine may include lameness, hoof disorders, and locomotion disorders. Ractopamine had a detrimental impact to the overall health of the feet in our study. A decline in foot health was observed for nearly each of the parameters measured with the exception of the number of pad cracks and the severity of pad cracks. Pigs supplemented with organic zinc had less severe foot ulcers than pigs supplemented with zinc oxide. This effect was especially apparent for the RAC fed pigs that were supplemented with organic zinc. Patience et al., (2011a) reported control pigs fed zinc sulfate had the best locomotion score and that RAC fed pigs supplemented with zinc sulfate had the poorest locomotion scores while RAC fed pigs supplemented with AZ for different durations had locomotion scores intermediate to these groups. From these results, and the results of the present study, there is some indication that supplementation with AZ may partially mitigate some of the adverse locomotion and foot disorders associated with feeding RAC.

Potential Mechanisms

The present study indicates that supplemental AZ has the potential to enhance the RAC response in finishing pigs. Zinc is a nutritionally important trace

element that confers function of over 300 proteins including those responsible for DNA and RNA replication, gene transcription and protein synthesis (Vallee et al., 1999). It was hypothesized from the initial study that AZ may act as a signaling molecule enhancing protein synthesis. An important pathway involved in protein synthesis and muscle hypertrophy is the mTOR pathway. Zinc has been shown to play a signaling role in this pathway in in-vitro studies (Kim et al., 2000 and Lynch et al., 2001). Rambo and co-authors are currently investigating the potential effect of supplemental zinc on this pathway in finishing pigs fed RAC.

Field research by Zinpro Corp. has fairly consistently indicated that supplementation with an organic zinc can enhance the RAC response in finishing pigs. More recent university research however does not agree with these results. In comparison of the experimental conditions between the two studies at Purdue allows for further speculation regarding the potential mechanism of action. Pigs used in the first study at Purdue experienced disease challenge in the weeks prior to the onset of the project. Additionally, 3 pigs were removed from this project during the pre-ractopamine feeding period as a result of severe illness or death. Necropsy work suggested that these pigs were challenged with swine influenza. In the second Purdue study growth was extremely good (1.11 kg/d ADG), no major health issues were observed, and all pigs that were started on test finished the study. As a result, this might suggest that the performance response to AZ plus RAC in the first study may be related to immune function or gut health. Southon et al. (1984) reported that meal fed rats, fed zinc deficient diets had reduced feed intake and BW gain than zinc adequate controls that were either meal or ad libitum fed. Additionally, zinc deficient meal fed rats had a shorter total small intestine length and a reduced crypt to villus ratio in the jejunum as compared to both meal and ad libitum fed zinc adequate rats, indicating that zinc deficiency has a negative impact on gut health and growth performance. While pigs in the first Purdue study were not zinc deficient per se, the greater bioavailability of AZ could have resulted in a more rapidly utilizable source of zinc for the intestine cells and indirectly improved growth performance, perhaps through a better gut immune function. More work is needed to clarify if supplemental zinc enhances the RAC response through improved gut

health and the immune system and/or as a signaling factor in the mTOR pathway and enhances muscle synthesis.

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Table 1. Diet formulations for Finisher 1 and 2 diets fed during the zinc source by Paylean study at Purdue University.

	Finisher 1 – Phase 1 (d 0-14)	Finisher 1 – Phase 2 (d 14-35)	Finisher 2 – Low Lysine (d 35-55)	Finisher 2 – High Lysine (d 35-55)	Finisher 2 – High Lysine + RAC (d 35-55)
Ingredient, %					
Corn	71.975	73.975	79.065	67.77	67.5825
SBM, 48% CP	9.30	7.25	9.32	20.60	20.60
DDGS	15.00	15.00	5.00	5.00	5.00
Swine Grease	1.00	1.00	4.00	4.00	4.00
Limestone	1.24	1.25	1.04	1.00	1.00
Monocal. Phos.	0.07	0.09	0.25	0.13	0.13
Vitamin Premix	0.125	0.125	0.15	0.15	0.15
Trace Min. Premix	0.10	0.10	0.10	0.10	0.10
Phytase	0.08	0.08	0.08	0.08	0.08
Salt	0.30	0.30	0.30	0.30	0.30
Lysine HCl	0.40	0.40	0.32	0.35	0.35
DL-Methionine	0.02	0.01	0.03	0.12	0.12
L-Threonine	0.11	0.11	0.12	0.18	0.18
L-Tryptophan	0.03	0.035	0.025	0.02	0.02
CTC-50	0.10	-	--	--	--
Tylan 40	--	0.125	0.05	0.05	0.05
Rabon	0.05	0.05	0.05	0.05	0.05
Paylean 1.8g/lb	-	-	--	--	0.1875
Treatment premix[1]	0.10	0.10	0.10	0.10	0.10
Calculated Analysis					
ME, kcal/kg	3383.1	3383.9	3528.9	3532.0	3525.5
CP, %	14.84	14.04	12.75	17.29	17.27
Total Lysine, %	0.92	0.86	0.79	1.12	1.12
TID Lysine, %	0.80	0.75	0.70	1.00	1.00
Dig. Lysine, %	0.75	0.70	0.66	0.95	0.95
Dig. M+C, %	0.46	0.43	0.41	0.59	0.59
Dig. Thre, %	0.49	0.46	0.44	0.64	0.64
Dig. Tryp, %	0.12	0.12	0.11	0.16	0.16
Ca, %	0.55	0.55	0.50	0.50	0.50
Avail. P, %	0.22	0.22	0.20	0.20	0.20
Analyzed values	ZnO/AvailZn	ZnO/AvailZn	ZnO	ZnO/AvailZn	ZnO/AvailZn
Zinc, ppm	164 / 162	139 / 142	173	156 / 152	165 / 159
Ractopamine, ppm	--	--	0.0	0.0 / 0.0	8.1 / 7.1

[1] Dietary supplemental zinc sources were added to a fine ground corn premix. The AvailaZn 100 premix was mixed as 454 g of AvailaZn with 454 g of finely ground corn to make the 2 lb inclusion per ton of feed. The zinc oxide premix was made by mixing 90 g of zinc oxide with 137 g of soy concentrate and 681 g of fine ground corn to make the 2 lb inclusion per ton of feed. Both of these inclusion rates were calculated to provide 50 ppm (45.4 g/ton) of supplemental available zinc from each source assuming 100% availability for the AvailaZn 100 source and assuming 72% Zn in the zinc oxide with a 70% availability.

Table 2. Effect of supplemental zinc source (Zn oxide or Availa Zinc®) on pig growth and performance during late finishing with or without ractopamine. –Day 35-55 and day 0 to 55.

Diets	1	2	3	4	5			Contrasts, P <		
Treatments	Control +ZnO	Lys+ZnO	Lys+AZ	Lys+ZnO+ RAC	Lys+AZ+ RAC	SE	Lysine[1]	RAC[2]	Zinc Source[3]	Zinc x RAC[4]
Day 35-56 Performance										
ADG, g	826[b]	731[c]	790[bc]	972[a]	1017[a]	26.0	0.01	0.001	0.05	0.75
ADFI, kg	3.15[a]	2.93[b]	3.10[ab]	3.16[a]	3.10[ab]	0.069	0.03	0.11	0.45	0.12
F:G	3.81[a]	4.06[a]	3.93[a]	3.27[b]	3.06[b]	0.100	0.10	0.001	0.11	0.69
G:F	0.262[bx]	0.249[bx]	0.255[bx]	0.307[ay]	0.33[az]	0.008	0.24	0.001	0.10	0.36
Gain, kg	16.75[b]	14.75[c]	15.98[bc]	19.66[a]	20.56[a]	0.519	0.01	0.001	0.05	0.75
Day 0-56 Performance										
Day 0 BW, kg	81.00	80.93	81.27	80.96	81.22	0.331	0.88	0.96	0.37	0.90
Day 56 BW, kg	129.59[bc]	127.25[c]	129.58[bc]	132.20[ab]	133.75[a]	0.930	0.09	0.001	0.05	0.68
ADG, g	872[b]	826[c]	863[c]	917[a]	940[a]	14.5	0.06	0.001	0.06	0.68
ADFI, kg	3.03	2.95	3.04	3.01	2.99	0.353	0.46	0.95	0.61	0.46
F:G	3.49[ab]	3.57[a]	3.53[a]	3.30[bc]	3.19[c]	0.074	0.46	0.001	0.34	0.65
G:F	0.286[b]	0.283[b]	0.285[b]	0.305[a]	0.313[a]	0.006	0.68	0.001	0.43	0.69
Gain, kg	48.59[b]	46.32[b]	48.30[b]	51.24[a]	52.53[a]	1.809	0.06	0.001	0.06	0.68

[abc]Means with different subscripts differ α = 0.05 using Duncan's means separation test.
[xyz]Means with different superscripts differ α = 0.10 using Duncan's means separation test.
[1]Contrast for the effect of lysine; treatment 1 vs. treatment 2 and 3.
[2]Contrast for the effect of RAC; treatments 4 and 5 vs. treatments 2 and 3.
[3]Contrast for the effect of supplemental zinc source; treatments 3 and 5 vs. treatments 2 and 4.
[4]Contrast for the interaction of zinc and RAC; treatments 2 and 5 vs. treatments 3 and 4.

