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World Pig Production, Opportunity or Threat?

Donald E. Orr Jr. and Yingran Shen
JBS United, Inc
Sheridan, IN 46069
317 – 758 2617
don.orr@jbsunited.com; sam.shen@jbsunited.com

Summary

The global production and consumption of pork has increased substantially in recent decades. This demand for pork clearly offers opportunities for both U.S. and foreign pork producers to expand international sales. Domestic demand for pork in individual countries is related to market size, supply and prices of competitive meats, per capita income effect on protein demand and pork demand's vulnerability to currency or economic instability. Pork production in countries dependent on high exports and also experiencing economic variation will cause returns to be lower and more variable. U.S. pork exports have been enhanced by the current low value of the U. S. dollar and the fact that Brazil has been unable to ship pork to key Asia markets due to Brazil's Foot and Mouth disease related restrictions. Primary challenges for the U.S. pork industry are animal welfare, ethanol's impact on feed stock price, labor availability, environmental/political issues and food safety/traceability programs. While strong competition for export markets will come from both old and new pork producing countries, an improving global economic growth and rising demand for pork, especially in the Asian countries, will contribute to gains for U.S. pork production and exports.

Introduction

World pork consumption has increased by 27% from 1997 to 2005, with total global pork consumption for 2005 at over 93 million metric tons (MT). Pork is the meat of choice worldwide and offers opportunities for both U.S. pork producers and foreign pork producers to expand international sales. The value of U.S. pork exports in 2005 was $2.28 billion or $22.01 per U.S. hog slaughtered (Plain, 2006).

Top Pork Producing Countries

The top 12 pork producing countries for 2005 and their pork tonnage are listed in Table 1. China, with about 50% of the world pig population, heads the list, followed by E.U.-25 countries of Europe, United States (USA), Brazil and Canada, for the top five pork production positions (FAS/USDA, 2006). While world pork production has increased by 15.1% from 2000 to 2005, the top five countries in percent increase in pork production over this five year period from the list of 12 countries are Brazil (39.3%), Vietnam (27.8%), China (23.2%), Russia (17.0%), and Canada (16.8%). During this 5 year period, USA percent increase in pork production was 9.3% while the E.U.-25 increased by only 2.3% (FAS/USDA , 2006).

Liberalization of trade worldwide has resulted in significant increases in global trade in pork. It has become increasingly essential to be competitive in the global market, as this can contribute significantly to the profitability of a country's primary pork producers (Young, 2005). To be competitive in the export markets will require:

- Low cost of production (not a guarantee for survival)
- Efficient production
- Quality and safety of products
- Reliability of supply

World Trade in Live Feeder Pigs and Slaughter Hogs

World trade in live hogs exported and imported for 2004, which includes feeder pigs and slaughter hogs, is presented in Table 2 (FAO, 2005). Canada heads the hogs exported list with 8.5 million head exported in 2004, while the USA imported in 2004 nearly the same number of live hogs to lead the list of hogs imported. The combination of pork exports and sale of feeder pig and slaughter hogs to

the USA accounts for nearly 70% of Canada's hog production. This large export trade in pork and live animals reflects the response of the North American pig industry to it's competitive advantages (Young, 2005). Canada has better herd reproductive efficiency than the USA, but the U.S. is very competitive in finishing pigs for market, along with a generally stronger American dollar so as to purchase pigs at a very competitive price.

Both the Netherlands and Denmark are large exporters of live hogs, with many of these going to Germany for feeding and slaughter or to Eastern Europe for feeding purposes. China is the primary provider of live market hogs for Hong Kong's wet slaughter market.

Top Pork Importing and Exporting Countries

Top pork import countries

As shown in Table 3, Pacific Rims, Russia, and Mexico are the major pork import countries. Among those, Japan is the biggest pork importer. In 2005, Japan imported a record amount of pork with 1.339 MMT, over 1.2 MMT being generic pork (chilled and frozen combined) and 90 thousand metric ton of prepared and processed pork. There were increased imports from U.S., Chile, Canada, Mexico, Ireland, and Austria with a decrease from Denmark. This record number is in part, due to the tight supply of beef in 2004 (FAS/USDA, 2006).

Japan has the most strict import standard and labeling requirement. New Japanese food import standards may require more U.S. testing and could force some U.S. pork producers to change what they feed their hogs. The new rules change maximum residue limits on all food products for 799 feed additives, veterinary drugs and agriculture chemicals, compared to the previous number of 283 substances (Bratton, 2006). Producers may have to stop giving hogs these additives for a longer time before slaughter to meet new limits.

As emphasized by Liddell and Bailey (2001), the U. S. pork industry is generally lagging its principal international competitors of EU and major international customers in terms of developing programs for traceability, transparency, and assurance. If EU further differentiates themselves in these areas, the U.S. may lose its competitiveness in the world market, especially in Japan, as Japan emphasizes heavily on imported food labeling.

Mexico is the second biggest export market for U.S. pork. Mexico's pork industry has not kept up with the rising domestic demand, and therefore Mexico has as deficit in pork production and is import dependent. Mexican consumer preferences for products and cuts not preferred in the United States help drive this market for chilled and frozen pork, variety meats, and processed meats and specific cuts for manufacturing, food service, and retail sale. Mexico is also a strong market for live hogs, although live hog imports have been less stable than have imports of pork and variety meats.

Russia is the major export market for EU and Brazil. Russian market share of Brazilian pork imports increased from 57.8% in 2004 to 66.6% in 2005.

Top export countries

As shown in Table 3, EU and Canada export more pork than the US. However, EU's export to Japan has decreased due to competition from the U.S., but EU's export to Russia has increased. Although EU, especially west European countries, has high production cost, they identify their pork as high quality, customer oriented. EU hog production has changed from production oriented to market oriented, with emphasis on traceability and safety requirements. EU will probably continue to be a strong competitor for the U.S. pork export market.

Brazil is another major pork exporter. Brazilian pork exports in 2005 increased by 22.4% in volume. In 2005, Brazilian pork exporters increased their shipments of pork cuts, which now account for over 75 percent of all pork exports. The increase in pork cuts reflects the strategy of Brazilian exporters to increase profitability by exporting higher value products.

Beside the fact that China is the biggest pork producing country in the world and that most pork produced is consumed domestically, China is also a key player for pork export. However, China only exports live pigs to Hong Kong, and is now exporting some pork or processed meat to neighboring countries like Russia and South Korea.

Chile ranks 6th among the major pork exporters in the world (FAS/USDA, 2006), and has benefited from being one of the fastest growing economies in the western hemisphere with increasing integration in their hog industry. Chilean pork exports have grown significantly during the last decade, from 2,755 MT in 1995 to over 129,000 MT in 2005, with an esti-

mated 174,000 MT in 2006 for an average annual increase of over 40 percent. The main destinations for Chilean pork are Japan, South Korea, Mexico and EU member countries.

USA Pork Production

U.S. pork production is domestic dependent, producing 9.392 million MT, with an increase of 9.3% from 2000 to 2005 (FAS/USDA, 2006). The estimated industry total daily processing capability is 423,500 head, with major packers making up about 90% of this capacity. The ten leading packers each process more then 10,000 slaughter hogs daily, with Smithfield Foods having a capacity of nearly 110,000 head per day in the U.S.

Increasingly export driven, the U.S. exported 1.2 million MT in 2005, up 100% over the year 2000. Japan continues to be the largest foreign customer for U.S. pork, (45% of all U.S. exports), followed by Mexico and Canada. U.S pork exports have been helped by the currently low-valued U.S. dollar, and the fact that Brazil has been unable to ship to key markets due to Brazil's Foot and Mouth disease (FMD)-related restrictions. U.S. hog slaughter has been complimented by increasing imports of Canadian feeder pigs for finishing and slaughter.

Economic predictions by Greenwood (2006) indicate that breakeven costs will be similar in 2012 as they are today. Ethanol production will lead to higher feed costs. Higher capital costs will occur in the replacement of older buildings. Thus, better production must occur to maintain current production costs.

Opportunities for the U.S. pork industry include being able to play a dominant role in the global protein market. The potential exists for the U.S. to export up to 25% of the pork production by 2012, with China possibly emerging as a major export market (Greenwood, 2006).

Primary challenges for the U.S. pig industry are animal welfare (driven by food companies down to the producer level), ethanol use of the limited raw feed stocks, labor availability, and environmental/political issues. Food safety and traceability projects for quality assurance will be of foremost importance, especially as related to pork exports (Greenwood, 2006). Information systems on traceability will be required, as will technology to reduce labor costs. Segmented products will have differing breakeven costs and margins will become a focus point equally important as costs.

A major compilation of worldwide pig production costs, feed costs and pig prices for 2005 was conducted by PIC, a worldwide breeding stock supplier. This summary indicated that the major countries with production costs below $1 US per kg live weight, starting with the lowest production costs, included Brazil, USA, China, Canada, Chile and Thailand (PIC, 2006)

Canada Pork Production

Unlike the U.S., Canada is a pork export-oriented country, as a result of policy change and modest population growth (Haley, 2005). Instead of exporting grains, Canada has developed a pork industry aimed at the export market since 1996. The production increased from around one million MT in early 1980's to the current production of about two million MT. The Canadian pork industry broke export records in 2005, shipping 1.029 million MT valued at $2.84 billion Canadian. Currently, Canada exports more than 50% of its total production, as compared to that of 12.9% in the U.S. (FAS/USDA, 2006).

The relationship of the Canadian hog industry to its counterpart in the U.S. is complementary. In fact, among Canadian hog exports of around 8.5 million pigs in recent years (around 70% being feeder pigs), the great majority of these exports go to the U.S. and make up most of the imported hogs for the U.S. hog industry. This represents more than an eight times increase from ten years ago. In a competitive assessment, Canada has the advantage in farrowing, while U.S. has advantages in finishing and packing (Haley, 2005).

Canada has successfully diversified its pork export markets while sales to the U.S. have been in decline over the past few years and now represents less than 40% of Canada's pork exports (Haley, 2005). After the export to the U.S., Canada exports its next most pork to Japan. It reached 266,000 MT at a cost of $1.01 billion in 2005. Canada is the third largest generic pork (chilled and frozen combined) provider to Japan (22% market share, following the 30% market share from the U.S. and 29% from Denmark). For prepared and processed pork, Canada is the second biggest provider (27% Japanese market share), following the 48% market share from the U.S. In this regard, Canada is clearly a competitor to the U.S. hog industry.

Latin America Pork Production

For the purpose of examining pork production in the area of the world south of the United States (USA), the three key pork producing countries are Brazil, Chile and Mexico. Domestic demand in most of these Latin American countries has been unstable over the last 15 years. The Brazilian and Mexican pork demand trend line demonstrates two critical drivers that are prevalent in the region's pork demand complex. First is the importance of per capita income on protein demand and, second, is pork demand's vulnerability to currency or economic shocks (Canfield, 2006).

Brazil's per capita pork consumption (12.4 kg) is only 14% of the total per capita meat consumption, while Chile's per capita pork consumption at 20.3 kg is nearly double that of Brazil's. Mexico is a net importer of pork, with the USA as its major provider. Mexico is a major importer of the ham muscle from the USA (Canfield, 2006) and typifies a domestic pork deficit country. Brazil and Chile export approximately 20% of their annual pork slaughter tonnage and have a similar pattern to the Canadian model for pork exports. The two largest pork processors in Brazil, Sadia and Perdigao, have recently embarked on joint export marketing for poultry and pork. Today, Chile has been able to capture lucrative export markets in Japan and South Korea, whereas Foot and Mouth Disease (FMD) has limited Brazil's export market to less prosperous countries such as Russia and the former Soviet block countries (Canfield, 2006). Brazil's rail and road infrastructure also limits its near-term competitiveness on pork exports.

European Pork Production

The West European market is characterized by four major factors (Hartog, 2005):

- Changed from production-oriented to market (consumer)-oriented.

- Critical consumers with requirements concerning sustainability methods of production.

- Large market of high income consumers demanding product traceability and food safety.

- High production costs relative to other areas of pork production.

The Danish pork industry is the largest exporter of pork in the world, with 17% of the world pork exports derived from 2% of the world's pig production. Exports account for 85% of Danish pig production.

Added value and flexibility to meet global market demands on products and quality are the cornerstone of Denmark's success. Denmark's labor costs are the most expensive in the world, which has led Danish Crown Company to finish products in the final markets, which include the UK, Germany, Poland and USA. Danish Crown operates three pork and bacon processing plants in the USA. The challenge to the Danish pork industry will be to lower pork costs by innovation, automation and entering foreign processing markets such as Poland and Eastern Europe (Johannesen, 2005).

Poland currently exports pork to South Korea and Polish companies will soon start to export pork to the Japanese market. Major Polish meat companies (Sokolow, Animex and Duda) will benefit due to the new European Union standards adopted by their industry. Poland has good access to feed grains, available low cost labor and excellent market location to access Germany and Russia (Luckman, 2006). Current limitations to pork production in Poland include weak management expertise, persistent outdated government policy and restricted access to capital. Smithfield Foods through its Animex company venture has succeeded by utilizing quality swine genetics, setting up artificial insemination boar stud centers; encouraging quality feed production and paying its pig producer customers on a more timely basis. Danish Crown has also invested in pork slaughter plants in Poland.

China Pork Production

China is the biggest pork producing country. However, its market is totally domestic oriented. China produced 49.7 MMT in 2005, slightly over 50% of the total world pork production. China's pork production is estimated to be 52 MMT for 2006, a 4.7% increase from that of 2005 (FAS/USDA, 2006). The per capita consumption for China (33.8 kg) is among the highest in the world, only slightly lower than that of Hong Kong, the EU, and Taiwan, which are countries or regions with higher per capita incomes (Fabiosa et al., 2005).

Despite its massive population, China is almost self-sufficient in pork supplies, and imports account for less than one percent of total pork production. Frozen boneless pork accounts for the major portion of China's pork imports for high end consumers. The USA is the largest variety pork supplier to China, accounting for 37% of China's total imports (226,736 MT) during the first 11 months of 2005. A favorable

dollar exchange rate will help the competitiveness of U.S. exports to China (GAIN Report, 2006).

China's swine and pork exports in 2006 are forecasted to increase 16% to 2 million head. China's swine export markets will not change, with Hong Kong, Japan, North Korea, and Russia as its major exports market. For the first time since 2004, Japan will become China's second largest pork market (GAIN Report, 2006).

Between 1996 and 2005, the compound annual growth rate of the production of pork in China is 5.1% (Boal, et al., 2005). Despite the majority (70%) of Chinese hog production being still small scale or backyard production, larger sized commercial farms have been increasing, thus improving production efficiency. The number of swine slaughtered from commercial farms increased 26% in 2004 over the previous year. This has increased pig production and lowered pork prices in China in 2005-2006.

The limiting factors for Chinese hog production are higher production cost, lack of capital resources, and limited market information. Official market statistic information is normally announced one to two years later. There are no official forecasts for future production. Furthermore, disease and residue control are also challenges. Animal diseases (e.g., FMD) are difficult to monitor and control in China's widespread, small-scale farming system (GAIN Report, 2006). China must develop pork systems with uniform, high quality genetics, which can be slaughtered and processed in modern pork processing plants if it is going to supply quality, uniform pork. This has already been achieved by the broiler industry in China, but a lack of modern processing plants has limited availability of high quality pork.

Literature cited

Boal, F., J. Chanoki, F, Costa, M. Klompenhouwer, A. Kusuma, C. Pan, G. Russel, K Shwedel, and P. Vizzone. 2005. Partnerships in the Animal Protein Industry. Agri Vision 2005. Rabobank.

Bratton, A. J. 2006. Japanese rules affect U.S. pork industry. Associated press. http://www.bradenton.com/mld/bradenton/business/14673493.htm.

Canfield, K. 2006. Pork production in Latin America: Processing sector. The Profit Improver, Volume 2 Spring issue, 2006.

Fabiosa, J. F., D. Hu, C. Fang. 2005 A case study of China's commercial pork value chain. Iowa State Univeristy.WWW.matric.iastate.edu.

FAO, 2005. http://faostat.fao.org/faostat/.

FAS/USDA. 2006. Livestock and Poultry: World Markets and Trade March 2006.

GAIN Report Number: BR6601: Brazil Livestock and Products Semi-Annual Livestock Report 2006. FAS, USDA.

GAIN Report Number: PL6008: Agricultural Situation Sensitive Agricultural Products for Poland 2006. FAS, USDA.

GAIN Report: CH6002. China, Peoples Republic of, Livestock and Products Semi-Annual Report 2006. FAS, USDA.

GAIN Report: CI5016. Chile Livestock and Products Annual Report. 2005. FAS, USDA.

Greenwood, M. 2006. What will the swine industry look like in 2012. Agstar Financial Services. Mankato, MN.

Hartog, L. den. 2005. Global Perspective on Integrated Pork Production. Pig News and Information. 26:73N-77N.

Haley, M. U.S.-Canadian Hog Trade: Market Integration at Work. http://www.ers.usda.gov/AmberWaves/February05/Features/USCanadian.htm.

Johannesen, K. Adding genuine value can defy apparent logic. Agri Vision 2005. Rabobank. Pp 22.

Liddell, S. and D. Bailey. 2001. Market Opportunities and Threats to the U. S. Pork Industry Posed by Traceability Systems: Economic Research Institute Study Papers ERI 01-06. Department of Economics, Utah State University.

Luckman, J. 2006. Personal communications. Smithfield Foods, Inc. Smithfield, VA.

Plain, R. 2006. Outlook for Hogs & Pork. University of Missouri-Columbia. Personal communication.

PIC, 2006. PIC Worldwide Survey. February, 2006, PIC Company.

Young, M. 2005. Efficiency of pork production: a USA, Canada, and Ireland comparison. Allen D. Leman Swine Conference. Pp 124.