Table 3. Effect of zinc source on carcass characteristics of finishing pigs harvested at Purdue University

Diets Treatments	1 Control +ZnO	2 Lys+ZnO	3 Lys+AZ	4 Lys+ZnO +RAC	5 Lys+AZ+ RAC	SE	Lysine[1]	RAC[2]	Zinc Source[3]	Zinc x RAC[4]
									Contrasts, P <	
Live weight, kg	129.98[b]	124.21[c]	129.24[b]	130.15[b]	134.14[a]	1.214	0.007	0.001	0.003	0.62
HCW, kg	97.67[bc]	94.79[c]	97.18[bc]	98.83[b]	101.99[a]	1.049	0.06	0.001	0.01	0.72
DP, %	75.69	76.39	75.10	75.90	76.03	0.417	0.23	0.61	0.17	0.09
LMA, cm^2	55.74[bc]	54.39[c]	55.99[bc]	59.35[ab]	60.71[a]	1.529	0.53	0.002	0.34	0.92
10th rib BF, cm	2.08	2.01	2.06	1.85	1.88	0.114	0.66	0.11	0.78	0.95
Percent lean[5]	55.44	55.64	55.70	57.24	57.06	0.721	0.84	0.04	0.93	0.88
Ham Data										
Primal weight, kg	12.35[bc]	12.11[c]	12.39[bc]	12.73[ab]	13.04[a]	0.183	0.37	0.001	0.12	0.96
Skin and fat, kg	2.41	2.34	2.54	2.30	2.28	0.086	0.53	0.10	0.32	0.20
Lean, kg	8.94[b]	8.82[b]	8.89[b]	9.45[a]	9.74[a]	0.086	0.62	0.001	0.31	0.54
Lean, %	72.36[bc]	72.75[abc]	71.71[c]	74.27[ab]	74.75[a]	0.714	0.70	0.002	0.70	0.29
Bone, %	7.75[a]	7.62[ab]	7.59[ab]	7.43[ab]	7.31[b]	0.135	0.52	0.08	0.58	0.75
Skin and fat, %	19.66[ab]	19.37[abc]	20.47[a]	18.06[bc]	17.17[c]	0.708	0.78	0.003	0.72	0.24

[a,b,c]Means with different subscripts differ $\alpha = 0.05$ using Duncan's means separation test.

[1]Contrast for the effect of lysine; treatment 1 vs. treatment 2 and 3.

[2]Contrast for the effect of RAC; treatments 4 and 5 vs. treatments 2 and 3.

[3]Contrast for the effect of supplemental zinc source; treatments 3 and 5 vs. treatments 2 and 4.

[4]Contrast for the interaction of zinc and RAC; treatments 2 and 5 vs. treatments 3 and 4.

[5]Percent lean containing 5% fat calculated according to the formula using $(7.231 + (.437*HCW, lb) - (18.746*10^{th}$ rib fat depth, in.$) + (3.877*LMA, in^2)) / HCW, lb.$

Table 4. Effect of supplemental zinc source and ractopamine on foot health in finishing pigs

Diets	1	2	3	4	5		Contrasts, P <			
Treatments	Control +ZnO	Lys+ZnO	Lys+AZ	Lys+ZnO+ RAC	Lys+AZ+ RAC	SE	Lysine[1]	RAC[2]	Zinc Source[3]	Zinc x RAC[4]
Feet score										
Overall score	0.97[b]	0.92[b]	0.91[b]	1.28[a]	1.24[a]	0.074	0.66	0.01	0.64	0.88
No. bruises	0.11[yz]	0.05[y]	0.05[y]	0.20[z]	0.20[z]	0.051	0.39	0.01	0.99	0.99
Severity	0.09[ab]	0.05[b]	0.05[b]	0.17[ab]	0.20[a]	0.047	0.49	0.01	0.74	0.74
No. horn cracks	0.53[ab]	0.50[ab]	0.38[b]	0.80[a]	0.63[ab]	0.103	0.83	0.01	0.15	0.82
Severity	0.51[ab]	0.48[ab]	0.38[b]	0.73[a]	0.61[ab]	0.103	0.83	0.02	0.28	0.91
No. ulcers	0.28[b]	0.31[b]	0.20[b]	0.72[a]	0.37[b]	0.099	0.83	0.01	0.02	0.23
Severity	0.23[b]	0.23[b]	0.25[b]	0.63[a]	0.39[ab]	0.088	0.95	0.01	0.24	0.15

[ab]Means with different superscripts differ α = 0.05 using Duncan's means separation test.
[yz]Means with different superscripts differ α = 0.10 using Duncan's means separation test.
[1]Contrast for the effect of lysine; treatment 1 vs. treatment 2 and 3.
[2]Contrast for the effect of RAC; treatments 4 and 5 vs. treatments 2 and 3.
[3]Contrast for the effect of supplemental zinc source; treatments 3 and 5 vs. treatments 2 and 4.
[4]Contrast for the interaction of zinc and RAC; treatments 2 and 5 vs. treatments 3 and 4.

Current Policy Issues Facing Agricultural Research and Animal Agriculture

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Summary

Washington has many issues, which must be addressed, but one common thread, which permeates them all, is the current budget process and its associated constraints. The current state of affairs in Washington is one of increased pressures and continuing political battles centering on the need for increased fiscal responsibility. These realities are no more obvious than in the agriculture sector and more specifically, the area of agricultural research. Also of importance are the ever present issues of antibiotic usage, animal care and biotechnology.

Agriculture Appropriations

The federal government is funded by the annual passage of thirteen appropriations bills, which provide the operating revenue for all federal agencies. These appropriations bills have seen increased stresses over the past several years, and the Agriculture Appropriations bill is perhaps no better example.

In analyzing the funds provided by Congress for those agencies directly related to agricultural research at the US Department of Agriculture (USDA), its helpful to have an understanding of previous funding and the current process. In past years, with few exceptions, funding for USDA agricultural research was centered on formula funds and congressionally directed spending (earmarks). While this process proved advantageous to certain universities and entities which were active in the lobbying realm, many envisioned a restructuring of the research function at USDA as a way to distribute the funds across a more level playing field which would lead to the betterment of research. Congress completed this reorganization, spurred by the end of earmarks, with the adoption of the 2008 Farm Bill. To this end, competitive grants, specifically though the National

Agriculture Research Initiative (NIFA) have grown, however, at not near the rate initially foreseen.

Upon the passage of the 2008 Farm Bill there was a perception among many that there was a new day dawning for agricultural research at USDA, and specifically at NIFA. The President requested a record $429 million for the program and many in the research community jumped to support the request. In the end the amount provided was far less, and for the first time there were questions regarding the viability of this new system. NIFA also went through some substantial changes during this period. For the first time those receiving funds began operating under the new request for Request for Application (RFA) process. This process has made many who were successful in the past feel they are no longer competitive. Congress, and more directly the Agriculture and Appropriations Committees, began complaining USDA was ignoring their direction in the establishment of priority areas, and a host of other issues arose. All these factors combined to raise questions for legislators on the possible continued success of the program. These concerns have been directly represented in the funding levels for the USDA research functions. As you look at the proposed funding levels for fiscal year 2013,

Table 1. USDA research funding in fiscal years 2012 and 2013

PROGRAM	FY 2012 FINAL	FY 2013 PRESIDENT	FY 2013 SENATE	FY 2013 HOUSE
ARS	$1,094,647,000	$1,102,565,000	$1,101,853,000	$1,073,499,000
NIFA-Hatch	$236,334,000	$234,834,000	$236,334,000	$231,607,000
NIFA-AFRI	$264,470,000	$325,000,000	$297,956,000	$276,515,000
NIFA-Smith Lever	$294,000,000	$292,411,000	$294,000,000	$286,062,000
NIFA-Integrated Activities	$21,482,000	$43,542,000	$24,982,000	$21,052,000

it becomes obvious these Congressional concerns continue.

In reviewing the numbers above, several points jump to the forefront. The first of these is the President's request for funding. Since his initial request in FY2010 for $429 million for AFRI, he has dropped his request signaling a more realistic amount in relation to current constraints. However, by requesting an increase, he still shows interest in expanding the program. What is not as obvious from the number is that while the requested increase of $60 million is substantial, animal agriculture is all but excluded from playing in the increase. The President specifically outlines where he would see the increase used, with half going to bioenergy development, and in the past animal agriculture has been specifically excluded from consideration under energy related RFAs. One other take away from the above numbers is the harsher constrains on funding in the House of Representatives as compared to the Senate. The House Agriculture Appropriations Committee received a substantially lower number for overall funding and it was reflected across all areas of the Agriculture Appropriations Bill. The Senate Agriculture Appropriations Committee specifically referenced the fact that significant cuts were made to research over the last couple of years and therefore left it largely untouched for FY2013.

2012 Farm Bill

2012 has also brought with it the consideration of a new Farm Bill. The Farm Bill passed in 2008 is expiring, and given the economic constraints facing the nation, it too has seen large cuts in the mandatory funding provided for agriculture and a refocusing of programs under research.

The main focus of the current Farm Bill consideration is the cost and how to cut substantial amounts from the USDA budget while still maintaining the support of the Department's many constituent groups. The divide between the House of Representatives and the Senate could not be greater on how to reach the cuts needed in the bill and still achieve passage. The Senate moved to consideration of the bill first and focused the vast majority of their cuts in traditional farm subsidy programs and the elimination of direct payments to commodity producers. By cutting a large amount from these programs, and to a lesser amount conservation programs, the Senate reached budget savings of over $27.4 billion over a ten years period. On the other hand, the House reached over $37 billion in savings by targeting the Supplemental Nutrition Assistance Program (SNAP) and traditional subsidies. This difference in priorities directly reflects the politics and views of the separate chamber of Congress. The Senate has passed the bill and the House is looking to consider the bill in the near future.

In the area of research, the Senate bill begins by reauthorizing the traditional major research programs such as AFRI and the formula funding accounts. It also provides mandatory funding for several programs. These programs include the Specialty Crop Research Initiative at $65 million annually until 2016 and at a level of $50 million/year thereafter. Also included in mandatory research funds is the Organic Research Initiative at $16 million annually, which may provide an opportunity for animal scientists to qualify. The last of these mandatory accounts to note is the Beginning Farmer and Rancher Initiative, which receives a one time infusion of $50 million. Perhaps the most controversial change in the bill relative to research

is the requirement by Congress for USDA research agencies to undergo a new budget submission process. This process would mandate the Department submit not only their annual budget for approval, but to outline more clearly the priorities, RFA timelines and research spending plans for upcoming years in order to receive funds. Congress sees this as a tool to prod USDA into more closely following the priorities as established by legislators in the Farm Bill and is opposed by the Department.

Also included in the Senate version of the Farm Bill is a new concept known as the Foundation for Food and Agriculture Research. The concept for this provision was advanced by an ad hoc coalition comprised of various groups in Washington, DC interested in agriculture research. The Foundation would be established as a non-governmental foundation similar to the National Institutes of Health Foundation or the Forest Service Foundation. The purpose is to find a new and different way to fund research though private investment. The Foundation would be seeded with a one-time investment of $100 million and require a minimum of a one to one match of private and Foundation funds for any award. The major concern expressed by the House Agriculture Committee, which chose not to include a similar provision, is the board of directors. A board of directors selected by the National Academies of Science (NAS) and "industry" would administer the foundation. The concerns arise because there is no clear definition of who or what would be considered "industry" for these purposes and if NAS is an appropriate entity to be included in the process.

Other issues of interest to animal agriculture

There are a number of issues, which present themselves on a regular basis in Washington relative to animal agriculture. These include issues related to animal care, antibiotics and biotechnology.

In the realm of animal care, few issues have been as divisive as the recent agreement between the Humane Society of the United States (HSUS) and the United Egg Producers (UEP). Last year the UEP and HSUS entered into an agreement on animal care to actively pursue legislation which would mandate certain production practices. These specific practices have been pursued for quite some time by HSUS, and have little scientific basis. While the UEP has been very supportive, all the other major animal agriculture groups have opposed any such legislation. The HSUS and UEP made a major effort to have this legislation included in the consideration of the Farm Bill to no avail. Given this failure, it is anticipated that the agreement will be off the table after Farm Bill consideration is complete.

The Preservation of Antibiotics for Medical Treatment Act (PAMTA) was once again introduced and is again being considering by Congress to restrict the "non-therapeutic" use of antibiotics in animals. The bill would phase out the "non-therapeutic" use of any kind of penicillin, tetracycline, macrolide, lincosamide, streptogramin, aminoglycoside, or sulfonamide; or any other drug or derivative of a drug that is used in humans or intended for use in humans to treat or prevent disease or infection caused by microorganisms. The bill targets the use of antibiotics for growth promotion, feed efficiency, weight gain, routine disease prevention, or other routine purposes. This is a highly controversial issue, specifically opposed by all major animal agriculture groups in Washington. With the close proximity to elections in November, it is highly unlikely any movement on controversial legislation will occur. In June of 2010, the FDA today rolled out proposed guidance on "The Judicious Use of Medically Important Antimicrobial Drugs in Food-Producing Animals". The FDA guidance and the PAMTA legislation take differing views on the use of antibiotics for disease prevention. The FDA guidance shares the view that there is specific value in the use of antibiotics for both prevention and treatment, while PAMTA would not allow use unless the animal is sick. However, under both scenarios, the use of antibiotics as a growth promoter is phased out over time. While consumer advocacy groups supported the guidance from FDA, its actions were viewed as a start and not a final product. The animal agriculture groups were much less enthusiast about the FDA guidance. These groups faulted FDA with not using sound science in their development of guidelines.

Congress and the Administration continue to discuss and debate the issues surrounding biotechnology. Recently, issues have arisen related to the Food and Drug Administration's approval process for new genetically modified organisms. Ironically, recent controversy has not revolved around the validity of the use of biotechnology, but trade protectionism parading as science. For example, several amendments have been offered on agriculture

appropriations bills specifically preventing funding for the approval of genetically modified salmon. Elected officials who offered these amendments cited scientific concerns and issues with the approval process. However, the real issue was competition. These officials were from the state of Alaska, the top supplier of wild-caught salmon in the U.S. They saw an attack on the science as an avenue to protect their local constituents. Thankfully, none of these amendments have been included in any legislation at this point.

Conclusion

While issues vary greatly which have impacts on animal agriculture, many are, and will continue to be, a direct result of the current budgetary constraints placed upon government. These will likely continue for the foreseeable future.

Constant issues which play a role in the realm of animal agriculture will be continue to be debated in the future, but due to their controversial nature, and the current political landscape, resolution and large shifts in policy are unlikely.

Dietary Effects on Pig Immunity

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Summary

The swine industry now has a rich supply of dietary technologies available to potentially improve pig health and performance by modulating inflammation. Among the several products for which available data are encouraging are mannan oligosaccharide, fat, plant extracts, and spray-dried plasma. Salient issues on these products are briefly reviewed.

Introduction

Swine products occupy an important position in the structure of human food consumption. The need to continue to increase food production with the earth's limited resources places the onus squarely on the swine industry to increase both efficiency and production. Nutrition, genetics, and management have been largely applied to improve efficiency of swine production. Protecting the health of animals and increasing the disease resistance of animals is also critical to production efficiency.

The pig's immune system is vital, as its proper functioning protects the pig from disease and death. When the immune system is stimulated, it triggers a cascade of protective mechanisms including production of acute-phase proteins in the liver and pro-inflammatory cytokines in many tissues, activation of protective immune cells, fever, inhibition of appetite, and eventually production of protective antibodies. The immediate response is called inflammation and contributes to the animal's ability to fight off infection. Unfortunately, these mechanisms also reduce growth. The inhibition of appetite reduces feed intake, limiting the pig's nutrient supply and therefore its growth. Production of acute-phase proteins, cytokines and immune cells takes amino acids and energy that are then not available to support growth.

The ideal situation when a disease challenge arises would be a vigorous immune response, but then a prompt reversion to normal growth as soon as the danger has passed. Unfortunately, the inflammation often continues for a prolonged period. Livestock immunologists now believe that reducing inflammation would improve growth performance of pigs amid the challenges of commercial pig production. We and others have shown that several feed ingredients or additives can do just that, as shown below.

Research in this area has been facilitated by use of the endotoxin lipopolysaccharide (LPS), a component of some bacteria, which causes a strong inflammatory response.

Mannan Oligosaccharide

Products described as mannan oligosaccharides (MOS) contain mannose and glucan components, being derived from the outer layer of the cell wall of yeast. The mannose is the key to at least one perceived mechanism of action of this product.

Miguel et al. (2004) analyzed the known available data using a meta-analysis to determine whether a MOS product improved the growth performance of nursery pigs. The results showed better performance of pigs fed MOS than of the controls. The response was larger where pigs grew more slowly. The addition of MOS was most effective immediately after weaning, but a smaller response may persist for several weeks.

MOS may contribute to improved growth performance through modifying immune responses. MOS enhanced the phagocytic activity of lamina propria macrophages isolated from nursery pigs

(Davis et al., 2004). Feeding MOS to animals also increased the immunoglobulin concentrations in serum and colostrum (Shashidhara and Devegowda, 2003; Spearman, 2004). An *in vitro* study from our lab has suggested that MOS may have direct effects on immune cells collected from pig lungs. Adding MOS to the cells in culture caused them to produce more of the pro-inflammatory cytokine TNF-α (Che et al., 2012a). However, when cells were stimulated by LPS to produce a high level of TNF-α, adding MOS reduced the production of this cytokine. This pattern of response suggests that MOS may provide protection by stimulating the immune system, but may also protect against costly excessive inflammation. Several types of data support this desirable pattern of response. For example *in vivo* studies (Che et al., 2011, 2012b) have indicated that MOS can increase leukocyte populations and antibody titers, reduce the serum concentrations of pro-inflammatory cytokines, and increase anti-inflammatory cytokines in pigs infected by a porcine respiratory and reproductive syndrome virus (PRRSV). The overall clinical effect of MOS was to ameliorate the fever caused by PRRSV infection (Figure 1, Che et al., 2011). Gene expression data also support the pattern.

Fat

Dietary fatty acids are of particular interest, since they are incorporated into the membranes of all body cells including those of the immune system. Dietary fat is an important energy source for pigs and it may also affect the immune response depending on the fat source and the specific pattern of n-6 and n-3 fatty acids incorporated into lymphatic tissue (Switzer et al., 2004). Conjugated linoleic acids (CLA) are a special class of polyunsaturated fatty acids (PUFA), which potentially regulate the immune response of pigs.

PUFA have been used as diet supplements influencing growth performance mainly through affecting health, immune function and prevention of diseases. Two groups of PUFA are distinguished: n-3 PUFA and n-6 PUFA (Calder, 1998). The n-3 PUFA are noted for anti-inflammatory and anti-proliferative effects on the cells of the immune system, while n-6 PUFA, via the arachidonic acid effect, are inflammatory and activate the immune system (Révajová et al., 2001).

CLA are a group of geometric and positional isomers of linoleic acid (C18:2), an n-6 PUFA. Pigs fed diets supplemented with CLA have greater gain:feed ratio and leaner carcasses than pigs not fed CLA (Dugan et al., 1997). This improvement might be attributed to CLA's modulation of the immune system of weaning pigs by altering the type and number of immunocytes (Corino et al., 2002). Dietary CLA have been shown to prevent immune-induced growth suppression following endotoxin injection in chicks and rats (Cook et al., 1993). CLA may have an effect on energy partitioning within the body. When challenged by infection, CLA may increase the energy available to the immune system. CLA have been found to limit or nullify the effects of immune stimulation on growth performance (MacDonald, 2000). After severe trauma, the body diverts energy away from immediately non-essential systems, such as the immune system, towards tissue repair. Diets enriched with CLA have been shown to bolster the immune system during such period of trauma (Pariza et al., 1999). Moreover, Yu et al. (2002) have shown that CLA exhibit anti-inflammatory effects by negatively regulating the expression of certain pro-inflammatory genes. .

Plant Extracts

Plant extracts (PE) are responsible for the odor and color of plants, and are composed of more than a hundred individual components. Plant extracts are secondary plant metabolites and can be obtained naturally from parts of plant materials, or synthesized directly. Most of the PE in oil form are commonly called essential oils, which are mixed oil compounds with variable chemical compositions and concentrations of individual compounds depending on the plants and extraction methods (Lee et al., 2004).

The supplementation of PE to the diet has resulted in variable growth responses of newly-weaned pigs (Sads and Bilkei, 2003; Manzanilla et al., 2004; Simonson, 2004; Neill et al., 2006). But in the grower-finisher period, the application of different levels and different sources of PE show some benefits on growth performance (Cullen et al., 2005, Janz et al., 2007).