Table 1. World Pork Production (1000 metric ton)

Country	2005
China (mainland)	49,685
EU(25)	21,200
United States	9,392
Brazil	2,800
Canada	1,915
Vietnam	1,850
Russia	1,755
Japan	1,250
Mexico	1,195
Philippine	1,100
South Korea	1,036
Taiwan	920

Source: FAS/USDA, 2006

Table 2. World Hog Trade, 2004

Import		Export	
Country	2004	Country	2004
United States	8,504,507	Canada	8,511,409
Germany	4,638,280	Neth'lands	4,821,845
Hong Kong	1,874,838	Denmark	2,495,938
Spain	1,092,199	China	1,972,911
Portugal	800,388	Spain	1,453,668
Italy	790,593	Czech Rep	947,945
Belgium	726,795	Germany	829,507

Source: FAO, 2005

Table 3. Top World Pork Import and Export Countries (1000 metric ton)

Import		Export	
Country	2005	Country	2005
Japan	1339	EU(15)	1350
United States	464	Canada	1083
Russia	675	United States	1207
Mexico	420	Brazil	761
Hong Kong	305	China (mainland)	331
South Korea	328	Chile	129
China (mainland)	41	Hungary	95
Canada	139	Poland	70
Romania	185	Mexico	59
Australia	99	Australia	53

Source: FAS/USDA. 2006.

Nutrient-Gene Interactions: Practical Implications

Scott Radcliffe
Purdue University
West Lafayette, IN 47907-2042
765-496-7718
jradclif@purdue.edu

Summary

We are just beginning to understand how nutrients and genes interact. However, it is clear that we can affect gene transcription through changes in the diet. As we gain a better understanding of these interactions it will be possible to better formulate diets with a focus on genes that we would like to enhance transcription of and those that we would like to decrease transcription of. In addition to host nutrient-gene interactions, it may also be necessary to obtain a better understanding of how nutrition can alter viral and microbial genomes.

Introduction

Improvements and advances in molecular biology techniques have allowed scientists to learn much about human and animal genomes. Genomic sequencing provides a genetic map, and was once viewed as the ultimate in our understanding of animal genetics. However, as more and more genomes have been sequenced, and as researchers try to understand how individual genes within the genome are regulated, the complexity of gene regulation is becoming more and more apparent. Therefore, it can be difficult to determine if there are any practical implications regarding regulation of gene expression. It has been known for quite some time that dietary nutrients can affect protein expression. For example, as the level of Ca in the diet decreases, an increase in active Ca absorption has been reported. However, only in the last 2 decades have we begun to understand how these changes occur, and how it might be possible to manipulate gene and protein expression. This paper will attempt to provide a broad overview of nutrient-gene interactions. Specific examples will be used to illustrate certain points.

Discussion

Genes are linear segments of DNA that contain coding regions for a specific protein. In order for the protein to be functionally expressed, the gene must be transcribed into RNA, and then the RNA must be translated into a protein. Finally, there are various post-translation modifications that may need to occur in order for the protein to be functional. This paper will focus on nutrients ability to affect gene transcription. Very simplistically, in order for a gene to be transcribed, a series or proteins must bind to the gene, upstream from the coding region, and recruit a polymerase, thus enabling gene transcription. Most genes also contain various response elements, where proteins can bind and inhibit or enhance the rate at which transcription occurs. Because there are numerous response elements on any given gene, and because in many cases these response elements require the response element binding protein to be bound with a mineral, vitamin, hormone, or to be homo- or hetero-dimerized, regulation of gene transcription can be very complex. Vitamin D is a good example of how a nutrient can alter gene transcription at multiple sites through multiple mechanisms.

The active form of vitamin D, $1\alpha,25$-dihydroxyvitamin-D_3 ($1,25(OH)_2$-D_3), is created through the dihydroxylation of vitamin D_3 (cholecalciferol). Vitamin D_3 can be endogenously produced in the skin through the photoconversion of 7-dehydrocholesterol, or it can be obtained from the diet as cholecalciferol or synthetic ergocalciferol (vitamin D_2). The two hydroxylation steps that transform vitamin D to the active form of vitamin D occur in the liver and the kidney. In the liver, 25-hydroxylase catalyzes the addition of a hydroxyl group to carbon 25. In the kidney, 25-hydroxyvitamin-D_3-1α-hydroxylase

catalyzes the addition of a hydroxyl group to carbon 1, creating the active form of vitamin D, $1,25(OH)_2$-D_3. Alternatively, $25(OH)$-D_3 can be hydroxylated at carbon 24 to create $24,25(OH)_2$-D_3 which does not possess the metabolic activity of $1,25(OH)_2$-D_3, and can ultimately be further metabolized and excreted in bile. The primary function attributed to $1,25(OH)_2$-D_3 is its role in Ca homeostasis. While the function of vitamin D in Ca homeostasis has been known for many years, the mechanisms through which these actions occur have only recently been established.

Vitamin D can transcriptionally regulate genes containing a vitamin D response element (VDRE). This VDRE consists of two nucleotide sequence repeats of AGGTCA (A = adenine, T = thymine, G = guanine, C = cytosine) separated by three bases (Umesono et al., 1991). In order for vitamin D to act in *trans* upon this *cis*-acting response element it must bind to a vitamin D receptor (VDR). The VDR is an approximately 50 kDa protein which can be divided into four functional domains: 1) an N-terminal domain, 2) a DNA binding domain, 3) a hinge region, and 4) a C-terminal ligand binding domain (McDonnell et al., 1987; Baker et al., 1988; Burmester et al., 1988). The ligand binding domain is the largest region of the protein, consisting of approximately 70% of the total amino acids. This domain is responsible for binding $1,25(OH)_2$-D_3, transcription factors, and for homeric or hetreomeric dimerization. The effects of $1,25(OH)_2$-D_3 mediated through VDR requires heterodimerization of VDR with the 9-*cis* retinoic acid receptor, RXR (Kliewer et al., 1992; Forman et al., 1995) The presence of $1,25(OH)_2$-D_3 increases the heterodimerization of VDR and RXR (Kimmel-Jehan et al., 1997); while the presence of 9-*cis* retinoic acid may decrease the heterodimerization of VDR and RXR and increase the homodimerization of RXR (Jones et al., 1998). In addition, to requiring the VDR-RXR heterodimerization to potentiate the transcriptional actions of $1,25(OH)_2$-D_3, multiple coactivator proteins are needed. Coactivator proteins include transcription factor IIB (TFIIB), whose binding overlaps the c-terminal side of the hinge region and the N-terminal end of the ligand binding region (Blanco et al., 1995; MacDonald et al., 1995). The actions of $1,25(OH)_2$-D_3 are mediated through binding to a VDR-RXR heterodimer. This $1,25(OH)_2$-D_3-VDR-RXR complex binds to the VDRE of vitamin D responsive genes, and with the help of various coactivators and transcription factors, initiates transcription of the gene.

Secretion of PTH increases in response to low serum Ca levels. The PTH acts upon receptors in the proximal convoluted tubules of the kidney to increase 25-hydroxyvitamin D_3-1α-hydroxlase mRNA through a cAMP dependent manor (Garabedian et al., 1972; Tanaka et al., 1975). In addition, PTH causes a decreased synthesis of 25-hydroxyvitamin D_3-24-hydroxylase (Shinki et al., 1992). The net result is an increased output of the active form of vitamin D, $1,25(OH)_2$-D_3, which acts to increase serum Ca through direct effects on the intestine, kidney, and bone.

In the intestine, $1,25(OH)_2$-D_3, causes an increased absorption of Ca. The effects of vitamin D on Ca uptake are due to its effects on Ca transport through the cell, and transport across the basolateral membrane. Calcium transport through the cell is aided by the Ca binding protein, calbindin D-9k in mammals (Umesono et al., 1991), and calbindin D-28k in birds (Christakos, et al., 1997). Both transport proteins have been shown to increase in response to $1,25(OH)_2$-D_3 (Umesono et al., 1991). The gene encoding calbindin D-9k has been cloned from rat intestine and contains a VDRE, which suggests that $1,25(OH)_2$-D_3 acts through transcriptional regulation to increase calbindin (Thomasett, 1997). Two transporters have been identified which are responsible for moving Ca across the basolateral membrane against an electrochemnical gradient. The first is a Ca-ATPase, which is thought to be the primary mechanism for Ca transport across the basolateral membrane (Garrahan and Rega, 1990). The second, which is thought to only have a minor role in Ca transport across the basolateral membrane, is a Ca/Na antiport system (Reeves, 1990). Wasserman et al. (1992) provided evidence which suggests that the Ca-ATPase may be inducible by $1,25(OH)_2$-D_3.

In the kidney, $1,25(OH)_2$-D_3 has two major functions. First, it increases Ca reabsorption in the distal convoluted tubule, and second, it down regulates $1,25(OH)_2$-D_3 production. The actions of $1,25(OH)_2$-D_3 on Ca reabsorption, much like in the intestine, appear to be mediated primarily through an increased transcription of the gene encoding the renal Ca transport protein, calbindin D-28k. This mammalian D-28k calbindin gene contains a VDRE (Gill and Christakos, 1993). Down regulation of $1,25(OH)_2$-D_3 production is a two-pronged effect which includes the down regulation of 25-hydroxyvitamin-D_3-1α-hydroxylase and the up regulation of 25-hydroxyvitamin-D_3-24-hydroxylase. The down

regulation of 25-hydroxyvitamin-D$_3$-1α-hydroxylase may be through a direct action of 1,25(OH)$_2$-D$_3$ complexed with VDR and RXR on a VDRE, or it may be indirectly through a down regulation of PTH production due to the direct actions of 1,25(OH)$_2$-D$_3$ on the parathyroid gland. Activity of 25-hydroxyvitamin-D$_3$-24-hydroxylase is upregulated in the proximal and distal convoluted tubules by 1,25(OH)$_2$-D$_3$ (Yang et al., 1999). However, the effects of 1,25(OH)$_2$-D$_3$ are confounded by levels of PTH and/or cAMP which display differential effects in the proximal and distal convoluted tubules (Yang et al., 1999).

The principle function of 1,25(OH)$_2$-D$_3$ in bone is to increase Ca resorption by increasing osteoclastic activity, increasing the movement of Ca from the bone into the bone fluid compartment, and increasing the movement of Ca from the bone fluid compartment into the plasma. All of these mechanisms of action require the presence of PTH. Osteoclastic bone resorption increases in response to 1,25(OH)$_2$-D$_3$ and PTH (Raisz et al., 1972; Stern, 1997). However, osteoclasts do not possess receptors for 1,25(OH)$_2$-D$_3$ or PTH (Jones et al., 1998). Instead, 1,25(OH)$_2$-D$_3$ and PTH act through receptors on osteoblasts. They cause a "rounding up" of osteoblasts through a cascade of cytoskeletal changes, which have yet to be elucidated (Suda and Takahashi, 1997). This results in the osteoblasts covering a smaller surface area of the bone which allows the osteoclasts to spread out, covering more surface area, and resorbing more bone. In addition, 1,25(OH)$_2$-D$_3$ causes osteoblastic production of an osteoclastic differentiation factor that causes the osteoclastic precursor, the monocyte, to differentiate into a mature osteoclast (Abe et al., 1981; Tanaka et al., 1982; Suda and Takahashi, 1997).

Finally, 1,25(OH)$_2$-D$_3$ may act directly on the parathyroid gland. The parathyroid gland has been shown to contain VDR (Hughes and Haussler, 1978), and the PTH gene contains a VDRE (Demay et al., 1992). Therefore, 1,25(OH)$_2$-D$_3$ may regulate production of PTH and the actions of PTH in the kidney and in bone by decreasing the transcription of the PTH gene through a 1,25(OH)$_2$-D$_3$-VDR-RXR interaction with the VDRE in the promoter region of the PTH gene.

In summary, the primary function of 1,25(OH)$_2$-D$_3$ is in the regulation of Ca homeostasis. Target organs for 1,25(OH)$_2$-D$_3$ relevant to Ca homeostasis, include the small intestine, kidney, bone, and parathyroid gland. The mechanisms through which 1,25(OH)$_2$-D$_3$ works are complex and only partially understood. The 1,25(OH)$_2$-D$_3$, through an interaction with a VDR-RXR heterodimer, can stimulate or inhibit gene transcription with the aid of various coactivators and transcription factors, which are only now beginning to be elucidated.

In contrast to focusing on one nutrient and how it affects the transcription of multiple genes, one can also focus on one protein and how numerous nutrients can alter its expression. Metallothioneins comprise a superfamily of proteins which are characterized by their low molecular weight, high Cysteine content, absence of aromatic amino acids, and their ability to bind heavy metals. Metallothionein was first discovered in 1957 by Margoshes and Valle in the equine kidney cortex. Since then MTs have been found throughout the animal kingdom, in plants and in eukaryotic and prokaryotic microorganisms. Hypothesized functions of MT include detoxification of heavy metals, zinc and copper homeostasis, antioxidants, and metal donors in the formation of metalloproteins. In addition, MTs can be transcriptionally regulated by a range of factors including: Zn (Sullivan and Cousins, 1997), Cu (Hidalgo et al., 1991), Cd, Pb, Hg, Ni (Tandon et al., 1993), Fe (Robertson et al., 1989), glucocorticoids (Hidalgo, 1988), TNF (De et al., 1990), IL-1 and –6 (Huber and Cousins, 1993), and PKC. These transcriptional regulators complex with response element binding proteins that bind to various response elements upstream from the MT promoter region. The functions of these proteins and their transcriptional regulation is MT isoform dependent, tissue specific, and age related.

Proteins within the MT superfamily are further subdivided into families, subfamilies, subgroups, isoforms, and finally clans. This paper will primarily deal with the family 1 MTs which contain vertebrate MTs. Within the family 1 MTs, 11 subfamiles exist designated m1, m2, m3, m4, m, a, a1, a2, b, ba, and t. The subfamiles m1, m2, m3, and m4 refer to mammalian MT-I, MT-II, MT-III, and MT-IV, respectively, and are encoded for by four separate genes. Metallothionein-I and MT-II contain 61-62 amino acids with 20 conserved Cys residues. They are found in most tissues with the highest concentrations being located in the kidney, liver, pancreas and intestines. Metallothionein-III, expressed in certain Zn sequestering neurons within the brain, contains 66-68 amino acids with 20 concerved Cys residues. Metallothionein-IV, expressed in squeamous epithelial cells, contains 62 amino acids with 20 conserved Cys residues.

Despite differences in the primary amino acid sequence of the four mammalian subfamlies of MTs, the structure of mammalian MTs is similar. Metallothioneins form a dumbell-like structure consisting of an α- and β-domain. Each domain contains a core of Cys amino acids capable of binding mono- and di-valent metals. All vertebrate MT genes have the same basic structure containing a 5' flanking region, a 5' untranslated region, three coding exons separated by two introns, and a 3' flanking region. The 5' flanking region contains various response elements which regulate transcription.

The α-domains of MT-I and MT-II contain 11 Cys and the β-domains contain 9 Cys capable of binding four and three divalent ions, respectively. Metallothionein-I preferentially binds Cd, while MT-II preferentially binds Zn. The literature contains much debate on the exact functions of MTs. Metallothioneins are capable of binding Cd, Pb, Hg, and Ni, and for this reason are considered to have a role in heavy metal detoxification. In addition, because of their ability to complex with Cu and Zn, MTs appear play a role in Cu and Zn homeostasis. Because of their relatively short half-life, MTs are not considered to be storage forms of Cu and Zn. Another proposal suggests that MTs may act as antioxidants. Metallothionein concentrations increase in response to oxidative stress, but their role as antioxidants is intertwined with Zn's role as an antioxidant. Metallothioneins may simply act as a metal donor to antioxidative enzymes such as Cu-Zn superoxide dismutase. In addition, MTs may act as zinc donors to stabilze sulfhydryl groups of proteins from oxidative damage.

Kelly et al. (1996) using MT-I and MT-II knockout mice observed a lower tolerance to Zn restriction and Zn toxicity in MT-I⁻/MT-II⁻ mice compared to control mice. They concluded that MT-I and MT-II serve to protect the animal from both Zn deficiency and toxicity. Davis et al. (1998) compared MT knockout mice (MT-I⁻/MT-II⁻), and mice overexpressing MT to control mice in an attempt to investigate the possible role of MT in Zn absorption. They found that serum Zn levels increased inversely to MT levels. In addition serum Zn was highly correlated with the zinc transporter ZnT-1. Therefore, they concluded that MTs have a negative impact on Zn absorption by decreasing serum Zn levels.

Metallothionein-II is transcribed at a basal level five times higher than MT-I (Read, 1998). It also contains a larger number of regulatory elements including, metal response elements (MREs), glucocorticoid response elements (GREs), interferon response elements (IREs; Read, 1998), antioxidant response elements (AREs) and AP-1 transcription factor binding sites (Ghoshal et al., 1998). Metallothionein-I genes have less complex regulator regions, containing only MREs, AREs, and CG rich segments which may be SP1 transcription factor binding sites proximal to the promoter region (Ghoshal, 1998; Read, 1998). The human MT-Ig gene contains five MREs upstream from the TATA box (Samson et al., 1995). Samson et al. (1995) using site directed mutagenesis, demonstrated that the TATA box and the MRE adjacent to the TATA box (MREa) were necessary for optimal promoter activity. They concluded that binding of the zinc containing, transcription activator protein, MTF-1 to MREa is necessary for transcription even in the presence of a functional non-mutated TATA box.