Numerous studies have shown the anti-inflammatory properties of PE, mainly through suppressing the pro-inflammatory cytokine production of macrophages, such as TNF-α, IL-1β,

and nitric oxide *in vitro* (Hart et al., 2000; Lang et al., 2004; Lee et al., 2007). The in vitro studies from our lab (Liu et al., 2012) have also indicated that all of 7 PE tested had anti-inflammatory effects, reducing the secretion of pro-inflammatory cytokines from LPS-stimulated porcine alveolar macrophages. Moreover, two *in vivo* disease challenge studies from our lab have suggested that feeding PE also showed anti-inflammatory effects. The first study reported that the supplementation of PE to young pigs reduced diarrhea whether or not they were challenged with *E. coli* (Figure 2). The PE also reduced inflammation caused by the *E. coli* challenge, as indicated by reductions of white blood cell number, serum pro-inflammatory cytokines, and serum acute phase proteins (Liu et al., 2011c,d). The PE partially counteracted the effects of *E. coli* infection on gene expression. The second study showed that feeding PE to nursery pigs enhanced the pigs' immune responses to a PRRSV challenge and may help alleviate negative impacts of infection, as indicated by reduced viral load (Figure 3), serum pro-inflammatory cytokine and serum acute phase proteins, and improved feed efficiency (Liu et al., 2011a,b).

Spray-Dried Plasma

Spray-dried plasma (SDP) is a complex mixture of many physiological components including immunoglobulins, glycoproteins, albumin, growth factors, peptides, and other physiologically active components (Moreto and Perez-Bosque, 2009). SDP has been commercially used in the swine industry to improve growth rate, feed intake, and feed efficiency and to reduce mortality and morbidity of early-weaned pigs (Coffey and Cromwell, 2001; Pettigrew, 2006; Pettigrew et al., 2006). As three previous review papers showed, SDP improves the growth rate of weaned pigs by increasing feed intake through immune-competence or high palatability, about 25% (Coffey and Cromwell, 2001), 27% (van Dijk et al., 2001), and 23% (Pettigrew, 2006), compared with control diets. In addition, these benefits are more pronounced in a conventional or non-sanitary environment (Coffey and Cromwell, 1995; Zhao et al., 2007).

Several studies demonstrate the beneficial effects of SDP in various disease challenge models (Van Dijk et al., 2002; Bosi et al., 2004). The mechanism by which SDP exerts its benefits appears to center upon its ability to modulate intestinal immune function and enhance mucosal barrier function (Perez-Bosque et al., 2004, 2008, 2010; Peace et al., 2011). For example, Perez-Bosque et al. (2010) and Peace et al. (2011) reported that feeding SDP down-regulated the expression levels of pro-inflammatory cytokines in the intestinal mucosa and increased the expression of anti-inflammatory cytokines. Recent studies in our lab evaluated the potential role of SDP in improving reproductive performance of sows by clarifying its impact on inflammatory damage to reproductive performance by using pregnant mice as a model for sows. The results showed that feeding SDP markedly attenuated the pregnancy failure of mated female mice caused by transport stress, apparently by alleviating the inflammatory response (Song et al., 2011a). Moreover, SDP attenuated acute inflammation of pregnant mice caused by LPS, as indicated by reducing the concentration of TNF-α and IFN-γ in uterus and placenta (Song et al., 2011b,c).

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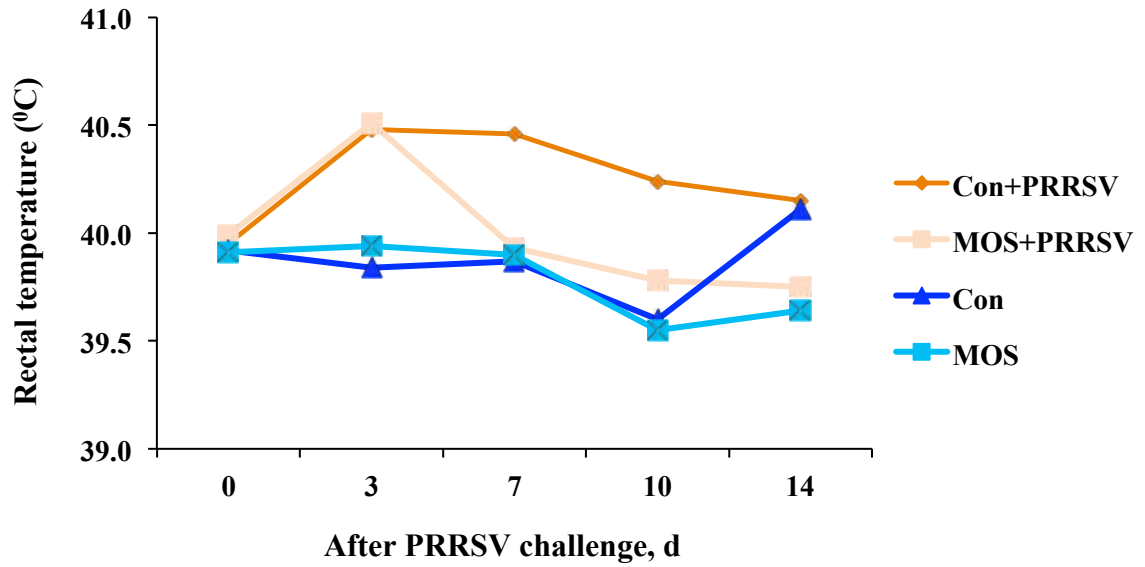
Figure 1. MOS ameliorated fever caused by PRRSV infection. Con: Control diet; PRRSV: challenged with porcine reproductive and respiratory syndrome virus; MOS: diet supplemented with mannan oligosaccharide
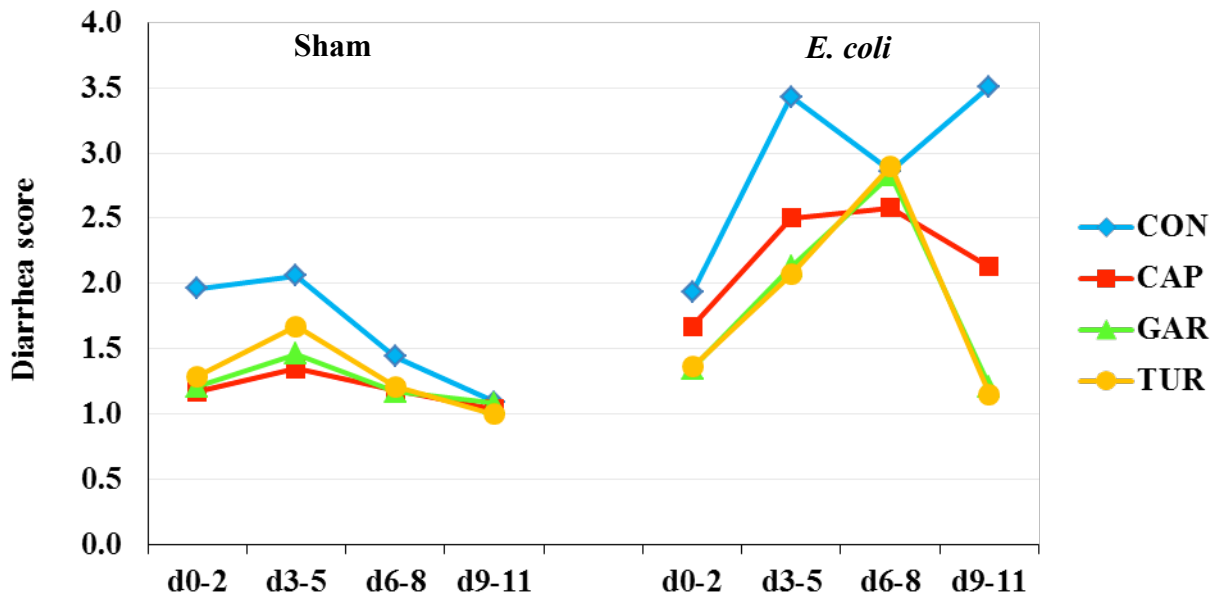

Figure 2. Plant extracts reduced diarrhea score of pigs. Sham: no infection; *E. coli*: infected with pathogenic *E. coli*; CON: control; CAP: capsicum oleoresin; GAR: garlicon; TUR: turmeric oleoresin.
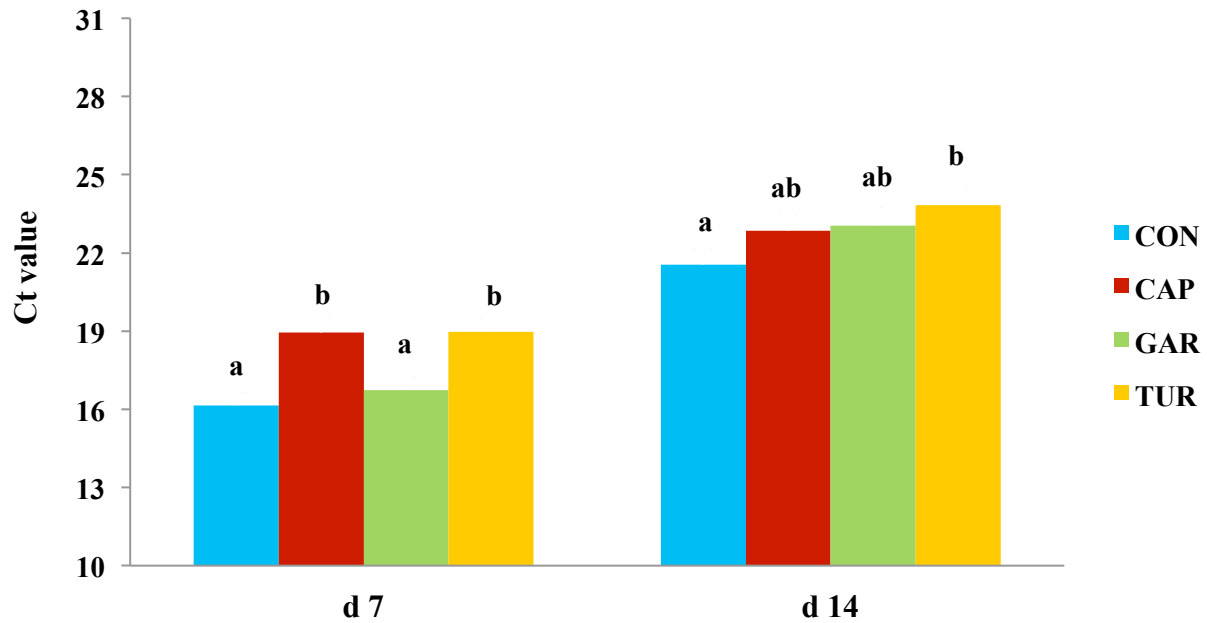
Figure 3. Plant extracts reduced serum viral load of PRRSV-infected pigs. Ct values are inverse to viral concentration. CON: control; CAP: capsicum oleoresin; GAR: garlicon; TUR: turmeric oleoresin. [a, b] means without a common superscript differ ($P < 0.05$) within the PRRSV challenge group.

Vitamin D Status of Pigs from Birth to Weaning as Affected by Gavage or Injection

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Summary

   Vitamin D is an important nutrient for pigs, necessarily required to maintain bone formation and development in association with calcium and phosphorus. However, pigs in confinement housing are born with low serum vitamin D concentrations, which may result in vitamin D deficiency and related problems. Some of the nursery death loss in routine production the past 2 years has responded to oral vitamin D supplementation leading to the postulate that modern production practices result in vitamin D-deficient pigs at weaning. Therefore, to enhance vitamin D status of pigs during lactation could potentially prevent some nursery problems related to vitamin D status of the pigs. Two experiments were conducted to investigate the effect of vitamin D administration to newborn pigs by oral gavage or intramuscular injection with different products. In both experiments, administration of vitamin D by oral gavage or intramuscular injection increased serum 25-hydroxycholecalciferol (25-OH D$_3$) concentrations (P < 0.01). Additionally, the injectable administration resulted in higher numerical serum values than oral administration in both studies. Significant differences in growth performance of nursing pigs were not observed with the various vitamin administrations. In conclusion, this study clearly demonstrated that vitamin D$_3$ supplementation to newborn pigs can increase serum 25-OH D$_3$ concentration regardless of administration routes.

The Impetus for the Current Concern about Vitamin D Status

   Vitamin D, the "sunshine vitamin", is one of the fat soluble vitamins. It is considered a steroid hormone, which plays important roles in bone strength and structure, immune regulation, and hormonal responses in the animal body. In its involvement in growth and bone development, not only is it related to calcium and phosphorous metabolism but also regulation of their absorption and homeostasis.

   Vitamin D has not been a major issue in the swine industry in recent decades but in the past few years attention on vitamin D and its status of pigs in the farm has risen with the increasing occurrence of metabolic bone diseases in some production settings.

The vitamin D status of pigs is clearly affected by access to sunshine (Table 1) and it is postulated that modern confinement production systems in which pigs do not have access to sunshine may be predisposing pigs to vitamin D deficiency. The main symptoms of vitamin D deficiency are metabolic bone diseases such as rickets, osteomalacia, and osteoporosis which are related to failure in bone mineralization and/or loss of bone mineral in pigs of various ages. Recently, low levels of serum vitamin D have been identified in peri-weaning failure to thrive syndrome (PFTS), noted by veterinarians and researchers since 2008 (Huang et al., 2011). Therefore, means to prevent pigs from metabolic bone diseases, prevent mortality, and maintain normal growth and bone development of pigs are of interest.

Vitamin D for Pigs

NRC (1998) has provided the vitamin D requirement estimates for pigs with the amount of vitamin D_3 for each growth phase or reproductive cycle. The vitamin D requirements ranged from 220 IU and 200 IU/kg diet for nursing and weaning pigs to 150 IU/kg diet for growing-finishing pigs. For all breeding pigs including gestating and lactating sows as well as boars, the requirement estimate was 200 IU/kg diet. In the recently released NRC (2012) the requirement estimate for gestating and lactating sows was raised to 800 IU/kg diet.

Historically, the major symptom of vitamin D deficiency in young and growing pigs has been rickets (a failure in adequate bone mineralization which results in bowed legs and, at times, spinal deviances) and in adult pigs has been osteomalacia (a demineralization of formed bone which can eventually lead to bone fractures).

When pigs are supplied with vitamin D in excess of requirement through either long- or short-term feeding, toxic symptoms of vitamin D are observed such as reduced feed intake, growth rate, and liver weight as well as hypercalcemia and soft tissue calcification in heart, kidney and lung (NRC, 1987; NRC, 1998). Toxicity of vitamin D_3 is higher than that of vitamin D_2 (NRC, 1987). According to the NRC (1987), the maximum safe level is 33,000 IU/kg diet for an exposure duration of less than 60 days, but 2,200 IU/kg diet is the maximum tolerable level for over 60 days of exposure. However, vitamin D toxicity occurs rarely in pigs.

Effects of Vitamin D Supplementation to Pigs

Weaning, and growing-finishing pigs

Studies have been conducted to observe the effects of vitamin D (25-OH D_3, vitamin D_3, and vitamin D_2) supplementation in swine diets in association with calcium and phosphorus (Combs et al., 1966; Foley et al., 1990; Li et al., 1998; O'Doherty et al., 2010). Based on these results, vitamin D supplementation to pig diets did not affect the growth performance but had partially positive influences on calcium digestibility.

Sows and offspring

Abbott and Madson (2012) suggested a vitamin D reference range for pigs and they also provided actual serum vitamin D (25-OH D_3) values of pigs in several settings. Lower serum vitamin D concentrations were observed in pigs raised indoors compared to the reference range but not in pigs housed outdoors (Table 1). The impact of ultraviolet exposure in the outdoor housing environment pigs on serum values compared to that of pigs raised indoors was marked.

Piglets have the lowest level of serum vitamin D at birth (Horst and Littledike, 1982). Nursing pigs in outdoor settings can acquire vitamin D via two sources - one synthesized by sunlight and the other from sow's milk, whereas pigs in confinement housing can acquire vitamin D through only sow's milk. However, sow's milk contains little vitamin D and placental transport of vitamin D is poor. Nonetheless, because fetal and nursing pigs are provided vitamin D via placental transfer and sow's milk, the maternal vitamin D status is extremely important to supply adequate amount of vitamin D for piglets. Goff et al. (1984) therefore suggested that the parenteral vitamin D_3 treatment before parturition by intramuscular injection of vitamin D_3 to sows at 20 days pre-partum was an effective method for enhancing vitamin D status of piglets because the vitamin D status of sows is closely correlated to that of fetus and neonatal piglets.

Several recent studies have been conducted to investigate vitamin D supplementation/administration to sows and piglets (Lauridsen et al., 2010; Witschi et al., 2011; Flohr et al., 2012; Rortvedt et al., 2012). The supplementation of vitamin D to gestation and lactation diets was demonstrated to improve serum vitamin D concentration of sows (Lauridsen et al., 2010). Similarly, Witschi et al. (2011) reported that piglets from sows that received 25-OH D_3 had higher serum 25-OH D_3 concentration at d 21, d 33, and d 77 postpartum. Regarding vitamin D supplementation of piglets, when the newborn piglets were supplemented with vitamin D via oral administration at 40,000 and 80,000 IU of vitamin D_3, linear increases of serum 25-OH D_3 concentration were detected on d 10 and 20 of age but there were no significant differences on growth performance or bone measures (Flohr et al., 2012). Similar results were reported by Rortvedt et al. (2012) wherein pigs orally administrated vitamin D_3 at 40,000 IU had higher serum 25-OH D_3 concentrations than those without vitamin D_3 administration but growth performance and bone mineralization were not affected. Based

on these results, vitamin D status of piglets can be improved via several efficient methods such as oral administration to piglets, supplementation to maternal feed and injection to sows. However, the relationship of that improved serum status to performance or bone measures is not always present.

The objective of the current research effort was to evaluate the effects of administration routes and a variety of supplemental products administered to young pigs.

Materials and Methods

Experiment 1: A total of 32 pigs (Yorkshire × Duroc) were used from 4 litters of pigs (8 pigs/sow). Within each litter, 2 pigs were assigned to 4 treatments. Treatments were: 1) control: no supplemental vitamin D_3, 2) oral administration of 0.8 ml of a vitamin complex (EMCELLE NEWBORN EAD containing 400 IU of vitamin E, 50,000 IU of vitamin A, and 50,000 IU of vitamin D_3 per ml), 3) oral administration of 1.0 ml of a vitamin D product (WEAN-D containing 40,000 IU of vitamin D_3 per ml), and 4) intramuscular injection of 0.8 ml vitamin complex (VITAL E-NEWBORN containing 500 IU of vitamin E, 50,000 IU of vitamin A, and 50,000 IU of vitamin D_3 per ml). All pigs in Treatments 2 - 4 were administered 40,000 IU of vitamin D_3. The commercial products used were from Stuart Products Inc. (Bedford TX; the EMCELLE NEWBORN EAD and VITAL E-NEWBORN) and from GlycoMyr Inc. (Ames IA; the WEAN-D).

Experiment 2: A total of 45 pigs (Yorkshire × Duroc) were used from 4 litters of pigs. Within each litter, pigs were assigned to 7 treatments; following the initial assignment of pigs, remaining pigs in each litter were allotted to Treatments 1 and 2. Treatments were: 1) control: no supplemental vitamin D_3, 2) intramuscular injection of 1.0 ml vitamin complex (VITAL E-NEWBORN containing 500 IU of vitamin E, 50,000 IU of vitamin A, and 50,000 IU of vitamin D_3 per ml) 3) oral administration of 1.25 ml vitamin D (WEAN-D containing 40,000 IU of vitamin D_3 per ml), 4) oral administration of 0.60 ml of vitamin D_3 (EMCELLE D3 containing 84,500 IU of vitamin D_3), 5) oral administration of 1.66 ml vitamin D and E complex (EMCELLE ED3 containing 30,000 IU of vitamin D_3 and 500 IU of vitamin E), 6) oral administration of 1.66 ml vitamin E (EMCELLE E containing 500 IU of vitamin E), 7) oral administration of 1.00 ml

vitamin complex (EMCELLE NEWBORN E-A-D containing 500 IU of vitamin E, 50,000 IU of vitamin A, and 50,000 IU of vitamin D_3 per ml,). All pigs receiving supplemental vitamin D received about 50,000 IU of vitamin D_3. The products used were from Stuart Products Inc. (Bedford TX; the VITAL E-NEWBORN, EMCELLE D3, EMCELLE ED3, EMCELLE E, and EMCELLE NEWBORN EAD) and from GlycoMyr Inc. (Ames IA; the WEAN-D).