Many studies have demonstrated a correlation between dietary Zn and MT levels in poultry (Oh et al., 1979), rats (Menard et al., 1981; Gasull et al., 1994), mice (Olafson, 1983), and humans (Thomas et al., 1992; Zapata et al., 1997). Additional work has demonstrated that Zn affects MT expression at the transcriptional level by binding to a transcription activator protein (MTF-1) which interacts with a MRE in the 5' flanking region of the gene. This results in increased MT mRNA levels (Menard et al., 1981; Peterson and Mercer, 1988; Cousins and Lee-Ambrose, 1992). Sullivan and Cousins (1997) using competitive RT-PCR demonstrated in vitro and in vivo that Zn was capable of increasing MT transcription in THP-1 cells (human monocytic cell line) and monocytes (obtained from 20 healthy male subjects from 19 to 35 years of age). Dietary zinc's ability to increase MT transcription is tissue dependent. Increased MT expression as a result of dietary Zn has been observed in the intestines, liver, erythrocytes, bone marrow, kidney, monocytes, placenta, and pancreas (Oh et al., 1979; Thomas et al., 1992; Huber and Cousins, 1993; Sullivan and Cousins, 1997; Barone et al., 1998).

Metallothionein expression can also be regulated by Cu, Cd, Ni, Pb, gluccocorticoids, IL-1, IL-6, TNF, Fe, stress, and endotoxins (Hidalgo et al., 1988; Tandon et al., 1993; Huber and Cousins, 1993; De et al., 1990; Blalock and Hill, 1988). The mode of action of many of these compounds in MT regulation remains unclear. Most of the metals probably act by binding to a transcription factor, and thereby causing conformational changes which allow the transcription factor

to bind to the MRE of MT. However, the interactive effects of various metals on absorption and MT binding must also be considered. For example, MT binds Cu with greater affinity than Zn. Therefore, Cu can induce MT transcription either by directly binding to a transcription factor or by displacing MT-bound Zn, thus increasing the pool of free Zn. This unbound Zn is then free to bind MTF-1 which subsequently binds to the MRE and initiates transcription of MT. A GRE element has been identified on MT-II, and therefore glucocorticoids may directly affect MT transcription through interaction with a GRE-binding protein. In addition, glucocorticoids also increase transcription of the immediate early gene (IEG) *c-fos*. *Fos* the translational product of *c-fos* acts as a third messenger, in combination with other nuclear proteins, to activate transcription by binding to the activtor protein-1 (AP-1) response element. Metallothionein-II contains an AP-1 transcription site, and therefore, glucocorticoids may act indirectly through increased transcription of IEGs in addition to their direct effects on MT transcription. The actions of most compounds which regulate MT transcription are very complex and currently poorly understood.

Finally, the role of nutrition on immune status has received much attention in recent years. Much focus has been placed on enhancing host immune status through nutrition. In general, nutritionally the immune system can be enhanced or weakened and most of these alterations are through changes in gene transcription. While there is some extremely interesting research in this area, perhaps more interesting is research which has clearly demonstrated that nutrition can also influence viral phenotypes through point mutations in the viral genome, causing an avirulent strain to become virulent and enhancing the virulence of an already virulent strain. Beck (1997) reported that coxsackie-induced myocarditis observed in a group of women and children in China could be prevented by supplementing their diets with Se. Initially, this seemed fairly straight forward: immune status was low as a result of a Se deficiency and when this deficiency was corrected, individuals were able to fight off the effects of the virus. Using a mouse model, Beck (1997) reported that mice infected with a virulent strain of coxsackievirus developed more sever heart pathology when fed a Se or vitamin E deficient diet compared to mice fed an adequate diet. This would indicate a depressed immune response in animals fed a nutrient deficient diet. However, when animals were inoculated with an avirulent strain,

cardiac pathology similar to animals infected with the virulent strain was observed in mice fed the Se or vitamin E deficient diet. Further research by Beck (1997) clearly demonstrated that the viral genotype was altered when mice were fed a Se deficient diet, causing the avirulent strain to become virulent and causing the virulent strain to become more virulent. This one piece of research really forces us to think differently about nutrition and disease. Instead of simply focusing on the host, it may now be important to consider how nutritional changes may affect viral or pathogen genomes.

Literature Cited

Abe, E., C. Miyaura, H. Sakgami, M. Takeda, K. Konno, T. Yamazaki, S. Yoshiki, and T. Suda. 1981. Differentiation of mouse myeloid leukemia cells induced by $1\alpha,25$-dihydroxyvitamin D_3. Proc. Natl. Acad. Sci. 78(8):4990-4994.

Baker, A. R, D. P. McDonnel, M. Hughes, T. M. Crisp, D. J. Mangelsdorf, M. R. Haussler, J. W. Pike, J. Shine, and B. W. O'Malley. 1988. Cloning and expression of full-length cDNA encoding human vitamin D receptor. Proc. Natl. Acad. Sci. 85:3294-3298.

Barone, A., O. Ebesh, R. G. Harper, and R. A. Wapnir. 1998. Placental copper transport in rats: effects on elevated dietary zinc on fetal copper, iron and metallothionein. J. Nutr. 128:1037-1041.

Beck, M. A. 1997. Increased virulence of coxsackievirus B3 in mice due to vitamin E or selenium deficiency. J. Nutr. 127:966S-970S.

Blalock, T. L. and C. H. Hill. 1988. Studies on the role of iron in zinc toxicity in chicks. Biol. Trace Elem. Res. 17:17-29.

Blanco, J. C. G., I. M. Wang, S. Y. Tsai, M. J. Tsia, B. W. O'Malley, P. W. Jurutka, M. R. Haussler, and K. Ozato. 1995. Transcription factor TFIIB and the vitamin D receptor cooperatively activate ligand-dependent transcription. Proc. Natl. Acad. Sci. 92:1535-1539.

Burmester, J. K., R. J. Wiese, N. Maeda, and H. F. DeLuca. 1988. Structure and regulation of the rat 1,25-dihydroxyvitamin D_3 receptor. Proc. Natl. Acad. Sci. 85:9499-9502.

Christakos, S., J. D. Beck, and S. J. Hyllner. 1997. Calbindin-D_{28K}. In: D. Fedlman, F. H. Glorieux, and J. W. Pike (Ed) Vitamin D. pp 209-221. Academic Press, San Diego, CA.

Cousins, R. J. and L. M. Lee-Ambrose. 1992. Nuclear zinc uptake and interactions and metallothionein gene expressio are influenced by dietary zinc in rats. J. Nutr. 122:56-64.

Davis, S. R., R. J. McMahon, and R. J. Cousins. 1998. Metallothionein knockout an transgenic mice exhibit altered intestinal processing of zinc with uniform zinc-dependent zinc transporter-1 expression. J. Nutr. 128:825-831.

De, S. K., M. T. McMaster, and G. K. Andrews. 1990. Endotoxin induction of murine metallothionein gene expression. J. Biol. Chem. 265:15267-15224.

Demay, M. B., M. S. Kiernan, H. F. Deluca, and H. M. Kronenberg. 1992. Sequences in the human parathyroid hormone gene that bind the 1,25-dihydroxyvitamin D_3 receptor and mediate transcriptional repression in response to 1,25-dihydroxyvitamin D_3. Proc. Natl. Acad. Sci. 89:8097-8101.

Fei, Y.-J., Y. Kanal, S. Nussbereger, V. Ganapathy, F. H. Leibach, M. F. Romero, S. K. Singh, W. F. Boron, and M. A. Hediger. 1994. Expression cloning of a mammalian proton-coupled oligopeptide transporter. Nature. 368:563-566.

Forman, B. M., K. Umensono, J. Chen, and R. M. Evans. 1995. Unique response patterns are established by allosteric interactions among nuclear hormone receptors. Cell. 81:541-550.

Garabedian, M, M. F. Holick, H. F. DeLuca, and I. T. Boyle. 1972. Control of 25-hydroxycholecalciferol metabolism by parathyroid glands. Proc. Natl. Acad. Sci. 69(7):1673-1676.

Garrahan, P. J. and A. F. Rega. 1990. Plasma membrane calcium pump. In: F. Bronner (Ed.) Intracellular Calcium Regulation. New York, Wiley-Liss, pp. 271-303.

Gasull, T., M. Giralt, J. Hernandez, P. Martinez, I. Bremmer, and J. Hidalgo. 1994. Regulation of metallothionein concentrations in rat brain: effect of glucocorticoids, zinc, copper, and endotoxin. Am. J Physiol. 266:E760-E767.

Ghoshal, K., Y. Wang J. F. Sheridan, and S. T. Jacob. 1998. Metallothionein induction in response to restraint stress. J. Biol. Chem. 273:27904-27910.

Gill, R. K., and S. Christakos. 1993. Identification of sequence elements in mouse calbindin-D_{28K} gene that confer 1,25-dihydroxyvitamin D_3- and butyrate-inducible responses. Proc. Natl. Acad. Sci. 84:2984-2988.

Hidalgo, J., L. Campmany, M. Borras, J. S. Garvey, and A. Armario. 1988. Metallothionein response to stress in rats: role in free radical scavenging. Am. J. Physiol. 255:E518-E524.

Hidalgo, J., L. Campmany, O. Marti, and A. Armario. 1991. Metallothionein-I induction by stress in specific brain areas. Neurochemical Res. 16:1145-1148.

Hidalgo, J., M. Giralt, J. S. Garvey, and A. Armario. 1988. Physiological role of glucocorticoids on rat serum and liver metallothionein in basal and stress conditions. Am. J. Physiol. 254:E71-E78.

Huber, K. L. and R. J. Cousins. 1993. Metallothionein expression in rat bone marrow is dependent on dietary zinc but not dependent on interleukin-1 or interleukin-6. J. Nutr. 123:642-648.

Hughes, M. R. and M. R. Haussler. 1978. 1,25-Dihydroxyvitamin D_3 receptors in parathyroid galnds. Preliminary characterization of cytoplasmic and nuclear binding components. J. Biol. Chem. 252:1065-1073.

Jones, G., S. A.Strugnell, and H. F. DeLuca. 1998. Current understanding of the molecular actions of vitamin D. Physiol. Rev. 78(4):1193-1231.

Kelly, E. J., C. J. Quaife, G. J. Froelick, and R. D. Palmiter. 1996. Metallothionein I and II protect against zinc deficiency and zinc toxicity in mice. J. Nutr. 126:1782-1790.

Kimmel-Jehan, C., F. Jehan, and H. F. DeLuca. 1997. Salt concentration determines 1,25-dihydroxyvitamin D_3 dependency of vitamin D receptor-retinoid X receptor-vitamin D-responsive element complex formation. Arch. Biochem. Biophys. 341(1):75-80.

Kliewer, S. A., K. Umensono, D. J. Mangelsdorf, and R. M. Evans. 1992. Retinoid X receptor interacts with nuclear receptors in retionoic acid, thyroid hormone and vitamin D_3 signaling. Nature. 355:446-449.

Low, A. G. and A. L. Rainbird. 1984. Effect of guar gum on nitrogen secretion into isolated loops of jejunum in conscious growing pigs. Brit. J. Nutr. 52:499-505.

MacDonald, P. N., D. R. Sherman, D. R. Dowd, S. C. Jefcoat, Jr., and R. K. DeLisle. 1995. The vitamin D receptor interacts with general transcription factor IIB. J. Biol. Chem. 270(9):4748-4752.

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McDonnell, D. P, D. J. Mangelsdorf, J. W. Pike, M. R. Haussler, and B. W. O'Malley. 1987. Molecular cloning of complementary DNA encoding the avian receptor for vitamin D. Science. 235:1214-1217.

Menard, M. P., C. C. McCormick, and R. J. Cousins. 1981. Regulation of intestinal methionein biosynthesis in rats by dietary zinc. J. Nutr. 111:1352-1361.

Oh, S. H., H. Nakaue, J. T. Deagan, P. D. Whanger, and G. H. Arscott. 1979. Accumulation and depletion of zinc in chick tissue metallothioneins. J. Nutr. 109:1720-1729.

Olafson, R. W. 1983. Intestinal metallothionein: effect of parenteral and enteral zinc exposure on tissue levels of mice on controlled zinc diets. J. Nutr. 113:168-175.

Peteson, G. and J. F. B. Mercer. 1988. Differential expression of four linked sheep metallothionein genes. J. Biochem. 419-429.

Raisz, L. G., C. L. Trummel, H. F. Holick, and H. F. DeLuca. 1972. 1,25-Dihydroxycholecalciferol: a potent stimulator of bone resorption in tissue culture. Science. 175:768-769.

Reeves, J. P. 1990. Sodium-calcium exchange. In: F. Bronner (Ed.) Intracellular Calcium Regulation. New York, Wiley-Liss, pp. 305-347.

Robertson, A., J. N. Morrison, A. M. Wood, And I. Bremmer. 1989. Effects of iron deficiency on metallothionein-I concentrations in blood and tissues of rats. J. Nutr. 119:439-445.

Samson, S. L.-A., W. J. Paramchuk, N. W. Shworak, and L. Gedamu. 1995. Functional analysis of the human metallothionein-IG gene. J. Biol. Chem. 270:25194-25199.

Shinki, T., Ch. H. Jin, A. Nishimura, Y. Nagai. Y. Ohyama, M. Noshiro, K. Okuda, and T. Suda. 1992. Parathyroid hormone inhibits 25-hydroxyvitamin D_3-24-hydroxylase mRNA expression stimulated by 1α,25-dihydroxyvitamin D_3 in rat kidney but not in intestine. J. Biol. Chem. 287(19):13757-13762.

Stern, P. H. 1997. 1,25-Dihydroxyvitamin D_3 interactions with local factors in bone remodeling. In: D. Fedlman, F. H. Glorieux, and J. W. Pike (Ed) Vitamin D. pp 341-352. Academic Press, San Diego, CA.

Suda, T. and N. Takahashi. 1997. Vitamin D and osteogenesis In: D. Fedlman, F. H. Glorieux, and J. W. Pike (Ed) Vitamin D. pp 329-340. Academic Press, San Diego, CA.

Sullivan, V. K. and R. J. Cousins. 1997. Competitive reverse transcriptase-polymerase chain reaction shows that dietary zinc supplementation in humans increase monocyte metalothionein mRNA levels. J. Nutr. 127:694-698.

Tanaka, H., E. Abe, C. Miyaura, T. Kuribayashi, K. Konno, Y. Nishii, and T. Suda. 1982. 1α,25-Dihydroxycholecalciferol and a human myeloid leukemia cell line (HL-60). Biochem. J. 204:713-719.

Tanaka, Y, R. S. Lorenc, and H. F. DeLuca. 1975. The role of 1,25-dihydroxyvitamin D_3 and parathyroid hormone in regulation of chick renal 25-hydroxyvitamin D_3-24-hydroxylase. Arch. Biochem. Biophys. 171:521-526.

Tandon, S. K., S. Khandelwal, V. K. Jain, and N. Mathur. 1993. Influence of dietary iron deficiency on acute metal intoxification. BioMetals 6:133-138.

Thomas, E. A., L. B. Bailey, G. A. Kauwell, D.-Y. Lee, R. J. Cousins. 1992. Erythrocyte metallothionein response to dietary zinc in humans. J. Nutr. 122:2408-2414.

Thomasset, M. 1997. Cabindin-D_{9K}. In: D. Fedlman, F. H. Glorieux, and J. W. Pike (Ed) Vitamin D. pp 223-232. Academic Press, San Diego, CA.

Umensono, K. K. Murakami, C. C. Thompson, and R. M. Evans. 1991. Direct repeats as selective response elements for the thyroid hormone retinoic acid, and vitamin D_3 receptors. Cell. 65:1255-1266.

Wasserman, R. H., J. S. Chandler, and S. A. Meyer. 1992. Intestinal calcium transport and calcium extrusion processes at the basolateral membrane. J. Nutr. 122:662-671.

Yang, W., P. A. Friedman, R. Kumar, J. L. Omdahl, B. K. May, M.-L. Siu-Caldea, G. S. Reddy, and S. Christakos. 1999. Expression of 25(OH)D_3 24-hydroxylase in distal nephron: coordinate regulation by 1,25(OH)$_2D_3$ and cAMP or PTH. Am. J. Physiol. 276(39)-E793-E805.

Zapata, C. L. V., T. M. R. Simoes, and C. M. Donangelo. 1997. Erythrocyte metallothionein in relation to other biochemical zinc indices in pregnant and nonpregnant women. Biol. Trace Elem. Res. 57:115-124.

The Changing Mineral Status of High Producing Sows -- What are their Needs and When are the Critical Periods ?

Don Mahan
Department of Animal Sciences
The Ohio State University
Columbus, OH 43210

Summary

With the introduction of high producing maternal lines into commercial swine herds, the number of pigs born, weaned and the subsequent increase in birth and weaning weights are increasing. During the last 14 days of pregnancy approximately 50% of the total minerals (macro and micro) minerals are retained in the body of developing fetal pigs. During lactation the mineral retention by the nursing litter is higher than late gestation and greater as litter size increases. The critical stage of minerals for the sow appears to be during late gestation and lactation. Sow milk mineral composition is largely under genetic control but is influenced by stage of lactation, and litter size. Feeding organic trace minerals over a 6 parity period showed improved reproductive performance and may enhance litter size by 1 to 2 pigs per year. High producing sows have a lower body mineral content than low producing or non reproducing sows with the amount of mineral depletion exacerbated by greater sow productivities.

Introduction

With the introduction of new maternal sow lines capable of producing litters of larger size and heavier birth weights, and sows with greater milk productions resulting in more pigs weaned at heavier weaning weights, the nutritional demand on these animals is exceedingly high. The large turnover rate in many sow herds conservatively approaches 30 to 45%, and it would be expected that sows of greater productivities would be more nutritionally challenged and thus among the first animals culled. Although the reasons for culling sows are many, they can be generally categorized in the areas of anestrus, poor conception rate, low litter size, and poor feet and legs. The anestrus and poor conception rates have largely been associated with poor sow condition and low lactation feed intakes, thus attributed to being energy and protein deficient, whereas the skeletal problems have been associated largely with Ca and P inadequacy. Calcium and P as well as the trace minerals are involved in skeletal formation as well as being associated in other biological functions influencing anestrus, conception rate, litter size, and feet and leg problems.