In both experiments, the gestation and lactation diets contained the following per kg diet: vitamin A, 6,600 IU; vitamin D_3, 880 IU; vitamin E, 44 IU; vitamin K (mendadione sodium bisulfite complex), 6.6 mg; riboflavin, 8.8 mg; d-pantothenic acid, 22 mg; niacin, 44 mg; vitamin B_6, 4.4 mg; vitamin B_{12}, 33 ug; d-biotin, 220 ug; and folic acid, 1,320 ug. All sows with pigs were kept in individual farrowing crates in an environmentally controlled farrowing facility without windows. Sows were provided 1.8 – 2.5 kg of the gestation diet before being brought to the farrowing rooms at about d 112 of gestation. Sows were provided the lactation diet *ad libitum* and water was freely available from water nipple throughout the experimental period. All pigs were processed at birth (within 15 hr) and assigned to a treatment. Processing of the piglets involved weighing, ear-notching, needle teeth clipping, and iron injection with 100 mg Fe as Fe dextran. With regard to administration of treatments, pigs were administered vitamin D by either injection or oral gavage. Injectable products were provided to each pig in the neck muscle on the opposite side of where the iron injection was given. Orally administered treatments were provided through a plastic tube attached to a 3 mL syringe into which the proper dosage had been drawn. The body weights of the pigs were also recorded about d 10, at weaning and 14 d postweaning to calculate growth performance. In addition, the body weights of sows were obtained at farrowing and weaning to determine weight change of sows during lactation.

Blood samples of sows were taken from the anterior vena cava at farrowing and weaning. Blood samples of pigs were collected from the anterior vena cava at d 0 (before administration of any treatments), about d 10 postadministration of treatments, and weaning. Blood samples were centrifuged for 15 minutes at 4 C; serum samples were then aliquoted into microtubes and stored at -20 C until analysis. Serum samples were sent to the Iowa State University Veterinary Diagnostic Laboratory for vitamin assay.

Results and Discussion

The effect of vitamin D_3 supplementation to newborn pigs in Experiment 1 on serum retinol, 25-OH D_3, and α-tocopherol concentrations is shown in Table 2. At d 10 after administration, all groups treated with a vitamin D_3 product had higher serum 25-OH D_3 concentration than the control group ($P < 0.01$). Additionally, when the pigs received the injectable product, serum 25-OH D_3 concentration was the highest among treatments ($P < 0.01$).

At weaning, serum values for all treatments had declined from d 10 but serum values for two of the three treatments remained elevated relative to serum values for the control pigs. The decline in all values from d 10 to weaning demonstrates that sow milk is not a good source of vitamin D and serum values are presumably diluted with the increase in blood volume associated with the rapid growth of the pigs. It should be noted that serum values for control pigs were higher at d 10 than at birth which suggests that the colostral contribution to the pig is significant. With regard to serum retinol and α-tocopherol concentrations, there were no significant differences except at d 10 when serum α-tocopherol concentrations of pigs in the injection group was the highest among all treatments ($P < 0.01$).

In Experiment 2 (Table 3), the effect of vitamin D and variable vitamin A and E administration to newborn pigs on serum 25-OH D_3 concentrations demonstrated again that the d 10 serum concentrations can be increased by either oral or injectable administration, that values decline from d 10 to weaning regardless of treatment, and that values at weaning can remain higher than those of control pigs in which no treatment is administered.

As would be expected, the injectable product resulted in the highest serum values but the results were not significantly higher than several of the oral administration treatments. These results, collectively, demonstrate that the vitamin D_3 status of pigs can be improved by administration of vitamin D_3 by a variety of methods. And the results agree with those of recent studies (Flohr et al., 2012; Rortvedt et al., 2012).

The effects of the treatments on body weight and growth in these experiments is provided in Tables 4 and 5. No significant differences among treatments were detected on body weight and average daily gain of pigs during suckling and weaning periods in either experiment which is undoubtedly a function of the limited number of observations in each experiment. However, these results again agree with some recent research (Flohr et al., 2012). In contrast, Rortvedt et al. (2012) reported a slight improvement of ADG in pigs administered a single oral mega-dose of vitamin D_3 at birth.

Conclusion

This study clearly demonstrated that vitamin D_3 supplementation to newborn pigs can improve vitamin D status by increasing serum 25-OH D_3 concentration regardless of administration routes. Further studies are needed to determine if this altered status has value in different production settings.

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Table 1. Reference range of serum vitamin D concentration (ng/mL) of pigs

Phase of production	Reference range	Jan Inside	June Inside	Outdoor
Newborn	5-15	-	-	-
10 day old pig	8-23	-	-	-
3-4 weeks old	25-30	8.42	13.75	58.54
Grower	30-35	21.80	18.04	61.03
Finisher	30-35	27.66	28.18	85.98
Mature animals	35-70	35.70	45.42	-
Pregnant sows	35-100	-	-	-

Source: Abbott and Madson, 2012.

Table 2. Effect of vitamin D administration to pigs on serum 25-OH D_3, retinol, and α-tocopherol concentration (Exp. 1)

		Treatments[1]					P-value
Criteria	Sow	Control	Oral vit. ADE	Oral vit. D	Inj. vit. ADE	SEM[2]	Trt
25-OH D_3, ng/ml							
Birth	21.23	2.60	2.65	2.51	2.67	0.11	0.741
d 10		9.24[d]	37.71[c]	60.56[b]	81.86[a]	4.81	<0.0001
Weaning	31.60	5.97[b]	9.99[b]	22.47[a]	30.72[a]	3.57	0.0004
Retinol, ng/ml							
Birth		0.16	0.14	0.12	0.13	0.01	0.081
d 10		0.37	0.27	0.32	0.37	0.05	0.470
Weaning		0.35	0.19	0.24	0.20	0.05	0.186
α-tocopherol, ng/ml							
Birth		2.25	1.83	2.23	1.83	0.32	0.662
d 10		6.85[b]	3.76[b]	7.10[b]	15.20[a]	1.66	0.007
Weaning		3.93	3.74	4.55	5.93	0.82	0.288

[1] See text for more complete description of treatments.
[2] Standard error of mean.
[a-d] Means without a common superscript differ (P<0.01).

Table 3. Effect of vitamin D administration to pigs on serum 25-OH D_3 concentration (Exp. 2)

			Treatment[1]						
Criteria	Sow	Control	Inj. AD_3E	Oral D_3(1)	Oral D_3(2)	Oral D_3E	Oral E	Oral AD_3E	SEM[2]
25-OH D_3, ng/ml									
Birth	26.45	4.41	4.47	4.33	4.38	5.45	5.10	4.40	0.80
d 10		8.25[b]	110.74[a]	91.43[a]	86.20[a]	84.68[a]	6.47[b]	77.17[a]	16.21
Weaning	32.65	5.02[c]	40.24[a]	34.50[ab]	30.88[ab]	27.30[ab]	5.10[c]	26.10[b]	5.02

[1] See text for more complete description of treatments.
[2] Standard error of mean.
[a, b, c] Means without a common superscript differ (P<0.05).

Table 4. Effect of vitamin D_3 administration to pigs on growth performance (Exp. 1)

| Criteria | Sow | Treatments[1] | | | | SEM[2] | P-value |
		Control	Oral vit. ADE	Oral vit. D	Inj. vit. ADE		Trt
BW, kg							
Birth	231.03	1.71	1.47	1.60	1.61	0.19	0.317
d10		4.16	4.02	3.82	4.00	0.47	0.560
Weaning	242.02	6.26	6.15	5.67	5.98	0.75	0.513
14 d post-weaning		11.13	10.61	10.12	10.33	1.04	0.321
ADG, kg							
Birth to d10		0.21	0.22	0.19	0.20	0.03	0.608
d10 to weaning		0.27	0.28	0.24	0.26	0.04	0.780
Birth to weaning		0.23	0.24	0.21	0.22	0.04	0.540
14 d in nursery		0.35	0.32	0.32	0.31	0.04	0.355

[1] See text for more complete description of treatments.
[2] Standard error of mean.

Table 5. Effect of vitamin D_3 administration to pigs on growth performance (Exp. 2)

| Criteria | Sow | Treatment[1] | | | | | | | SEM[2] |
		Control	Inj. AD₃E	Oral D₃(1)	Oral D₃(2)	Oral D₃E	Oral E	Oral AD₃E	
Body weight, kg									
Initial	229.5	1.56	1.55	1.52	1.58	1.60	1.83	1.51	0.169
d 10		3.51	3.27	3.78	3.87	3.05	4.37	3.84	0.453
Weaning	248.2	5.53	5.12	5.99	6.44	4.12	6.90	5.84	0.728
ADG, kg									
Birth to d 10		0.17	0.16	0.21	0.21	0.14	0.24	0.19	0.030
d 10 to weaning		0.25	0.23	0.26	0.31	0.14	0.28	0.25	0.041
Birth to weaning		0.20	0.19	0.23	0.25	0.14	0.26	0.21	0.033

[1] See text for more complete description of treatments.
[2] Standard error of mean.

NRC (2012) Modeling Approach to Estimate Nutrient Requirements of Swine

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Summary

During the summer of 2012, the 11th revised edition of "Nutrient Requirements of Swine" from the National Research Council (NRC, 2012) was released. For this publication dynamic and biology based mathematical models were developed to represent the partitioning of energy intake and to estimate amino acid, phosphorus and calcium requirements of growing-finishing pigs, lactating sows and gestating sows; requirements can be related to varying levels of animal performance in a relatively disease and stress free environment. All model calculations are described in detail in the publication. Energy intake - which can be defined on a digestible, metabolizable or net energy basis – is a model input or is predicted in a rather empirical manner from effective environmental temperature and either body weight and gender (growing-finishing pigs) or parity (sows). Partitioning of energy intake is based on maintenance energy requirements, energy retention in products of conception (in gestating sows), energy output in milk (estimated from litter growth rate; in lactating sows) and changes in body protein and body lipid mass. Body weight changes are predicted from changes in body protein and lipid mass and can be compared to observed values. Amino acid, calcium and phosphorus requirements are estimated based on partitioning of energy intake. Amino acid requirements can be expressed as standardized ileal digestible, apparent ileal digestible, or total dietary levels; the latter being applicable to corn and soybean meal-based diets only. In a similar manner, phosphorus requirements can be expressed as standardized total tract digestible, apparent total tract digestible, or total dietary levels. Calcium requirement are expressed as total dietary levels. Nutrient requirements can be explored on individual days or across days and body weight ranges, for the development of phase feeding programs for growing-finishing pigs and sows. The model includes a data base of feed ingredients and a simple feed formulation system, which allows for comparison of estimated nutrient requirements with nutrient levels in formulated diets. The models highlight the need to consider animal performance levels and energy intake when estimating nutrient requirements for specific groups of pigs.