The NRC (1998) swine mineral recommendations, has not materially changed, except for Se, for the past 25 years (1973 to 1998), even though sow productivity has increased tremendously during this time frame. Any effect of mineral inadequacy or supplemental trace minerals on sow turnover rate is unknown. Clearly the sow cannot meet her biological need for nutrients, particularly the minerals, using recommendations of the previous decades. A recent report has demonstrated that sow mineral reserves are depleted over a 3 parity period, and that sows of a higher productivity had a greater loss of both macro and micro minerals than sows of lower productivities (Mahan and Newton, 1995).

To counter the anticipated greater biological need for minerals by high producing sow lines, the feed industry and university specialists have routinely recommended higher dietary fortification levels of both macro and micro minerals, as well as other nutrients, in gestation and lactation sow diets. Although this practice is perhaps logical and may be exactly what these sows need for higher productivities, it is generally not based on research but field observations and "educated guess work". This brief review will investigate when the mineral requirements of sows are

greatest, what is the effects of fortifying additional minerals, evaluating the role of organic and inorganic trace minerals, and examining sow mineral status in high producing sows over a long reproductive life.

Calcium and Phosphorus

Calcium and P are the two major minerals largely associated with leg structure and integrity. The research of Nimmo et al. (1981) demonstrated that a higher percentage of gilts were unable to stand through the first parity when fed NRC (1978) dietary levels of Ca and P during developmental and reproductive periods. Other work has shown that sows of greater productivities have greater amounts of bone demineralization taking place during their reproductive life (Maxson and Mahan, 1986). These combined results suggest that during the developmental growth period and the reproductive period there is a high Ca and P demand for these two minerals. These minerals can thus be removed from bone tissue when milk production demands are great. Other research by Mahan and Fetter (1982) demonstrated that the trabecular bone (i.e., spongy bone) was the main reservoir where these minerals were initially removed, but later bone demineralization takes place in the cortical bone shaft. Posterior paralysis or "downer sow syndrome" has been common in many sows and is generally observed during late pregnancy and early lactation, This suggests that when fetal demands are high or when sow milk production is great, the mineral needs for these physiological functions are not easily met by the diet fed to the sow, particularly when fortified with existing recommendation levels.

An experiment to evaluate fetal deposition of minerals, from 45 days post coitum to late pregnancy was conducted. The data suggested that the total body mineral content of the developing litter approximately doubled every 15 to 20 days of pregnancy, but more than 50% of the total mineral content in the developing litter occurred during the last 2 weeks of gestation (Figure 1). Although this graph reflects the total mineral content of the litter, when the individual minerals were plotted for the same period, both Ca and P approximately doubled during the last 2 weeks of pregnancy (Figure 2). Thus it is understandable why the sow undergo bone demineralization during this critical stage of gestation, and that the responses would be exacerbated in sows having larger litter size or milk production capabilities.

Upon farrowing sow colostrum is low in its Ca concentration but rises as lactation progresses (Figure 3). The low Ca level at parturition can be explained by the diminishing Ca status of the gestating sow because she has been transferring tremendous amounts of Ca to her developing fetus. This has resulted in minimal body stores for later transfer to the mammary tissue. Consequently, the amount being secreted into colostrum is lowered. During the postpartum or lactation period when feed intake increases, the demands for fetal development have been eliminated, milk secretion now has the primary demand for Ca, the amount of Ca in the mature milk thus is increased (Figure 3). There appears, however, to be an effect of litter size or amount on the resulting Ca composition in the milk possibly increasing bone demineralization. When sows nursed 8 versus 11 pigs per litter the amount of Ca in the milk of sows nursing the larger litter size was lower ($P < 0.05$). The same trend was true for milk P where sows nursing larger litters and thus producing more milk had low milk P contents (Figure 4).

As a result of the above findings the total deposition of Ca and P in litters of pigs at weaning (11 or 21 days) was greater in larger litter sizes (Figures 5 and 6). When expressed on an individual pig basis, there was no difference in the Ca and P content of these individual pigs suggesting that the progeny had approximately the same mineral contents. Consequently, the trace mineral content in individual pigs in at least somewhat under genetic control, and that the sow supplied additional Ca and P not only from the diet but also from her body tissue (i.e., bone) for the nursing litter.

Micro-minerals

The data presented in Figures 1 to 3 implies that the largest response to the increased mineral retention in the developing litter was attributable to Ca and P. The data demonstrated that all essential trace minerals followed the same general pattern of retention as Ca and P, but they also showed some differences. This difference is attributed to the different biological functions of each element as to when it is needed by the fetus at a specific stage of development or later in gestation, where the fetus retains minerals for its subsequent postnatal life. For example, the greater Zn content in the fetus is in largely in the epidermal tissue and its increase would be expected to be in

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proportion to body surface area, whereas the greatest need for Fe would be during late gestation when the need for blood hemoglobin synthesis is high in the neonate.

Two of the critical trace elements (Fe, and Zn) will be presented in Figure 7. Although the amount of Zn did not double during the last 2 weeks of fetal development, as did Ca and P, the quantity of Fe increased greatly during this latter gestation period. Although total Fe content is shown to increase greatly during late gestation, it is still below that necessary for the neonate postnatally. Consequently, an exogenous supply is needed to prevent anemia in the young pig. The amount of Fe secreted into the mammary tissue is considered to be inadequate in meeting the high Fe demands of the rapidly growing pig. Sow colostrum and milk Fe composition is presented in Figure 8. The Fe content in colostrum and later in the mature milk declined as lactation progressed, and that its content during late lactation appeared to be also influenced by the number of pigs nursing the sow. Pigs of a larger litter size received milk of a lower Fe contents than pigs nursing sows of a lower litter size.

The total Fe content in litter sizes of 8 or 11 pigs when weaned at 11 or 21 days of age showed that larger litters had greater total Fe contents (Figure 9). Consequently, sows nursing larger litters would be expected to have a lower body Fe status or the sow had to consume more feed during lactation to maintain her body Fe status. Fields reports are indicating increasing evidence of anemia in adult sows.

The Zn content of the developing litter during gestation presented in Figure 7 demonstrates that the Zn content in the litter increased greatly over the gestation period with the greatest increase occurring during the last 2 weeks of pregnancy. Colostrum had the highest concentration of Zn compared to later milks. Zinc concentration declined in the later milk. There appeared to be little effect of litter size on milk Zn concentration during lactation.

The total Zn content in the litter increased as the pig reached weaning age, and sows having larger litters had litters with the greater total Zn contents.

Organic vs. Inorganic mineral sources

Trace minerals perform several roles in the body and are essential for several reproductive functions. Not only are they involved in enzyme control of various metabolic and hormonal processes, but they are also important in growth processes, health and immune control. When provided in slight excess they are retained in the liver but they have also been shown to be pro oxidants, and thus can be a detriment to body functions. Consequently, the form of the element provided to the animal may become more important in the future as dietary needs increase. For example, inorganic or organic Se when provided to meet the pig's requirement will enhance the immune system and antioxidant control systems. However, when either form in provided in some excess, much of the organic Se is retained in tissue whereas excess inorganic Se has been shown to cause oxidative damage to the tissue and thus is detrimental to animal performance. Therefore the role of different forms of trace minerals may now become more important, particularly when higher dietary levels are fed.

With increasing mineral needs of sows, there is concurrently an interest in increasing dietary trace mineral levels in sows during gestation and lactation. Research investigations have been lacking in this area, and most of the dietary adjustments by specialists (University, Feed industry, and Veterinarians) have simply increased each of the trace minerals in proportion to estimated needs. We have recently completed a long term (6 parity) sow study evaluating various dietary trace mineral levels when fed as either as inorganic (sulfate or oxide form) or organic trace minerals (Bio Plex). The experiment included NRC (1998) levels or higher trace mineral levels typical of what is provided by the industry. Two additional treatments were initiated at breeding where the gilts had been fed the industry level of the trace minerals during their developmental period, but at breeding additional Ca and P were provided along with the higher trace mineral level. The experiment involved a total of 375 litters and the overall results are presented in Figure 12 (Peters, 2006). Although not presented here the total number of pigs born was approximately 1 additional pig per litter when the organic trace minerals were fed. As evident in Figure 12 there was no difference in the number of live pigs born when NRC (1998) was provided. However when pigs were fed the industry level of both trace mineral sources along with the groups fed additional Ca and P, litter size was lower when inorganic minerals were fed. Although this experiment needs to be confirmed with another set of animals, the results suggest that organic minerals may be superior to inorganic minerals, and that extra fortification of minerals in the organic form may be beneficial to sow

reproductive performance.

Sow Mineral Status

Sows during their reproductive life not only have greater trace mineral needs, and they also eat more feed and thus consume more minerals. However, the net effect is that they also have a greater loss of body minerals during gestation through lactation (Mahan and Newton, 1995). As sow productivity increases, the nutritional demand on the sow would expectedly increase, and thus their body mineral reservoirs would diminish. When the mineral contents of sows completing 3 parities were compared to a set of non reproducing gilts of the same age, the results showed that most of the minerals were lower in sows that had reproduced (Figure 13). Both Ca and P had more of the greater loss having approximately 15 to 20% less total contents of these two minerals. Of the remaining minerals Mg, Cu, Se and Zn also had lower contents in the reproducing sow. It is of interest to note that sows of higher productivities had a greater loss of minerals than the sows of lower productivities.

Future

Although mineral requirements are poorly defined for reproducing animals (Hostetler et al., 2003), continued research is needed to determine these requirements. Clearly high producing sows have a greater need for minerals than sows of lower productivities. The results presented in these series of studies imply that there is perhaps an "ideal ratio" and perhaps "critical window of need" for the trace minerals for reproduction. This "ideal ratio of minerals" and their biological need at specific time periods during gestation might also differ by stage of reproduction. Higher productivities have higher dietary requirements for these minerals thus depleting body reserves.

Although we are accustomed to increasing dietary minerals in proportion to estimated needs, this practice may be in error because of the differing "windows of need" and the potential detrimental effects of excess levels. Mineral needs are perhaps regulated both genetically and by litter size, whereas lactation mammary secretions may not only reflect genetic input into milk secretion patterns, but may

also reflect an avenue where excess minerals may be excreted by the body. The requirement for the trace minerals may be influenced by the form of mineral provided. It is also possible that higher dietary minerals may be desirable at some stages of reproduction and detrimental at other stages. The role of organic minerals in this area is as yet unknown, but our results indicate that they may have a positive influence on sow reproductive performance when elevated in the diet, whereas when inorganic minerals are provided at the "normal" higher levels they may be detrimental, particularly if provided continually. Determining the mineral needs of the reproducing sow is indeed in its infancy compared to other nutrients. More extensive research needs to be conducted and their requirement appears to be exacerbated as the genetic capability of the animal changes.

Literature cited

Hostetler, C.E., R.L. Kincaid and M.A. Mirando. 2003. The role of essential trace elements in embryonic and fetal development in livestock. Vet. J. 166:125-139.

Mahan, D. C., and A. W. Fetter. 1982. Dietary calcium and phosphorus levels for reproducing sows. J. Anim. Sci. 34:283

Maxson, P. F., and D. C. Mahan. 1986. Dietary calcium and phosphorus for lactating swine at high and average production levels. J. Anim. Sci. 63:1163-1172.

Nimmo. R. D., E. R. Peo, Jr., B D. Moser, and A. J. Lewis. 1981. Effect of level of dietary calcium –phosphorus during growth and gestation on performance, blood and bone parameters of swine. J. Anim. Sci. 52-1330.

NRC. 1979. Nutrient Requirements of Domestic Animals. Nutrient Requirements of Swine.8th Revised Ed. National Academy of Sciences.

NRC. 1998. Nutrient Requirements of Domestic Animals. Nutrient Requirements of Swine.10th Revised Ed. National Academy of Sciences.

Peters, J. C. 2006. Evaluating the efficacy of dietary organic and inorganic trace minerals in reproducing female pigs on reproductive performance and body mineral composition. PhD thesis.

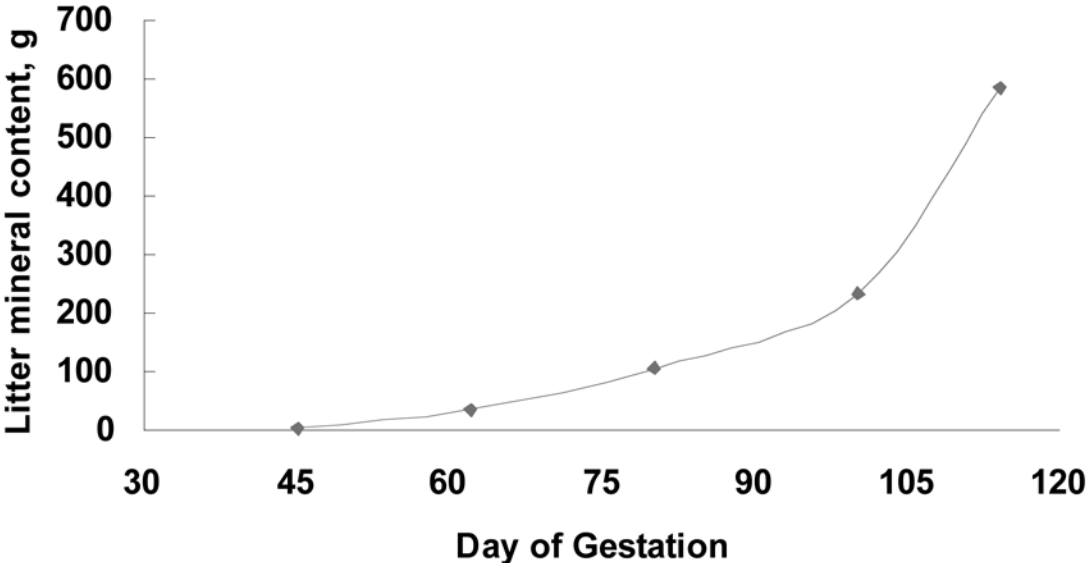**Figure 1. Total mineral content of developing pig litters from 45 days postcoitum to birth**

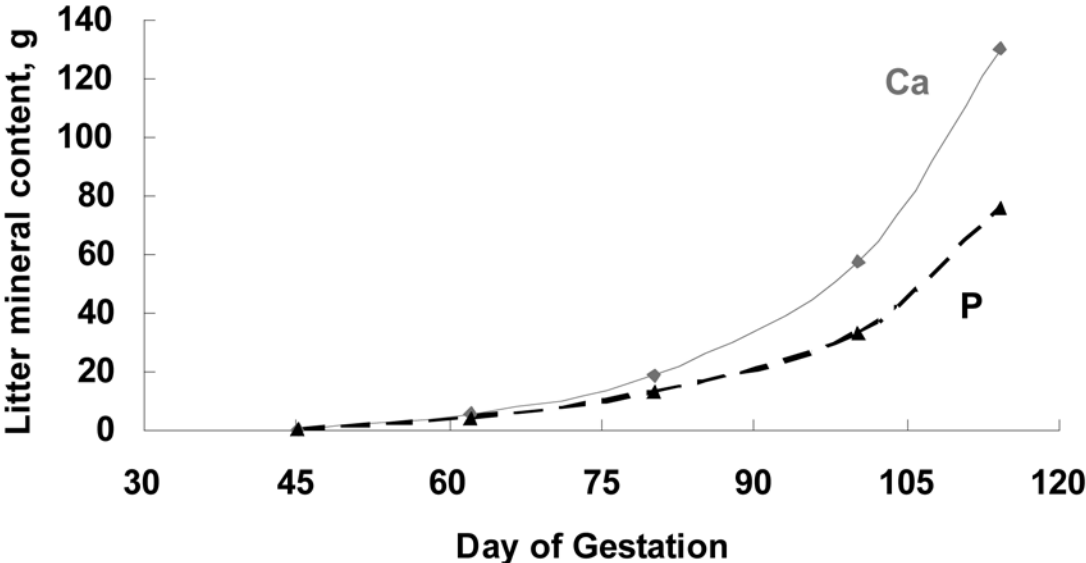**Figure 2. Total calcium and phosphorus content of developing pigs from 45 days postcoitum to birth**

Figure 3. Calcium content of colostrum and milk at birth, 11, and 21 days postpartum of sows nursing two litter sizes
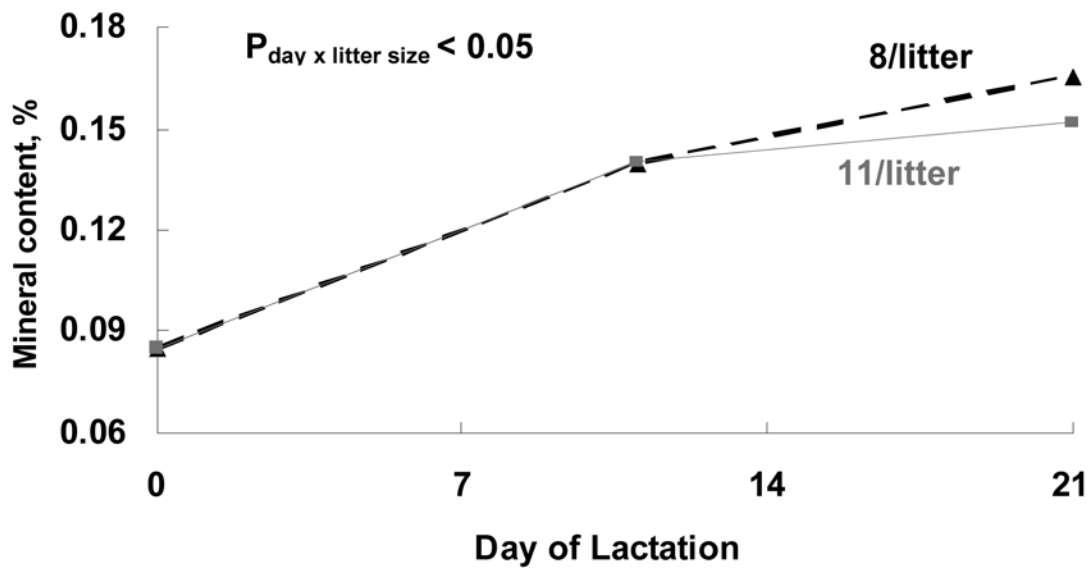
$P_{\text{day x litter size}} < 0.05$

8/litter

11/litter

Mineral content, %

0.18
0.15
0.12
0.09
0.06

Day of Lactation

0   7   14   21

Figure 4. Phosphorus content of colostrum and milk at birth, 11 and 21 days postpartum of sows nursing two litter sizes

$P_{\text{day x litter size}} < 0.06$

8/litter

11/litter

Mineral content, %

0.15
0.14
0.13
0.12
0.11
0.10
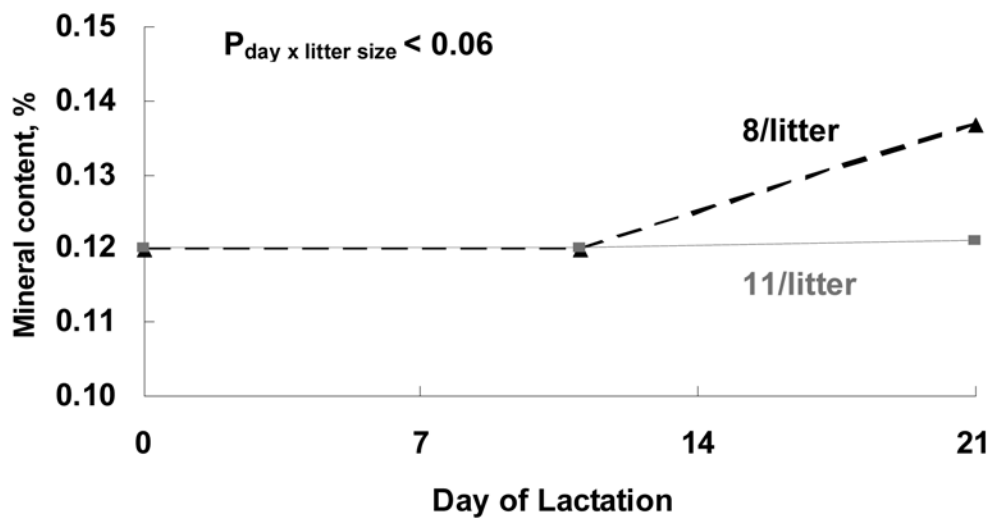
Day of Lactation

0   7   14   21

Figure 5. Total litter calcium content of neonatal and nursing pigs at birth, 11, and 21 days postpartum of two litter sizes
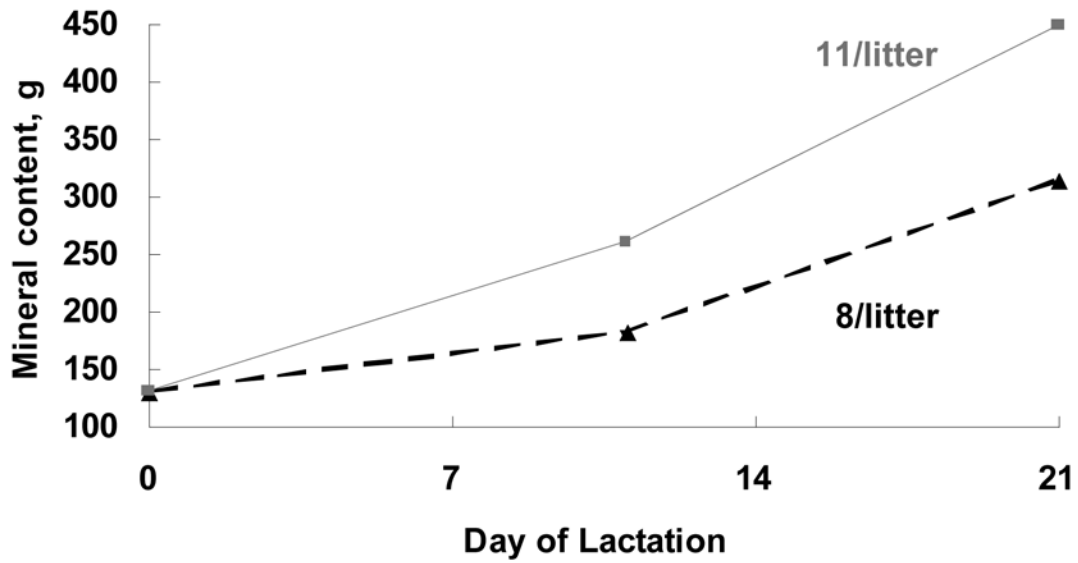

Figure 6. Total litter phosphorus content of neonatal and nursing pigs of two litter sizes at birth, 11, and 21 days postpartum
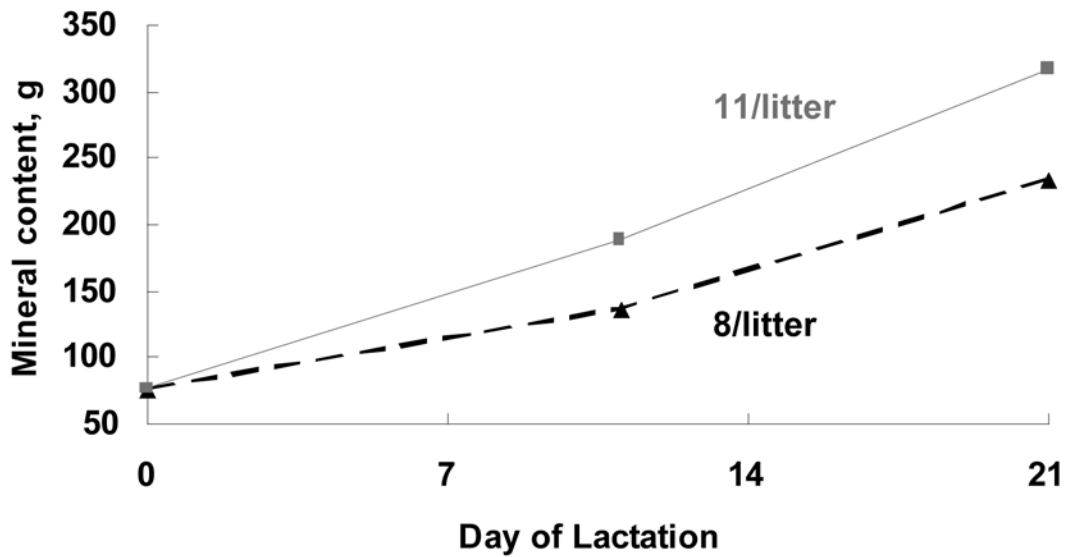
Figure 7. Total iron and zinc content of developing pig litters from 45 days postcoitum to birth
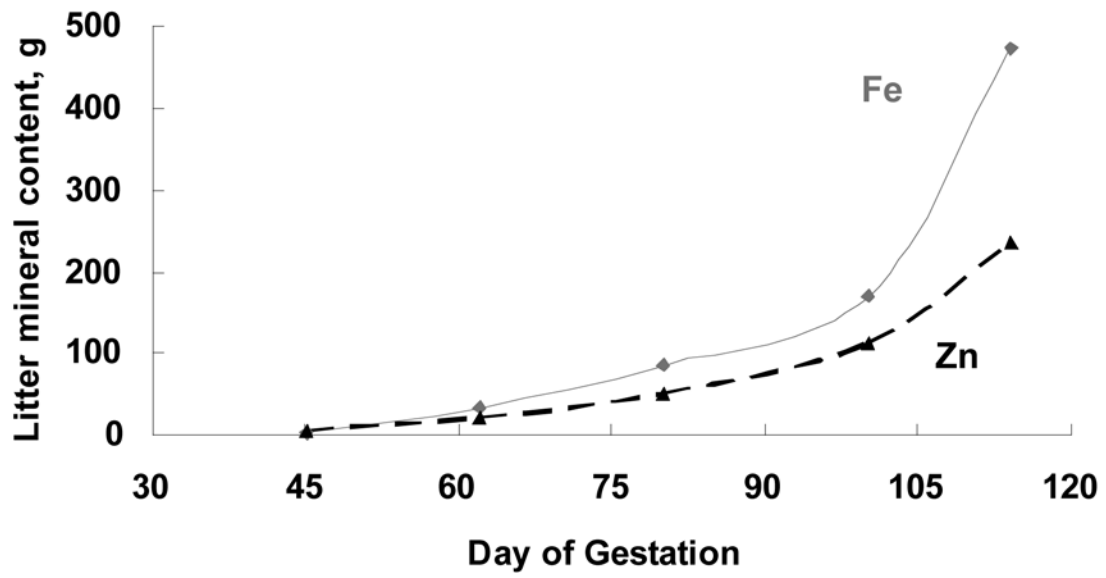
Figure 8. Iron content of colostrum and milk at birth, 11, and 21 days postpartum of sows nursing two litter sizes

$P_{day} < 0.01$

8/litter

11/litter

Mineral content, ppm

Day of Lactation

Figure 9. Total iron content of neonatal and nursing pigs at birth, 11, and 21 days postpartum of two litter sizes

11/litter

8/litter
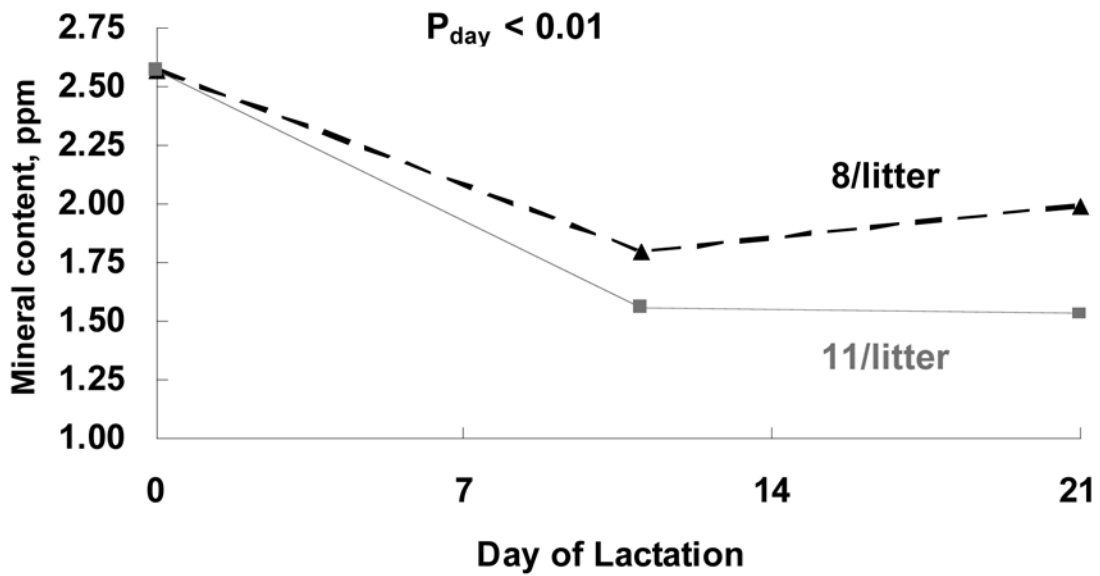
Mineral content, g

Day of Lactation
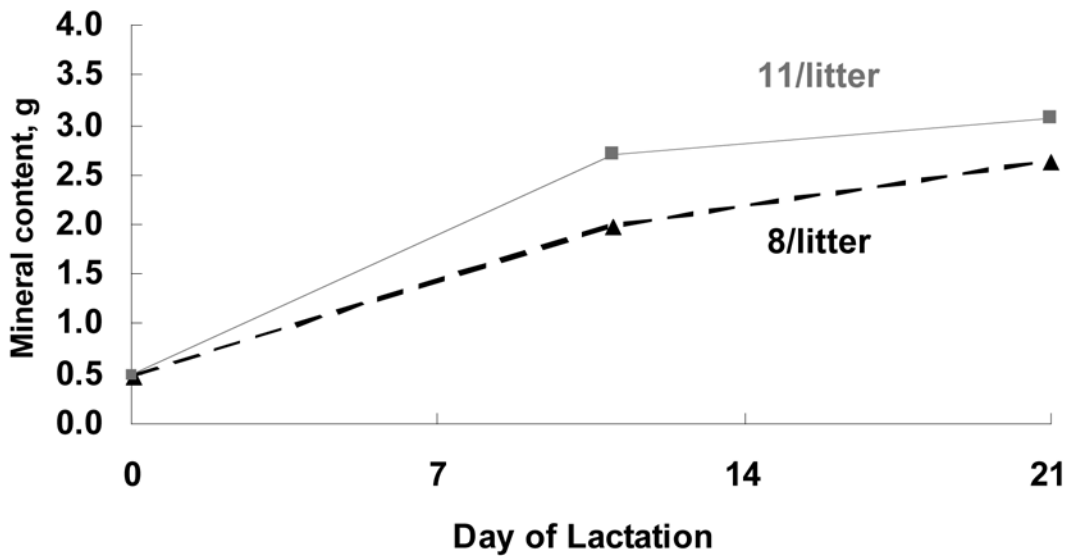
Figure 10. Zinc content of colostrum and milk at birth, 11, and 21 days postpartum of sows nursing two litter sizes

$P_{day} < 0.01$

Mineral content, ppm

8/litter

11/litter

Day of Lactation

Figure 11. Total zinc content of neonatal and nursing pigs at birth, 11, and 21 days postpartum of two litter sizes

Mineral content, g

11/litter
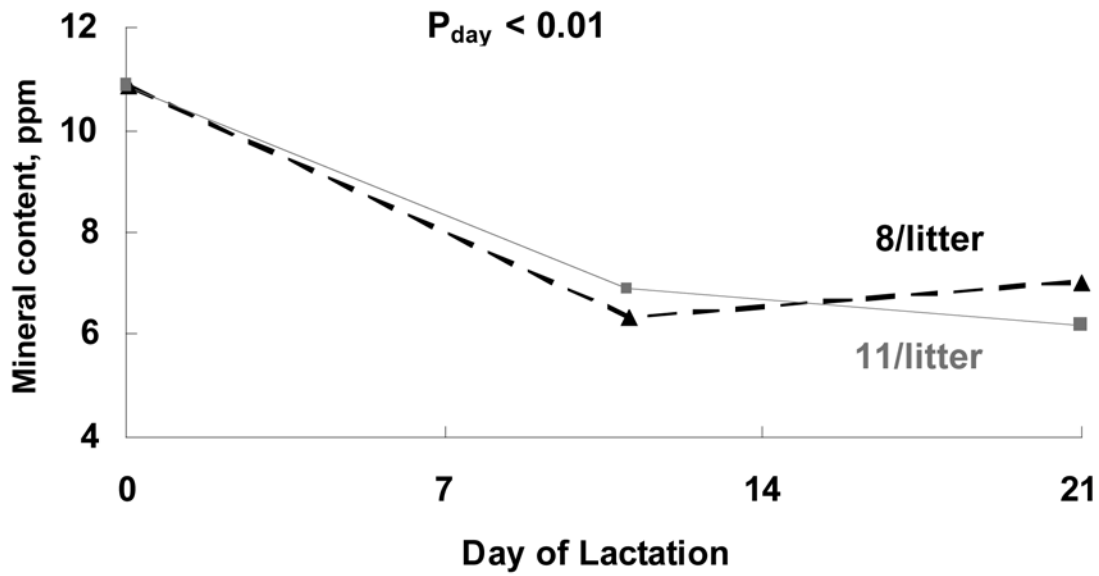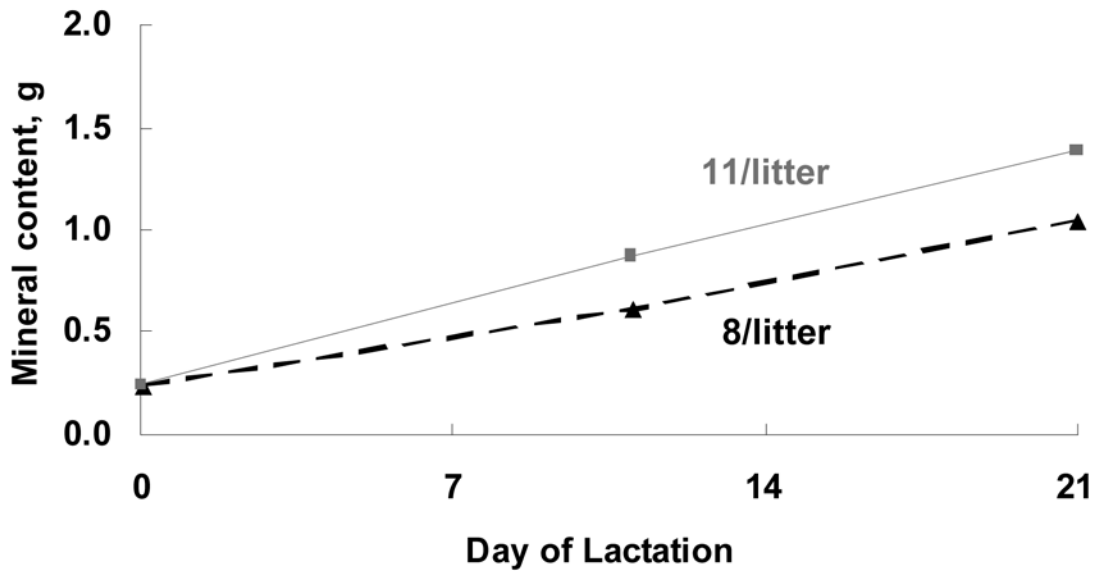
8/litter