Introduction

As in NRC (1998), mathematical models are used in NRC (2012) to estimate nutrient requirements of growing-finishing pigs, lactating sows and gestating sows. Models are used to represent the partitioning of energy intake and to then estimate amino acid, phosphorus and calcium requirements of swine in a relatively disease and stress-free environment. During development of these models ease of use, transparency and simplicity were balanced with predictive accuracy and practical relevance. All model calculations are described in detail in NRC (2012). Extreme care has been taken to ensure consistency between model generated estimates of nutrient requirements and results from conventional nutrient requirement studies. The models can be used to explore the impact of animal performance levels on nutrient requirements at the various stages of production.

In this short review, key aspects of the NRC (2012) models to estimate nutrient requirements of various categories of swine are presented.

General Description of the Models

The three NRC (2012) models to estimate nutrient requirements of growing-finishing pigs, gestating sows and lactating sows are dynamic, mechanistic and deterministic.

The models are dynamic because changes in energy utilization and nutrient requirements are represented on a daily basis. This is in contrast to the NRC (1998) sow models in which only mean values across entire gestation or lactation periods were considered. As a result, daily changes in nutrient requirements can be assessed for the development of phase feeding programs for specific groups of pigs, especially growing-finishing pigs and gestating sows. For estimating nutrient requirements across days or body weight ranges, means of daily requirements are calculated.

The models can be considered mechanistic because the underlying biological functions that contribute to nutrient requirements are represented, largely in terms of protein and lipid deposition in the various pools. These aspects are described in more detail in the next section.

The models are deterministic because estimated nutrient requirements represent mean requirements for groups of animals without explicitly representing between-animal variability. However, between-animal variability is considered implicitly in the models by adjusting estimates of post-absorptive efficiencies of nutrient utilization, which is discussed later in further detail; these efficiencies are lower for groups of animals than in individual animals (e.g., Pomar et al., 2003). However, differences across groups in between-animal variability are not considered in NRC (2012).

The models are used to represent the partitioning of energy intake - which can be defined on a digestible energy (DE), metabolizable energy (ME) or net energy (NE) basis – and to then estimate standardized ileal digestible (SID) amino acid, standardized total tract digestible (STTD) phosphorus and total calcium requirements. In the models, estimates of apparent ileal digestible (AID) amino acid and apparent total tract digestible (ATTD) phosphorus requirements are derived from SID amino acid and STTD phosphorus requirements,

respectively. For corn and soybean meal-based diets, estimates of total dietary amino acid and phosphorus requirements are generated as well. Nutrient requirements of pigs below 20 kg body weight and requirements for vitamins and minerals other than phosphorus and calcium have been estimated empirically and are integrated in the models for completeness.

With the NRC (2012) publication, a relatively user-friendly computer program is available that includes these models. To run the program, Microsoft Excel™ is required. The computer program also includes the ingredient data base and a simple feed formulation routine, which allows for a direct comparison of calculated diet nutrient contents with model-generated estimates of nutrient requirements. The program also allows direct comparisons between model-generated estimates of animal performance – based on the partitioning of energy intake - and observed performance. Confidence in model-generated estimates of nutrient requirements is generally greater when model-predicted performance is similar to observed performance. To evaluate observed performance of growing-finishing pigs, information about local carcass evaluation schemes may be specified and default values for typical USA and Canadian carcass grading systems are included. The program includes a User Guide and case studies to illustrate the use of these models.

Partitioning of Energy Intake

Energy intake is a model input or is predicted in a rather simple manner from effective environmental temperature and either body weight, gender and floor space per pig (growing-finishing pigs) or parity (sows). It is acknowledged that the NRC (2012) approach to predicting energy intake is highly empirical and fails to adequately reflect the complex interactions among environmental and animal factors that are known to influence energy intake, such as floor type, air quality and movement, pig genotype and dietary levels of nutrients and anti-nutrients (e.g. Torrallardona and Roura, 2009). The application of the NRC (2012) approach to predicting energy intake is merely to demonstrate potential interactions between some environmental factors, energy intake and estimated nutrient requirements. The animal's response to energy intake is predicted; therefore, the NRC (2012) models cannot be used to predict energy requirements from observed levels of performance.

Partitioning of energy intake is based on maintenance energy requirements (estimated from body weight and some environmental conditions), energy retention in products of conception (estimated from anticipated litter size and mean piglet birth weight; in gestating sows), energy output in milk (estimated from litter size and litter growth rate; in lactating sows), body protein deposition (Pd) and body lipid deposition (Ld). Body lipid deposition can be regarded as the residual energy pool. When energy requirements for maintenance, products of conception, milk and Pd - given constraints on minimum ratios between Pd and Ld – have been satisfied, all remaining energy is used for Ld. When sows are in a negative energy balance, either body lipid (e.g., gestating sows during late gestation at low levels of energy intake) or both body protein and body lipid (e.g. high producing lactating sows) are mobilized. Changes in body weight and body composition (e.g., back fat thickness) are predicted from changes in body protein and body lipid mass.

The models allow direct comparison between model predicted changes in body weight and back fat thickness with values observed on individual pig units. In order to more closely match predicted with observed performance, key aspects of energy utilization may be adjusted to local conditions or pig types. These adjustments relate to maintenance energy requirements and constraints on the ratio between Ld and Pd in body weight changes.

In the **gestating sow model,** the partitioning of retained energy in the maternal body between Pd and Ld is a function of parity, stage of gestation and energy intake. For example, in parity 1 sows (gilts), mean daily total Pd, including both maternal gain and products of conception, during the first 90 days of gestation is estimated at 67 g/d, while it is 119 g/d during days 90 to 114 of gestation. Also, in parity 1 sows, a mean daily maternal Pd of approximately 60 g/d is suggested, while this value is forced to gradually decline to 20 g/d in parity 5 sows. The impact of this on nutrient requirements is discussed in the next section.

For the development of the **lactating sow model**, analysis was conducted of the relative contributions of changes in body protein and body lipid mass to the sow's body energy balance. These analyses revealed that lactating sows in a negative body energy balance mobilize both body protein and body fat, while lactating sows in a positive energy balance gain both body protein and body lipid. Unfortunately, only

limited information was available to carefully assess the impact of sow type, stage of lactation, parity and nutritional history on this important aspect of energy partitioning. Therefore, in NRC (2012), one constant default value for the relative contributions of changes in body protein and body lipid mass to the sow's body energy balance is suggested. However, if information is available about changes in sow body weight and back fat thickness during lactation, then the model user may adjust the default value to more closely match local conditions.

In the **growing-finishing pig model** and within body weight ranges, the linear-plateau model to relate Pd to energy intake is maintained in NRC (2012). In other words, in growing pigs and when energy intake generally limits pigs from expressing their Pd potential, the actual rate of Pd (and associated minimum Ld) is predicted from the linear relationship between energy intake and Pd. The slope of the linear relationship is dependent on pig type (the slope increases with increased Pd potential), body weight (the slope gradually decreases with increasing body weight), and environmental temperature (the slope decreases with increasing effective environmental temperature). Moreover, this slope may be adjusted by the model user, in order to more closely match model-predicted growth rates and back fat thickness at slaughter with observed values.

Approach to Estimating Nutrient Requirements

Once performance levels and changes in body weight and body composition are estimated from model inputs and partitioning of energy intake, then requirements for amino acids, total nitrogen, phosphorus and calcium are estimated. Total nitrogen requirements are used as an approximation of the requirements for the sum of all (essential plus non-essential) amino acids. The latter can be of concern when insufficient nitrogen is supplied in the diet for required endogenous synthesis of non-essential amino acids.

Maintenance amino acid requirements are predicted from basal gut amino acid losses (as a function of feed dry matter intake), skin and hair losses (as a function of metabolic body weight; $BW^{0.75}$) and minimum urinary nitrogen losses (as a function of amino acid losses into the gut and with skin and hair). This approach is a deviation from NRC (1998), where maintenance amino acid

requirements were predicted from $BW^{0.75}$ only. As a result, the revised models more accurately represents the impact of feed intake, and thus diet energy density, on amino acid requirements and the optimum dietary amino acid balance. In a similar manner, maintenance phosphorus requirements are predicted from basal gut losses (as a function of feed dry matter intake) and minimal urinary P excretion (as a function of $BW^{0.75}$).

Unique to threonine is the increase in dietary requirements with increased fermentable fiber intake. This reflects the extremely high threonine content – relative to all other essential amino acids – in endogenous gut protein secretions and the use of these secretions by enteric microbes as a nitrogen source (Libao-Mercado et al., 2009). Increased threonine requirements are consistent with experimental observations showing reduced threonine availability for Pd in growing pigs fed threonine limiting diets and when fermentable fiber intake is increased (Zhu et al., 2005; Libao-Mercado et al., 2006).

Amino acid requirements for production or growth are derived from Pd in the various body protein pools or protein output with milk and their unique amino acid profiles. For example in the gestating sow model, Pd and amino acid profiles in the fetus, uterus, placenta (including uterine fluids), mammary gland, and the maternal body are considered. In growing-finishing pigs, the amino acid profile of Ractopamine induced Pd (which is primarily muscle protein) is assumed to be different from Pd in pigs fed no Ractopamine.

In the **gestating sow model,** Pd in the various protein pools is dependent on either time or energy intake, and Pd in products of conception is varied with anticipated litter size and mean piglet birth weight. Based on changes in Pd with stage of gestation and across parities, the gestating sow model clearly shows the need to increase feeding levels and daily amino acid intakes towards the end of gestation, in order to satisfy increased energy and amino acid requirements for products of conception and to avoid negative maternal energy and body protein balances. It also supports reductions in daily amino acid requirements with increasing parity.

In the **lactating sow model,** milk protein output is dependent on time and varied with litter size and mean piglet weight gain over the entire lactation period.

In the **growing-finishing pig model,** Pd curves can be defined by the model-user in various ways. Default Pd curves are given for barrows, gilts and entire males. These default curves can be adjusted by entering mean Pd between 25 and 125 kg body weight, entering parameters for either a 3rd order polynomial function or a growth function based on generalized Michaelis-Menten kinetics, or specifying a maximum daily Pd that is independent of body weight in combination with the body weight at which maximum daily Pd starts to decline. As mentioned in the section on energy partitioning, the actual Pd may be lower than Pd defined by the default curves or user-defined Pd, when energy intake limits Pd. In the growing-finishing pig model, the dynamics of Pd when feeding varying levels of Ractopamine or after the second (booster) dose of Improvest™ to immunize pigs against gonadotropin-releasing factor (GnRF; to control boar tainted meat from entire males pigs) are represented as well.

For each amino acid, a unique post-absorptive efficiency of using SID amino acid intake for production is considered. This efficiency has been used to match model-predicted amino acid requirements with observed amino acid requirements in carefully scrutinized empirical requirement studies. For growing-finishing pigs, this efficiency is also related to body weight (heavier pigs are less efficient) and pig performance potentials (pigs with improved Pd capacity are more efficient).

For estimating **STTD P requirements**, that rate of P retention is predicted from Pd in the various body protein pools, or protein output with milk, and unique ratios between Pd and (maximum) P retention. In the growing-finishing pig model, an adjustment is used to reduce maximum P retention to the rate of P retention for maximum growth performance. It is thus implied that P retention in growing-finishing pigs (e.g., the extent of bone tissue mineralization) can be reduced without compromising growth performance. In a manner that is consistent with the approach for amino acids, a post-absorptive efficiency of P for P retention is used to match model predicted performance with empirical requirement studies. Calcium requirements are estimated directly from STTD P requirements and using simple ratios that are unique for gestating sows, lactating sows and growing-finishing pigs.

In NRC (2012), modelled amino acid and phosphorus requirements for typical levels of energy intake and varying levels of animal performance are

presented in nutrient requirement tables and have been tested carefully for consistency with empirical nutrient requirement studies.

Boundaries and Limitations

As is the case for any model, it is important to recognize boundaries and limitations. In the NRC (2012) models, boundaries for model use are controlled largely by the imposed minimum and maximum values for model inputs; i.e. determinants of nutrient requirements. As mentioned earlier, the models include some routines to predict feed intake and to represent the impact of environmental conditions on estimated nutrient requirements. However, these routines are a highly simplified representation of reality, being largely intended for educational purposes and should be interpreted with caution when extrapolated to commercial conditions. When establishing nutrient requirements for individual pig units, it thus recommended entering observed levels of feed intake as inputs for the NRC (2012) models.

The models are fairly easy to use, but some understanding of the underlying principles is required for effective application. This applies in particular when choosing the more complex options to characterize Pd curves in the growing-finishing pig model, or when manipulating feed intake, aspects of energy utilization, and other model inputs to match model-predicted with observed changes in body weight and back fat thickness.

Three limitations of the NRC (2012) models that relate directly to estimating nutrient requirements are: (1) effects of nutritional history and compensatory growth on nutrient requirements are not considered; (2) the model cannot be used to assess the marginal response to varying nutrient intake levels and, therefore, to conduct cost-benefit analyses; and (3) the effect of differences in between-animal variability among groups of pigs is not considered. The latter implies that nutrient requirements of groups of pigs under commercial conditions, and when between-animal variability in performance is larger than under experimental conditions, may be slightly higher than the estimates generated by the model.

Evaluation of NRC (2012) Nutrient Requirements

It is clearly stated in NRC (2012) that estimated nutrient requirements do not include any intentional surpluses. In practice, a margin of safety may be added to the stated requirements to account for variability in nutrient content and bioavailability in feed ingredients, presence of inhibitors or toxins in ingredients, inadequate processing or mixing of diets, partial loss of nutrients from storage, impact of environmental stressors on nutrient requirements, and other factors. The cost of increasing dietary nutrient levels should thus be weighed against potential improvements in performance under potentially stressful conditions. Therefore, some knowledge of the nutritional constraints and limitations is important when interpreting nutrient requirements suggested in NRC (2012).

In general nutrient requirements for supporting typical levels of performance and expressed as dietary contents are slightly higher in NRC (2012) than NRC (1998). However, this is largely a reflection of increases in typical performance levels and, in the case of starting and growing-finishing pigs, reductions in feed intake. For various nutrients, especially vitamins and several of the minerals, nutrient requirements in NRC (2012) have not changed from those in NRC (1998), simply because no meaningful requirement studies have been conducted since NRC (1998) was published.

Direct Comparison of NRC (2012) to NRC (1998) for Amino Acids, Phosphorus and Calcium Requirements

In NRC (2012), direct comparisons are presented for estimated amino acids, phosphorus and calcium requirements based on the approaches used in NRC (1998) versus NRC (2012) and at typical performance levels that were used in NRC (1998).

Based on these direct comparisons, NRC (2012) yields estimates of mean lysine requirements over the 114-day gestation period for **gestating sows** that are slightly higher in parity 1 sows (gilts), slightly lower in parity 2 sows, and substantially lower in parity 3 and 4 sows than in NRC (1998). These differences can be attributed largely to changes in maternal Pd across parities, which are increased in NRC (2012). Relative to lysine, requirements for tryptophan and valine are increased and requirements for isoleucine are reduced in the revised model. These changes in requirements are consistent with the amino acid composition of the various protein pools in gestating

sows. The requirements for STTD P and Ca have been reduced in the revised model, largely based on European reviews on P requirements (Jongbloed et al., 1999, 2003; BSAS, 2003; Jondreville and Dourmad, 2005; GfE, 2008). It should be noted that an important feature of the NRC (2012) gestating sow model is that nutrient requirements can be estimated for early gestation (e.g. day 1- 89) and late gestation (day 90-114), and these requirements are presented in the nutrient requirement tables.

At comparable levels of **lactating sow** performance, NRC (2012) yields estimates of mean lysine requirements over a 21-day lactation period that are 10-15% lower than requirements according to NRC (1998). This discrepancy can be attributed largely to an updated interpretation of lysine requirement studies, and a more mechanistic representation of the contribution of sow body weight losses to amino acid output with milk. In addition, lysine requirements according to NRC (2012) are more consistent with recent lysine requirement studies. Relative to lysine, requirements for threonine, tryptophan, methionine, and methionine plus cysteine are increased in NRC (2012). For threonine and tryptophan, these changes are consistent with recent amino acid requirement studies. For methionine and methionine plus cysteine requirements, the post-absorptive efficiencies of amino acid utilization were decreased from values required for matching NRC (1998) requirements to yield utilization efficiencies that are more consistent with those for growing-finishing pigs and gestating sows. Milk contains substantial amounts of taurine (Wu and Knabe, 1994), which is generated from cysteine and reduces the efficiency of methionine plus cysteine utilization for methionine and cysteine output with milk. The revised model yields estimates of optimum dietary SID methionine and methionine plus cysteine to lysine ratios that are more in line with other recommendations (e.g., BSAS, 2003; Dourmad et al., 2008; GfE, 2008). The requirements for STTD P and Ca have been reduced in the revised model relative to NRC (1998), largely based on European reviews on P requirements (Jongbloed et al. 1999, 2003; BSAS, 2003; Jondreville and Dourmad, 2005; GfE, 2008).

At comparable levels of **growing-finishing pig performance**, NRC (2012) yields estimates of lysine requirements that are about 3% lower in pigs between 20 and 50 kg body weight, and about 8% higher in pigs between 100 and 130 kg body weight

than NRC (1998). These differences are consistent with increased estimates of maintenance lysine requirements and increases in lysine requirements per 100 g Pd with increasing body weight in NRC (1998). By implementing these adjustments, the apparent underestimation of estimated lysine requirements of pigs between 80 and 120 kg body weight that was noted in NRC (1998) has been addressed. Relative to lysine, requirements for methionine and arginine are increased and requirements for isoleucine and tryptophan are reduced in the revised model. These changes in requirements are consistent with recent requirement studies. For other critical amino acids, NRC (2012) yields minor changes in requirements of growing-finishing pigs, when expressed relative to those of lysine. The requirements for STTD P have been reduced in NRC (2012), largely based on European reviews on P requirements (Jongbloed et al., 1999, 2003; BSAS, 2003; Jondreville and Dourmad, 2005; GfE, 2008). Unlike NRC (1998), dietary P requirements according to NRC (1998) vary with pig growth rate, driven by changes in Pd. As a result, dietary P requirements are estimated to be higher in entire males than in gilts and barrows, which is consistent with empirical observations. In pigs with high rates of Pd, the dietary P requirement estimates approach values suggested by NRC (1998) and exceed requirements according to Jongbloed et al. (1999, 2003), Jondreville and Dourmad (2005), BSAS (2003), and GfE (2008). Relative to P, Ca requirements are slightly increased from NRC (1998).

Conclusions and Implications

In NRC (2012), the mathematical models to estimate the pig's response to energy intake and to estimate requirements for amino acids, nitrogen, phosphorus and calcium of gestating sows, lactating sows and growing-finishing pigs have been refined, and nutrient requirement tables have been expanded. Response to energy intake is estimated most accurately when using the NE system. Estimates of requirements for amino acids and phosphorus are most accurate when using SID amino acids and STTD phosphorus values. Estimates of nutrient requirements are now also given for sows during early and late gestation, growing-finishing pigs fed ractopamine and for entire male pigs that are immunized with Improvest™ to control boar tainted meat.

In general, nutrient requirements for supporting typical levels of performance and expressed as dietary contents are slightly higher in NRC (2012) than NRC (1998). However, this is largely a reflection of increases in typical performance levels and, in the case of starting and growing-finishing pigs, reductions in feed intake.

The models highlight the need to consider animal performance levels and energy intake when estimating nutrient requirements for specific groups of pigs.

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