Day of Lactation

26

Figure 12. Effect of Organic and Inorganic trace mineral sources at two dietary levels over a 6 parities
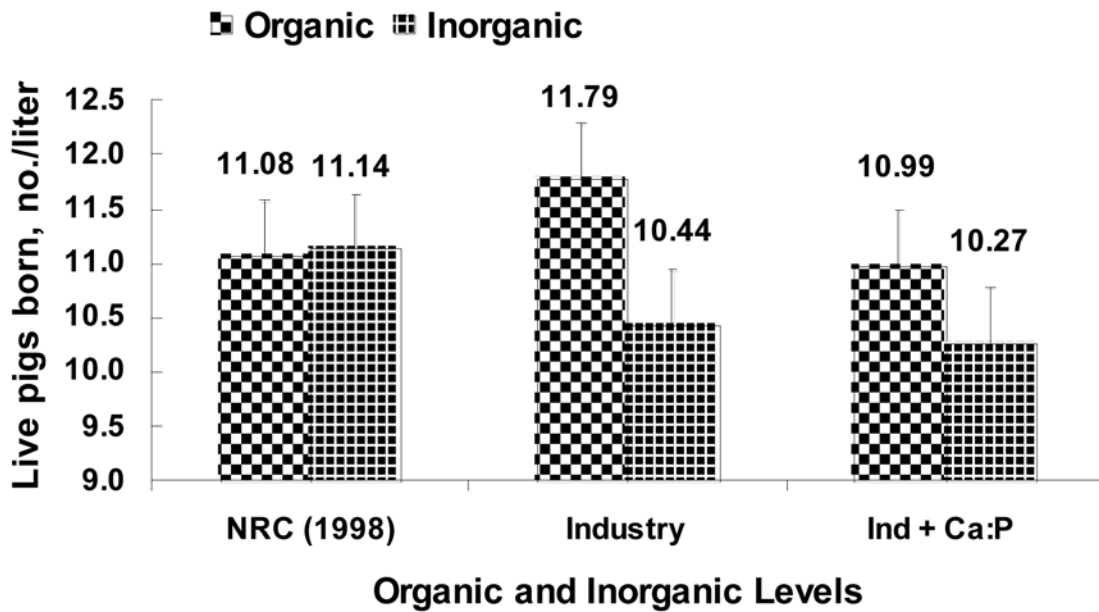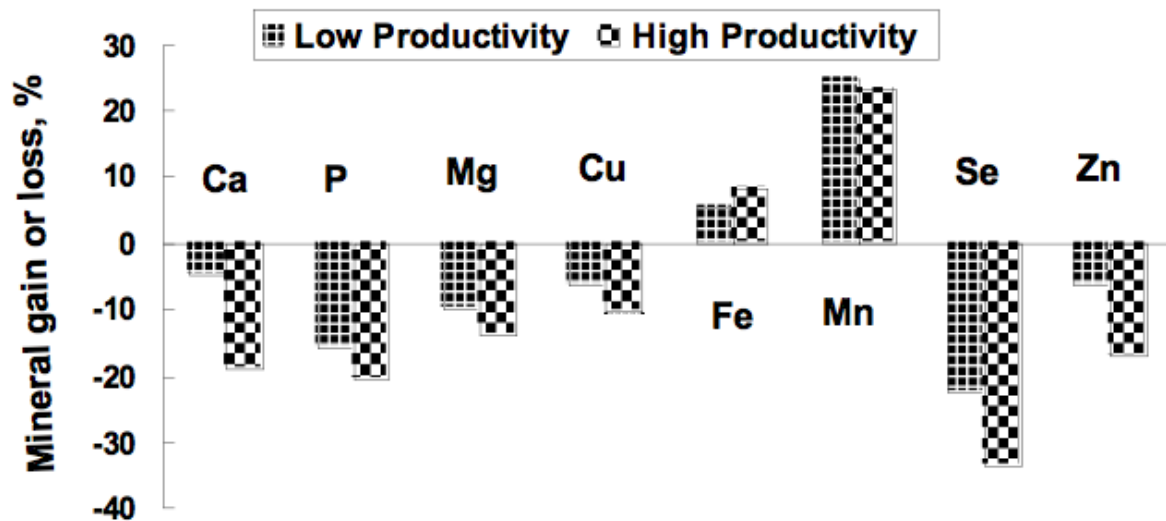

Figure 13. Mineral losses or gains after a 3 parity period (compared to non gravid control)

Corn and Soybeans: What's Here? What's Coming?

Daniel B. Jones, Ph.D.
Pioneer Hi-Bred International, Inc.
7100 N.W. 62nd Avenue
Johnston, IA 50131
515-334-7025
daniel.jones@pioneer.com

Summary

New and improved grain functionality traits are being developed and commercialized. These traits show promise for delivering significant utility to grain end-users and upgrading the overall value creation from row crop production. Commercialization of these traits will require buyers to begin establishing improved specifications for grain trade based on the grains' functional value. With improved, market recognized functionality standards in place supply chains can begin to recognize value and the processes to develop products that meet these improved standards can be focused and accelerated

Introduction

It is estimated that 78% of the corn and virtually all of the soybean meal produced in the United States is fed to livestock (USDA, 2004). Until recently seed companies largely ignored the ultimate end-use of the grain produced from their seed products and little had been done to improve or characterize grain coming from specific hybrids for its utility for animal feeding or other end-use purposes. This has been driven in large part by grain grading/trading standards that do not differentiate adequately on the basis of end-use utility. Therefore, plant breeding efforts have largely focused on increasing productivity (as measured by harvestable dry matter yield) with little consideration of the nutritional or industrial functionality of the grain products produced. With new technologies emerging to measure grain functionality plant breeders and end-use industries have begun to focus on the opportunities to enhance end-use utility and value of hybrid grain products. With the advent of improved breeding techniques and biotechnology applications, the stage is set for significant functional quality improvement of grains to occur. A key driver that is lacking to accelerate this change process is purchasing and trading specifications that monetize value of grain according to its intended use.

Focus areas for grain improvements?

Available Energy Concentration

Feed energy represents 60 to 70% of the total cost of livestock production, and in most of the world course grains such as corn, grain sorghum and wheat, and plant protein meals such as soybean meal make up the majority of animal rations. Corn is arguably the worlds most prevalent and abundant feed grain and can be considered to be the "energy currency of animal production". When this is considered, it is logical that characterizing existing genetic lines for available energy yield, and employing technologies to increase available energy yield rank as a high priority for seed companies.

Developments of technologies capable of delivering improvements in this area in corn are focused on:

1) Increasing gross energy by increasing oil concentration in the kernel.

2) Increasing digestibility of energy containing components (protein, oil, starch, fiber).

3) Employing both routes simultaneously.

Improving dry matter and/or energy digestibility also offers the desirable side benefit of an incremental reduction in animal waste excretion associated with any improvements.

Improved protein quality

Corn does supply a large amount of total protein in mono-gastric diets due to its high proportion of use in typical pork and poultry formulations. However, the composition of corn protein is not ideal due to its low concentration of several essential amino acids such as lysine, threonine, and tryptophan. This has lead seed companies to pursue possibilities to improve corn protein value. In the past we have seen Opague2 high lysine corn come and go. Currently, at least one company is pursuing the commercialization of a high lysine corn derived using biotechnology techniques (Monsanto, 2006).

With increasing environmental constraints pushing the industry to lower levels of nutrient excretion, and the constant need to optimize space partitioning in rations to fulfill animals' energy and amino acid needs there is increasing interest in using biotechnology to change more than a single amino acid in corn. The traits that come forward from this effort will potentially endow corn with amino acid concentrations that are balanced more appropriately to the growth needs of the animals (DuPont, 2006; Monsanto, 2006). These products have potential to dramatically change the need to supplement both protein meals and crystalline amino acids while at the same time lowering nitrogen excretion and freeing up available energy space in formulations.

Improved Availability of Phosphorus

Improving the availability of phosphorus in corn and soybeans has tremendous potential impact on nutrient management systems tied to animal production. There have been attempts to commercialize low phytate corn and soybean products within the last seven years. These products have relied on the use of conventional breeding techniques based on the use of genetic mutants which produce normal concentrations of total P, and reduced amounts of phytic acid bound P resulting in much higher levels of P availability than wild type grain (Bregitzer and Raboy, 2006). Commercialization of these products has been stalled in corn and soybeans because the resulting hybrids express a number of agronomic challenges that resulted in reduce stand establishment, stand integrity, and ultimately yield. Focus in this area has now turned to using the tools and techniques of biotechnology to produce the specific genetic manipulations required to increase P availability in hopes that the agronomic challenges can be overcome via this route.

One company is pursuing the development of a corn product that carries its own heat stable phytase enzyme as a solution to increasing P availability rather than decreasing phytic acid directly (Syngenta, 2006)

Fatty Acid Composition of Grains

With the rapid growth of the ethanol industry and the subsequent increase in availability and use of DDGS as a feedstuff for swine it is apparent that changing the fatty acid profile of corn oil would be desirable in terms of pork carcass fat quality. DuPont did commercialize some high oil corn products that were higher in oleic acid and lower in linoleic acid several years ago. These products reduced the iodine value of the corn oil from approximately 125 down to approximately 80. These products were based on the use of a recessive trait which made the breeding effort for new products and field production difficult and hence they are no longer being offered. The search for a dominant biotechnology derived trait that can significantly reduce iodine value is in progress but commercialization is likely to be several years away.

In soybeans there has been more rapid commercialization of products with altered fatty acid profile. This has largely been driven by food labeling regulations related to reduction or elimination of *trans*-fatty acids. DuPont, Monsanto, and Iowa State University all have commercialized soybeans with low linolenic acid concentration to address this marketplace need (DuPont, 2006, Monsanto, 2006, Iowa State University, 2006). Further fatty acid modifications, which may include increasing oleic acid and reducing total saturates, appear to be coming in the future.

The marketplace environment

It is of notable interest that nutritionists have historically treated yellow corn as an undifferentiated, homogenous commodity. Single average values are routinely used in diet formulation procedures with minimal consideration for the nutritional variation that exists. Specifications beyond the standard grade factors are rarely communicated back into the grain production and supply chain. The animal feeding industry has just chosen to operate on the "use whatever we get" principal. Even though the same industry has taken note of some of the trends that have occurred over the years, such as the steady decline in corn protein concentration, no significant actions have been implemented on a wide scale to change the course.

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In 1914 the USDA developed a set of standard rules and definitions to define corn quality in order to facilitate grain marketing in domestic and export trade. These rules were adopted as official standards in 1916. The original standards were chosen because at that point in time physical attributes and industry observations of how physical attributes impacted a particular process were the best available means to describe grains' fitness for use. They have remained largely unchanged since implementation due mainly to a lack of clarity about the utility of standards in trade, and clear process to implement any changes. In 1986 the North American Export Grain Association produced a report based on industry wide input that outlined a consensus to serve as guidelines for Congress and FGIS to use in revising standards (U.S. Congress, 1989). Key in this report was a clear definition of what grain standards should provide. These objectives were incorporated in the 1986 Grain Quality Improvement Act, which became law on November 10, 1986. This gave FGIS, for the first time, a basis on which to evaluate proposals for change. The objectives are listed in sub-point (b) below.

Chapter 3, Sec. 74. - Congressional findings and declaration of policy

(a) Grain is an essential source of the world's total supply of human food and animal feed and is merchandised in interstate and foreign commerce. It is declared to be the policy of the Congress, for the promotion and protection of such commerce in the interests of producers, merchandisers, warehousemen, processors, and consumers of grain, and the general welfare of the people of the United States, to provide for the establishment of official United States standards for grain, to promote the uniform application thereof by official inspection personnel, to provide for an official inspection system for grain, and to regulate the weighing and the certification of the weight of grain shipped in interstate or foreign commerce in the manner hereinafter provided; with the objectives that grain may be marketed in an orderly and timely manner and that trading in grain may be facilitated. It is hereby found that all grain and other articles and transactions in grain regulated under this chapter are either in interstate or foreign commerce or substantially affect such commerce and that regulation thereof as provided in this chapter is necessary to prevent or eliminate burdens on such commerce and to regulate effectively such commerce.

(b) It is also declared to be the policy of Congress –

(1) To promote the marketing of grain of high quality to both domestic and foreign buyers;

(2) That the primary objective of the official United States standards for grain is to certify the quality of grain as accurately as practicable; and

(3) That official United States standards for grain shall -

(A) Define uniform and accepted descriptive terms to facilitate trade in grain;

(B) Provide information to aid in determining grain storability;

(C) Offer users of such standards the best possible information from which to determine end-product yield and quality of grain;

(D) Provide the framework necessary for markets to establish grain quality improvement incentives;

(E) Reflect the economic value-based characteristics in the end uses of grain; and

(F) Accommodate scientific advances in testing and new knowledge concerning factors related to, or highly correlated with, the end use performance of grain

Despite this revised framework for creating new standards or grades, and in the midst of myriad advances in corn genetics, growing and handling practices, grain analysis technology, and nutrition science minimal changes have been made to the original grading standards for corn implemented in 1916. The exception to this is that in 1986 moisture was removed as a grade-determining factor. Table 1 shows the current grading standards that are in place (FGIS, 1986).

It is common practice for buyers to use some type of incentive (discounts, premiums, or a combination of the two) based on grade factors to attract sellers to offer the quality of grain they believe best fits their use (Hall and Rosenfeld, 1982). These same researchers have also shown that the higher the end-use utility/value of the grain the more aggressive the incentive structure will be to sellers that deliver sub-standard quality. Tools to rapidly describe the functional characteristics of grains will facilitate the development of systems to discourage the delivery of sub-standard grains and encourage the production of grains that meet the new specifications. However, to see large scale changes to the functional value of corn and soybeans the users of the grain must be willing to

join in setting the course by providing clear directional specifications for the industry, and the supply chain to react to. Key in this is will be influencing the grain handling industry level of the supply chain to recognize their customers needs for different specifications which more appropriately represent the utility of the grain at the end-use. Grain standards should include only those factors that supply the most useful information to the prospective buyers.

Overall, grain quality produced by farmers is foremost impacted by hybrid choice, but during the growing season myriad factors such as soil types, climate, insects, and management factors such as harvesting, drying, and storing can impact deliverable quality and functional utility. Of these factors, hybrid genetic background sets the bar for determining the ultimate functional quality of grain much like the impact of swine genetics on leanness and carcass quality. We are in an era now in which we have a deeper understanding of how the hybrid mix available to farmers for production can ultimately impact the end-use functionality and value of grain, and systems to manage grain in the supply chain are beginning to emerge.

Pioneer Hi-Bred International, Inc. has been leading the industry in development of new measurement systems designed to quantify end-use functionality of corn grain for the major grain consuming industry segments. These segments, in order of total corn grain volume consumption include, 1) animal feed, 2) dry grind ethanol, 3) corn wet milling, and 4) food corn. Each of these segments has different measures of corn functionality. For example, the animal feed segment is most concerned with available energy concentration. Wet milling focuses on the extractable starch percentage. Dry grind ethanol values fermentation potential, or ethanol conversion efficiency per unit mass. And, food corn processors tend to focus on physical characteristics such as color, density, and endosperm hardness. Armed with the knowledge that these functionalities are driving these industries Pioneer has developed measurement systems that will first enable corn breeders with a new set of selection tools, and ultimately allow the grain consuming industries to measure value associated with functionality.

Currently, Pioneer has chosen to utilize Near Infrared (NIR) measurement systems operating in transmittance mode as the platform for assay development. NIR offers many advantages including: speed, accuracy, precision, and adaptability to commerce systems by allowing non-destructive analysis of whole grain. Using NIR technology Pioneer has developed calibrations that measure 1) extractability of starch (in cooperation with the University of Illinois), 2) total fermentable potential of corn, 3) digestible energy concentration of corn for mono-gastric animals, 4) density of corn grain, and 5) fatty acid concentrations of corn and soybeans.

The most recent addition to Pioneer's NIR calibrations provides for direct measurement of Digestible Energy (DE) concentration in whole corn grain for mono-gastric animals. The tool has been used to characterize Pioneer's commercial hybrid products for potential to deliver DE. Pioneer is currently the only seed company that provides DE characterization information on the products they sell. Also, the DE calibration is currently being tested for broad industry use in several large scale commercial supply chain pilots. So far industry interest has been very high toward the concept, but wide scale implementation awaits the outcome of the pilot activities.

Literature Cited

Bregitzer, Phil and Victor Raboy. 2006. Effects of Four Independent Low-Phytate Mutations on Barley Agronomic Performance. Crop Science. 46:1318.

DuPont, 2006, website, http://www2.dupont.com/DuPont_Home/en_US/index.html.

Hall, L.L. and Rosenfeld, A. 1982. Price-quality relationships for grains: An evaluation of buyers' discount behavior. Res. Bull. 82-37. Dept. Agric. Econ., N.Y. Agric. Stn., Cornell Univ. Ithaca.

Monsanto, 2006, website, http://www.monsanto.com/monsanto/layout/investor/financial/presentations.asp.

NRC. 1988. Nutrient Requirements of Swine. 9th rev. ed. Natl. Acad. Press, Washington, DC.

Syngenta, 2006, website, http://www.syngenta.com/en/investor/index.aspx

U.S. Congress, Office of Technology Assessment, Enhancing the Quality of U.S. Grain for International Trade, OTA-F-399 (Washington, DC: U.S. Government Printing Office, February 1989).

United States Grain Standards Act (as amended), Part 810 - Official United States standards for grain. http://www.usda.gov/gipsa/lawsandregs/lawsregs.htm

USDA, 2004, World Agricultural Supply and Demand Estimates, http://www.ers.usda.gov/publications/waobr/view.asp?f=wasde-bb

Table 1. Grades and grade requirements for corn. (FGIS, 1986)

Grade	Minimum Test weight per bushel, pounds	Maximum limits of		Broken corn and foreign material, %
		Damaged kernels		
		Heat damaged, %	Total %	
U.S. No. 1	56.0	0.1	3.0	2.0
U.S. No. 2	54.0	0.2	5.0	3.0
U.S. No. 3	52.0	0.5	7.0	4.0
U.S. No. 4	49.0	1.0	10.0	5.0
U.S. No. 5	46.0	3.0	15.0	7.0

U.S. Sample Grade
 U.S. Sample grade is corn that:
 (a) Does not meet the requirements for the grades U.S. Nos. 1, 2, 3, 4, or 5; or
 (b) Contains stones with an aggregate weight in excess of 0.1 percent of the sample weight, 2 or more pieces of glass, 3 or more crotalaria seeds (Crotalaria spp.), 2 or more castor beans (Ricinus communis L.), 4 or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s), 8 or more cockleburs (Xanthium spp.), or similar seeds singly or in combination, or animal filth in excess of 0.20 percent in 1,000 grams; or
 (c) Has a musty, sour, or commercially objectionable foreign odor; or
 (d) Is heating or otherwise of distinctly low quality.

Biosecurity? – Current and Emerging Threats to Commercial Animal Production

Robert A. Norton
Department of Poultry Science
Auburn University
Auburn, AL 36849-5416
334-844-2604
nortora@auburn.edu

Summary

The United States has historically faced many threats to commercial agriculture and the food supply. Large programs in several countries were specifically designed to produce weapons that could be used to disrupt the U.S. food supply. More recently proxy groups, including al Qaeda have explored methods by which the U.S. animal and plant production systems could be disrupted or destroyed. On the domestic side, animal rights and ecoterrorist groups have openly discussed the intentional introduction of foreign animal diseases as a means of destroying the animal production and processing systems.

Introduction

Commercial agriculture, which includes the animal feed, production and processing systems is an example of what is called a "critical infrastructure", that being a system without which our society could not function. Agriculture's contribution to the overall economy, exceeding a trillion dollars annually, accounts for approximately one sixth of the gross domestic product. Serving as the nation's largest employer it includes one out of every eight Americans, who are employed directly or indirectly in the many and varied facets of food production, processing, transportation distribution and sales (Parker, 2002).

Being a complex system of many interlocking subsystems, animal agriculture is in particular, vulnerable to disruption at many points including, maintenance of genetic stocks, replacement populations and distribution, feed ingredient storage and transportation, feed production and distribution, animal transportation and processing, value added processing, finished product storage, transportation and sales. Acting essentially as a pipeline, interference at any point, could eventually lead to the partial or significant disruption of the end supply for the consumer. Within agriculture, the more the subsystem is integrated, the more vulnerable it becomes to disruption through natural disaster or terrorist attack (Norton, 2002).

Historical Global Threats

The use of using the food supply as a weapon is as old as history. Castles, towns and villages have been conquered for centuries past when food and water supplies were severed. More recently several nations, including the United States have conducted biological programs of varying sizes specifically targeting the food supply. Although, the United States abandoned this program under President Nixon, other nations including the Soviet Union, South Africa, North Korea and others did not. The largest of these programs was conducted by the Soviet Union. Contained within the larger parent *Biopreparat* Program, the military employed as many as 16,000 scientists, technicians and staff, specifically tasked to develop biological weapons for use against the U.S. plant and animal production systems. After the breakup of the Soviet Union, many of the scientists and technicians lost their jobs, forcing some to enter the clandestine world of biological weapons production. Biological materials were also diverted to the highest bidder on the black market, enabling some countries like Iraq and North Korea to obtain weapons material as the breakup of the USSR continued and the government laboratories lost control of their inventories.

More Recent Global Threats

Time has lessened the threat of some of the bioweapons material produced by the former Soviet Union. Programs within Russia and supported by the United States and United Nations has resulted in the re-employment of some of the former "weaponeers". The United States, with the assistance of Russia has also aggressively pursued the reacquisition of material of potential significance, throughout the world. Many of the success stories still remain classified. Other programs, such as the search for chemical and biological weapons in Iraq have resulted in failures, although even here former weapons scientists were identified, interviewed and precursor materials identified and reacquired.

As the Soviet Union was fading as a threat, a new threat emerged in the form of Islamic terrorists, who aggressively explored the potential use of biological weapons used against the U.S. population and agriculture. Documents captured in Afghanistan and scientists captured in several countries paint a picture of an organization seriously trying to develop biological weapons and other weapons of mass destruction, although lacking the ability to develop the logistical means by which to carry out the threats. Since the invasion of Afghanistan and subsequently Iraq, many of the threats were eliminated or neutralized. Other threats still remain, including biological weapons programs in other nations, such as China, Iran and North Korea.

Domestic Threats

The Federal Bureau of Investigation currently lists animal rights and ecoterrorism violence as the number one domestic terrorism issues. Starting in the 1980's many of the groups became more organized and gained economic strength from the inflow of millions of dollars from U.S. supporters. Accompanying this maturity and with influence from Great Britain, some of the groups became more radicalized, to the point that they became directly or indirectly involved with acts of violence, including arson, animal theft and property destruction.

Originally confined to targeting animal research laboratories, some of the groups have turned almost exclusively on commercial animal agriculture and retail food operations. Well financed and accompanied by an army of lawyers, some of the groups have attempted legal challenges to dramatically alter animal production systems in the U.S. With the expansion of legal operations, the U.S. has also experienced an escalation in "direct action" violence and calls for further violence. Where once all of the activist groups totally ruled out violence against people, there has recently been a plethora of splinter groups develop and with them the emergence of "Lone Wolves", who openly call for violence against people.

Currently, there is no open source intelligence that gives any indication that animal rights and ecoterrorist groups are attempting to develop biological or chemical weapons that could be used against animal agriculture. That being said, there are potential threats that could negatively impact the animal industries. Although, it might appear counterintuitive several activist leaders have openly "wished" the United States animal production systems would experience the introduction of foreign animal diseases such as foot and mouth disease. The rationalization for such a call by some leaders is that it is better that an animal be dead than to be "exploited". Most worrisome, accompanying this is the fact that many of the organizations have a world wide reach enabling them to have the potential ability to divert material from endemic disease areas into the United States. Should such a diversion of infectious material occur, very simple methods could potentially be used to introduce the disease into a susceptible or naive animal population and if not successful in starting more than an isolated outbreak, still having the potential of causing substantial economic damage in the form of commodity prices and trade.

Take Home Lessons

Animal agriculture should take serious the threats and better prepare itself to fend off adversaries. Although, neither the global or domestic threats are currently elevated, the potential for the introduction of foreign animal diseases or chemical materials into commercial agriculture does exist. Animal agriculture must realize that it is a potential target and adversaries with varying capabilities do exist. For biosecurity plans to be comprehensive they must include methodologies by which adversaries can be kept out and if failing that, once inside the industry, can be quickly detected and the potential damage contained. Animal protein contributes greatly to the safe, economical and abundant U.S. food supply, which continues to be the envy of the world. New safeguards are needed and will be needed in the future as our adversaries evolve and our production system consolidates.

References

Norton, R.A. The Consolidated American Network for Agricultural Resource Intelligence (CANARI) Addressing the Food Security Issues of the 21st Century – A Proposed Comprehensive Plan. Report to the National Infrastructure Protection Center, U.S. Department of Justice, Washington, D.C. 2002.

Parker, H.S. Agricultural Bioterrorism: A Federal Strategy to Meet the Threat. McNair Paper No. 65. Institute for National Strategic Studies, National Defense University, Washington, D.C. 2002.

Will Nutrition and Management Stop Hemorrhagic Bowel Syndrome? A Veterinarian's Perspective

William L. Hollis, B.S., D.V.M.
Carthage Veterinary Service, Ltd.
Professional Swine Management, LLC
P.O. Box 220
Carthage, IL 62321
217-357-2811
hollis@hogvet.com

Summary

Hemorrhagic bowel syndrome is such defined due to the low prevalence and inability to target one specific disease process or organism as the contributor to the syndrome. In order to answer the question of nutrition and management we have to review both nutritional offerings and management practices that have made efforts at changing the incidence of hemorrhagic bowel syndrome. Unfortunately, very little scientific research is available for example, in preparation for this presentation over 106,000 research articles specific to swine disease management and health were searched. Of these thousands of articles only 6 research articles were identified specific to hemorrhagic bowel syndrome or similar disease consequence. The most recent of these is a research article from Barbara Straw which outlined two specific farms and the contributing factors to the disease from a causative agent standpoint. Pig manufacturers and suppliers have continued to evaluate the ability of alternative ingredients to swine diets in an effort to reduce the incidence of hemorrhagic bowel syndrome. Most nutritional products are based on the gut is quickly voided of fecal material and through feed outages or just gut transit time the mycoflora or normal bacteria allowed to overgrow such as more commonly defined in ruminant nutrition.

Efforts at swine nutrition to reduce this syndrome have provided both fiber content outlines and direct fed microbial outlines as a comparison to traditional swine diets. Antidotal data is provided. However, field experiences are still mixed and controlled proven studies are difficult to identify in the published research.

Management practices are an avenue I personally can see direct correlation. Barb Straw in her research evaluated a combination of management practices and environmental influence leading to an increase in the incidence of hemorrhagic bowel syndrome. (Factors associated with death due to hemorrhagic bowel syndrome in two large commercial swine farms, Straw, 1976)

Finally, the bulk of response from my experience can be achieved through predictable behavior and maintaining standard growing environment, square footage, and eating behavior as consistent as possible. Our practice recommendations include management practices specific for square footage, feeder space, good daily pen management, feeder management, and the inclusion of pulsed therapeutics or alternative ingredients when appropriate. The performance comparisons our clients have shared show 1-2% reduction in late finisher mortality by these recommendations. This is highly variable and difficult to standardize.

Introduction

Hemorrhagic bowel syndrome is defined by Drs. Barbara Straw and Cale Dewey as such: "Hemorrhagic bowel syndrome has taken on more importance and prominence in the last decade. It primarily affects rapidly growing pigs between 4 and 6 months of age (7 to 120 kg). The size and otherwise excellent health of the affected animals make this condition of particular economic importance. There is considerable ambiguity in the clinicopathological definition of HBS. The term "hemorrhagic bowel syndrome" has been applied when finishing swine die suddenly without premonitory evidence of diarrhea or other clinical signs, and on post mortem examination of a recently dead animal, there is marked pallor of the skin and pronounced distention of the abdomen. The small intestine is thin-walled and filled with either clotted or unclotted blood. The large intestine contains tarry fecal material, but lesions suggestive of gastric ulceration, necroproliferative enteritis, salmonellosis, swine dysentery, or other identifiable disease processes are absent."

Will nutrition and management stop the syndrome? The short answer is yes we have found that we can reduce the incidence of hemorrhagic bowel syndrome with intervention that prohibits the generally accepted cause of the syndrome. In a general sense the gut is either empty or transit time is accelerated leading to volvulus and dilatation of the bowel. Similar argument could be made that overgrowth of the mycoflora lead to destruction of the lining thinning of the bowel and erosion of the vascular integrity.

In order to reduce the incidence of this syndrome gut-fill eating behavior and reduction in mycoflora overgrowth all lead to improvement in survivability. Most important to keep in mind is when mortality occurs an appropriate definition is required to understand if the intervention method you are taking is appropriate. We will only discuss hemorrhagic bowel syndrome in the clearest form which is the thin walled gut lining and possibility of volvulus. We will not include the well defined and well accepted causes of bloody diarrhea such as swine dysentery or Lawsonia intracellularis. We are purely discussing the syndrome of hemorrhagic bowel syndrome as described above.

Body

Hemorrhagic bowel syndrome is not clearly defined within the scientific community due to the inability to recreate consistently the syndrome. The culmination of several things lead to mortality and most producers and veterinarians accept that there are many triggers which can lead to mortality from hemorrhagic bowel in large pigs. First and highest on my list when reviewing both the research and discussing with producers is the inability of a pig to consistently eat a normal diet every day. This trigger will consistently create fighting and binge eating. Combine this with the extreme heat of the summer and binge eating is accelerated even to a short time period throughout the night.

How will we stop this syndrome with nutrition and management? Again, this is antidotal and poorly defined in research. However, I will propose to you that products on the market to reduce the possibility of a gut devoid of fecal matter and also maintain normal growth rates will be successful. I also submit that many of our clients find an appropriate stocking density, well managed environment, acceptable and appropriate feeder space as well as a uniform loadout process all contribute to improvement and prevent the extreme swings of mortality from hemorrhagic bowel syndrome as well.

Nutrition

❋ Gut fill: Infrequent meals and large volumes of gut fill predispose the intestine to rotate. (The effect of feeding on the motility of the stomach and small intestine in the pig. Ruckebusch and Bueno.)

❋ Dried Distillers Grains: Fiber content and motility changes due to gut fill offer some promise of benefit. 10% or 200 lbs/ton in swine diets throughout are quite common today. Ethanol increases in production will make this standard. Feeding dried distiller grains greater than 10% leads to a decrease in carcass yield due to gut fill/offal as well as some reports of changes in fat color and consistency due to vegetable oil content.

❋ , Calsporin®– Calpis Co. Ltd., BioPlus 2B - Chr. Hansen BioMoss –Dr. Jim Pettigrew is researching this product. (direct fed microbials): Peer reviewed research is desperately needed in this area. Dr Jim Pettigrew has shown performance benefit and highly recommends the practice. Producer skepticism and a lack of economic performance data in the

research community have left these products as small consideration for most of our clients. Nursery or starter pig rations are not.

❋ Mycotoxins: Mycotoxins have been implicated as a cause of HBS in early literature (Biehl, 1977) 1977 professional journal. However, my opinion is such that the feed refusal created the environment leading to HBS, rather than a direct causative agent. In the research case cited above, the same feed known to contain mycotoxins fed to another population of pigs did not create the same outbreak.

❋ Fiber source (soy hulls, wheat mids)

Management

❋ Binge eating/gut-fill (Table 1)

❋ Feed outages: Dr. Mike Bramm has created a training program for growers and feeding barn managers to follow, which is designed to prevent feed outages. Foremost in this program is the need to manage feed bins properly. His study found that feed outages occurring even once for 24 hours during a growing period cost the population over $1.00 per pig on a 1,000 head population.

❋ Stocking density: Management of stocking density can be a contentions issue with producers. Some genetics can handle less square footage than others. My recommendation is to follow the controlled studies of your genetic supplier, and base your judgment on market weight maximums not average weight. Most of our clients feed PIC pigs correctly. The current PIC recommendation is 7.3 square feet for 280 pound slaughter weight (320 lb. maximum weight). We recommend 7.5 square feet initial stocking which allows for some minimal sort off and losses. These recommendations are for the PIC C22 female crossed with either the 327, 337, or 380 boar lines. (Pig Improvement Company; Franklin by: Dr Noel Williams, PhD)

❋ Starting pigs on feed

❋ Sorting to slaughter

Tables

To accept the producers prospective of hemorrhagic bowel syndrome we also have to define the impact of mortality with economics. I have created 2 tables to bring to light the cost of mortality at stan-dard figures of cost of production. These tables are simply to reference the impact as we look at antidotal data on mortalities and prevalence in the industry. If we accept that 2% of late finisher mortality as a result of hemorrhagic bowel syndrome and those pigs will be 200 pounds we are then looking at a cost per 1,000 head finisher of $1798 or nearly $2 per pig. Please use this reference chart as you review production for swine producers and help them to understand the need to take intervention seriously.

Most of my clients see hemorrhagic bowel syndrome but not an economic threat to their herd. I try to encourage evaluation of the higher level of performance as well as decrease mortality as we review intervention measures. Pigs lost from hemorrhagic bowel syndrome are most commonly perfectly otherwise healthy pigs with a little performance loss and in many cases the larger pigs in the population. For that reason most clients are not inclined to evaluate intervention strategies that run the risk of a reduction in daily gain performance. I have also included with this report referenced to Mike Bramms performance data on feed outages. This table shows the incidents of feed outage occurrence and the cost to the producer. For that reason I highly recommend double bins and tandem and a training process where by producers know how to ensure that feed is always available onsite.

References

Straw B, Dewey C, Kober J, Henry C. Factors associated with death due to hemorrhagic bowel syndrome in two large commercial swine farms. *J Swine health Prod.* 2002;10(2):75-79.

Biehl L. Hemorrhagic bowel syndrome in Swine. *Prof Journal.* 1977

Refereed

Schultz RA, Daniels GN. Use of BMD to control hemorrhagic bowel syndrome in swine. *Vet Med.* 1984:79;253-256

Smith WJ, Shanks, PL., Intestinal haemorrhage syndrome. *Vet Rec.* 1971;89:55-56.

Christensen G, Sorensen V, Mousing J. Diseases of the respiratory system, In: Straw BE, D'Allaire S. Mengeling Wl, Taylor DJ, eds. *Diseases of Swine,* 8th ed. Ames, Iowa: Iowa State University Press; 1999:913-940.

Ruckebusch Y, Bueno L. The effect of feeding on the motility of the stomach and small intestine in the pig. *Br J Nutr.* 1976;35:397-405.

Ewbank R, Bryant MJ. Aggressive behavior amongst groups of domesticated pigs kept a various stocking rates. *Anim Behav.* 1972;20:21-28.

Non Refereed

Schultz RA, Daniels GN. Use of BMD to control hemorrhagic bowel syndrome in swine. *Proc 8th IPVS Cong.* 1984;363.

Lomax L. Hemorrhagic bowel syndrome. *Proc AASP.* Kansas City, Missouri. 1979;1-9.

Table 1

Death loss from any cause in gilts compared to barrows, by season, in thirteen 1,000-head finishing barns[1] in a multi-site, wean-to-finish commercial operation (Farm 1)					
	Gilts		**Barrows**		
Season [2]	**No. Dead (No. at risk)**	**% dead**	**No. Dead (No at risk)**	**% dead**	**P Value[3]**
Winter	324 (7431)	4.36	137 (2812)	4.87	.29
Spring	31 (1037)	2.99	41 (1026)	4.00	.21
Summer	356 (5729)	6.21	403 (5057)	7.97	.0009
[1] Finishing barns housed either gilts or barrows [2] Winter: pigs entered finishing buildings Nov. 14 through Feb. 6; Spring: pigs entered finishing buildings Mar. 20 to 27; Summer pigs entered finishing buildings May 15 through Aug. 14. In each case, the finishing period was approximately 26 weeks. [3] Chi-square analysis.					

Table 2. Cost of Death Loss of one pig

Inputs $0.19   cost per pound of gain
            $30.00   initial cost per weaned pig
            $20.00   fixed cost per pig space

Cost of Loss at Specific Weight

150	lbs	$76.60
175	lbs	$81.35
220	lbs	$89.90
225	lbs	$90.85
250	lbs	$95.60

Table 3. Cost of Death Loss by percent mortality in 1000 head population

	150	175	200	225	250	WEIGHT
1.0%	$766.00	$813.50	$899.00	$908.50	$956.00	
2.0%	$1,532.00	$1,627.00	$1,798.00	$1,817.00	$1,912.00	
3.0%	$2,298.00	$2,440.50	$2,697.00	$2,725.50	$2,868.00	
4.0%	$3,064.00	$3,254.00	$3,596.00	$3,634.00	$3,824.00	
5.0%	$3,830.00	$4,067.50	$4,495.00	$4,542.50	$4,780.00	

DDG/S Production: Present and Future

Matthew L. Gibson, Ph.D.
and
Kip Karges, Ph.D.

Dakota Gold Marketing
Dakota Gold Research Association
4506 N. Lewis Ave.
Sioux Falls, SD 57104
(605) 965-6273
MGibson@DakotaGoldMarketing.com

Summary

The recent growth in production of high-quality Distillers Dried Grains with Solubles (DDG/S) has made this a valuable feed resource for swine production. Most of this growth has come from production of fuel ethanol from corn grown in Midwest USA. If care is taken to understand the product, modern DDG/S can be used quite effectively in swine production. Nutrient content and digestibility are, generally, higher than those listed in peer-reviewed literature. Care must be taken to account for product variability and effects on animal production. New technologies in the ethanol production process result in new distillers products – some of which are dramatically different than traditional product.

Introduction

The ethanol industry is experiencing an explosive growth in available product from the dry-grind process. This is due to a myriad of reasons beyond the scope of this report; however, there is a clear culture of increased ethanol production in the USA. Along with this growth in ethanol production is a concomitant growth in production of DDG/S. Further, new process technologies are constantly being implemented by the ethanol industry. Due to this rapid process evolution, little data exists in traditional, peer-reviewed publications that provide "good" nutrient profile data. This paper will review how DDG/S is produced, what are the characteristics of "new" DDG/S, how the "new" DDG/S is currently being used in swine production, and what the future holds for even newer distillers products which are just now coming into the feed market.

The Ethanol Production Process

Modern ethanol production can be described by its ultimate use: either potable or for fuel. Both processes are remarkably similar, in general (Figure 1). Simplistically, whole corn is ground into a meal, water is added, the resulting mash is cooked (to gelatinize the starch), enzymes are added to cleave free glucose from the starch, yeast is added, and the mixture is allowed to ferment. During this fermentation, two main products are formed: ethanol and CO_2. The CO_2 is (usually) scrubbed and vented to the atmosphere. The fermented mash is distilled to recover the ethanol. The resultant whole stillage is dried into the feed product Dried Distillers Grains with Solubles (DDG/S).

Even though the two processes are, essentially, identical, the ultimate goal of these two industries is widely divergent. For example, the potable ethanol industry is highly concerned with organoleptic characteristics of the end-product – primarily taste. To achieve different taste profiles, the potable distillers use many techniques such as varying the "mash bill" (essentially, the grain mixture), altering fermentation times (and conditions), aging, as well as many others which are both proprietary and beyond the scope of this discussion. The fuel ethanol industry is focused on one goal: conversion of starch into the greatest amount of ethanol, as quickly and as efficiently as possible.

Regardless of the goal of each industry, one thing is clear: differences in the ethanol production process result in differences in the DDG/S produced. Some of these differences will be reviewed later in this paper.

Fuel Ethanol Industry

The current state of the fuel ethanol industry can best be characterized by the phrase "explosive growth." Most of this growth is localized in the upper Midwest. The reasons for this explosive production increase are myriad and beyond the scope of this paper; certainly many market forces play an economic role. However, the uses of ethanol as a fuel are well-documented and summarized elsewhere (Gibson and Karges, 2005).

Other Information Resources

For further insight into the fuel ethanol industry, many excellent resources are available from industry organizations such as: (1) the Renewable Fuels Association (RFA) at www.EthanolRFA.org; (2) the American Coalition for Ethanol (ACE) at www.Ethanol.org; and (3) the National Ethanol Vehicle Coalition (NEVC) at www.E85Fuel.com.

Ethanol Production Processes

Due to the relatively recent availability of feed co-products from the ethanol industry, a short discussion on the various processes and resulting feed products is warranted. The two types of facilities which produce fuel ethanol are "wet-mill" vs "dry-grind" operations. The last wet-mill operation was commissioned in 1995. The entirety of growth experienced since that time has occurred in dry-grind operations. The significance of this observation (for animal producers) is that the main feed co-product generated from dry-grind production is DDG/S. Thus, the recent growth of dry-grind ethanol has generated a concomitant growth in supply of DDG/S (Figure 2).

Feed Products

In the feed industry, confusion reigns with respect to the products available from corn milling and ethanol production facilities. There are primarily two types of corn processing facilities, currently, in operation. A brief review of the two is necessary to understand the feed products. Both types begin with the whole corn kernel.

Wet-milling corn processors subject the whole corn to a dilute sulfur dioxide "steep" process for several hours. From there, the corn is ground and milled into various fractions – mainly, bran, starch, protein, oil, and others. The main feed products from wet-milling operations are: steep liquor, bran, germ meal, gluten meal, and gluten feed.

Dry-grind ethanol producers basically process the whole kernel through the entire operation. The resulting feed product is primarily DDG/S. In effect, most other feed products – such as Wet Distillers Grains and Corn Condensed Distillers Solubles – are really "products of convenience" from the post-distillation evaporation processes.

Another difference in wet-mills vs dry-grind operations is in the feedstocks used for production. Obviously the wet-millers are using corn to generate corn oil, corn starch, high-fructose corn syrup, etc. However, dry-grind ethanol producers may use any source of starch (such as any of several grains, grits, screenings, etc.) to produce fuel ethanol.

The Association of American Feed Control Officials (AAFCO, 2006) requires the majority grain to be declared on the label of DDG/S. That is, DDG/S resulting from fermentation of a mixture of 49 % grain sorghum and 51 % corn will be labeled exactly the same as DDG/S from 100 % corn fermentation.

As has been observed, DDG/S production has experienced dramatic growth. Further, this growth curve is expected to remain steep for at least the next 5 – 6 years. Despite aggressive predictions, the growth of the market is exceeding those expectations. For example, the total production of DDG/S for crop-year 2005 – 2006 is certainly expected to exceed 10 million tons; production will be in excess of 1 million tons per month by the 4th quarter. Earlier predictions – though aggressive – showed the production to reach 12 million tons per year in 2008.

Although many alternative uses of DDG/S are being pursued, for all intents and purposes, the stark reality is that almost all DDG/S will be fed to livestock. Thus, market development in all species of livestock will become crucial sooner than later. An understanding of DDG/S nutrition is vital to the continued success of both the ethanol and livestock industries.

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Nutrient Considerations

The DDG/S of today is quite different than that produced just a few short years ago. Old "book values" may or may not be appropriate for use in modern swine diets.

As noted, the dry-grind ethanol industry has experienced rapid evolution. Also, as more DDG/S has become available and has received more attention from the feed industry, some producers have made serious investments into improving DDG/S to the point where it is an acceptable feedstuff for all species of livestock (and pets!). And, due to the rapid growth in this industry, there is a tremendous "data void" that needs to be filled in order to effectively use the product.

When polling nutritionists about DDG/S, the biggest concerns today seem to be centered on nutrient quality and product variability as well as physical factors such as flowability. Several factors are notable and should be discussed individually.

Plant-to-Plant Variation

Due to wide variances in technology and processes, DDG/S coming from plants within close proximity to each other may be quite variable. Even DDG/S coming from one plant may be quite variable on a day-to-day basis. A study by Robinson (2004) examined DDG/S from several sources. He clearly demonstrated that DDG/S may vary widely for certain nutrients; even those nutrients with similar mean values may likely have widely divergent variability between sources (Table 1).

Energy Nutrition

Several factors contribute to the differences in ME values. Certainly, the "New" technology product has more energy than "Old" technology product (Tables 2 & 3). The Swine NRC lists the ME content of DDG/S as 3,032 kcal / kg on a Dry Matter Basis (DMB). Both Spiehs, et. al. (1999) and Allee, et. al. (2005) demonstrated a value closer to 3,900. The Allee data is particularly convincing in that his Corn control was determined to have an ME value of 3,864 which almost exactly matches the NRC-listed value of 3,842.

This variability in ME content is likely due to the over-processing of "old" type DDG/S resulting in Maillard reaction products (which tie up available carbohydrates). Also, "old" DDG/S had lower fat

levels than "new" DDG/S (approximately 8 % and 11 %, respectively; NRC & DGRA).

Nutritionists should be aware that both types of DDG/S products are still widely available. Also, the ME of the "new-new" DDG (de-branned / de-fatted; Dakota Gold HP) seems to be fairly similar to that of the "new" DDG/S (Table 3). Care should be taken that proper values are used for diet formulation.

Amino Acid Nutrition

Amino acid nutrition of DDG/S for swine has probably received more scrutiny in recent years than all other nutrient factors, combined. Obviously, the cost of amino acid nutrition in the diet is a significant contributor to this effort. However, the aforementioned Maillard reaction – so common in "old" DDG/S – has been overcome, somewhat, with the "new" DDG/S production. Much effort has been expended to demonstrate the effective use of DDG/S as a protein source.

The Swine NRC is particularly conflicted in its treatment of LYS with respect to all distillers products. Although this treatise is not focused on either Dried Distillers Grains (DDG) or on Corn Condensed Distillers Solubles (CCDS) – both, byproducts of the ethanol process – a brief comparison of these products with DDG/S demonstrates the confusing data.

The LYS levels listed for DDG, DDG/S, and CCDS are 0.74 %, 0.62 %, and 0.82 %, respectively. As the DDG/S product is, essentially, a 50:50 combination of DDG and CCDS, it is easy to see that the data are conflicted with respect to these ingredients. Regardless, the level listed for DDG/S is 0.62 %.

As the protein in DDG/S is derived from that in the corn – and given the concentration factor of 3 – it follows that the LYS should follow this 3-fold increase from corn to the resulting DDG/S. However, the listed level (0.62 %) is only 2.4-fold higher than that in corn (0.26 %). Given the severe heat-damage of the "old" process, these data probably do accurately reflect the "old" DDG/S product.

The Swine NRC lists a regression equation for calculating the LYS level in DDG/S with the variables of: a = 0.0090, b = 0.0221, and r = 0.94. Data from DGRA indicate that for one source of DDG/S these variables are approximately: a = 0.97, b = 0, and r = 0. These data are on an As-Fed Basis (AFB).

Further, an examination of these DGRA data demonstrates the LYS in this source of DDG/S is ap-

proximately 3.7-fold higher than that in corn (0.95 % vs. 0.26 %) – much different than the level listed for the "old" DDG/S.

Another anomalous observation about LYS is with respect to corn protein levels. It is widely known that corn nutrition can vary on a year-to-year basis. Data from the Broin companies indicate a definitive decline in corn protein between the 2004 and 2005 crop-year (Figure 3). However, during this same period, the DGRA showed that LYS did not decrease in one source of DDG/S (Table 4). Obviously, a close examination of DDG/S from any given source is in order to evaluate exact nutrient levels.

Not only is the LYS level confusing, the digestibility can be quite variable. A listing of various studies (Table 5) indicates a Digestibility Coefficient (DC) ranging from a high of 63 % to a low of 0 % – quite a range, indeed.

Color is frequently mentioned as a quick, subjective indicator of DDG/S quality. This is especially true of LYS digestibility. Ergul, et. al. (2003) and Batal, et. al. (2006) demonstrated that Hunter L* and b* scores were highly correlated with LYS digestibility (Table 6). The Ergul study demonstrated that product with a Hunter L* score of 53.8 and a Hunter b* score of 32.9 had a Digestible LYS content of 0.65 whereas product with a Hunter L* score of 41.8 and a Hunter b* score of 42.8 had a Digestible LYS content of 0.38. The Batal study demonstrated that product with a Hunter L* score of 60.3 and a Hunter b* score of 25.9 had a Digestible LYS content of 0.66 whereas product with a Hunter L* score of 50.4 and a Hunter b* score of 7.41 had a Digestible LYS content of 0.18. Although these studies clearly indicate a good correlation of color with LYS digestibility, it must be noted that differences in Hunter scores are not absolute. Obviously, darker product has undergone more extensive Maillard browning.

One problem with determining amino acid digestibility is the long assay period and high associated costs. Typically, data obtained from a chick assay will cost several hundred dollars and will take many weeks. Similar data from a piglet assay will cost several thousand dollars and will take many months.

A new *in vitro* assay (IDEA™; NOVUS, Intl.) holds some promise for a quick, inexpensive alternative for determining the LYS digestibility in DDG/S. Schasteen, et al. (2005) found a very good predictive relationship in poultry (Figure 4). Obviously, a pig is not a chicken. However, an examination of a similar assay for SBM indicated a good correlation between the two species (Figure 5).

One notable point: when examining the poultry data, LYS digestibility ranged from a low of approximately 59 % to approximately 83 %. The products used in this study were mostly sourced from high-quality, "new" DDG/S production.

Phosphorus Availability

Allee and Fent (2005) estimated the P digestibility to be 85 %. He used a Slope Ratio bioavailability assay with mono-sodium phosphate as the control comparison. The variables measured were piglet fibula ash and breaking strength.

Variation in Fat Values

Fat levels will vary along with other nutrients as discussed previously. However, many nutritionists also consider the fat in DDG/S to be identical to corn oil. Analysis indicates this is not so. The fat in DDG/S has lower linoleic acid and higher omega-3, the iodine value is lower and the FFA content is higher. (Table 7).

Animal Performance

Sow Lactation: Hill, et. al. (2003) compared a control diet (with 5 % Beet Pulp) to a diet containing 15 % DDG/S. There was no difference (P > 0.05) in sow weight change (-6.2 kg vs -8.0 kg), day 18 litter weight (62.9 kg vs 62.3 kg), litter gain during lactation (41.7 kg vs 43.4 kg), or number of pigs weaned (10.9 vs 10.8) for control diet vs DDG/S diet, respectively.

Grow / Finish: Cook (2005) fed graded levels (0, 10, 20, and 30 %) of DDG/S to approximately 1,000 head of pigs. Pigs were housed with 26 head per pen and had an initial weight of 42 kg with an average weight of 117 kg when finished.

The source of the DDG/S was from a "new" process ethanol facility. Nutrient values used for formulating rations were provided by the supplier. Most importantly, an adequate number of samples were analyzed to provide accurate means and variance about those means for all necessary nutrients. Further, statistics were applied to determine formulation matrix values. Digestibility values used for ME, LYS, and P were 1550 kcal / lb, 70 %, and 85 %, respectively.

He found no overall difference in ADG, ADFI, or Gain:Feed. Mortality decreased linearly. Carcass Yield decreased linearly, while Lean Yield and Backfat were not different (Figures 6 and 7). Cook concluded that when proper nutrient values are used, DDG/S can be used effectively at moderate levels for growing / finishing swine with few negative effects.

Gourley (2005) fed graded levels of DDG/S to approximately 1,000 head of pigs. Pigs were housed with 26 head per pen and had an initial weight of 33 lb with an average weight of 290 lb when finished.

The source of DDG/S was from a "new" process ethanol facility. This one differed from the Cook study in that it was from an even "newer" BPX™ process facility. (More on the BPX™ process later in this paper). As in the Cook study, adequate sample nutrient analysis (with resultant statistical analysis) was provided to determine formulation matrix values. Similar digestibilities were applied for ME, LYS and P.

The Gourley study used a different scheme for determining the DDG/S inclusion rates. In this study, a typical corn-soy diet was formulated and a calculated NDF level was determined. Then, DDG/S was included at increasing levels to raise the NDF by 1.5 % increments. The resulting diets contained 7.3, 14.6, 21.9, and 29.3 % DDG/S. Due to a collection error, no data were reported for the 14.6 % diet.

As in the Cook study, Gourley found no differences for ADG, ADFI, or Pig Weight Sold. There was an improvement in Feed:Gain for the higher DDG/S inclusion rates. There was no difference in Carcass Weight. As in the Cook study, there was a decrease in Carcass Yield with increasing DDG/S, but no difference in Lean Yield. Interestingly, although there was no difference in Lean Yield, there was a non-statistical increase in both studies.

Gourley also took fat samples from the carcasses and analyzed for Iodine Value (IV). There was a statistical increase in IV at the highest DDG/S inclusion rate.

New Technologies

As noted, the production of ethanol in dry-grind facilities is undergoing rapid technological evolution. And, as should be clearly evident at this point, any alteration of the ethanol process will result in changes to the resultant DDG/S. Some new technologies which have recently appeared in the marketplace are

of particular note – especially, due to their profound changes on the resulting DDG/S.

BPX™

A new technology which completely revolutionizes ethanol production has recently been introduced. The technology is named BPX™. The process is patented by the Broin Companies. Essentially, the process allows production of ethanol without "cooking" the mash to gelatinize the starch. The changes on the resultant DDG/S – although not completely understood – are profound. The BPX™ product exhibits greatly improved physical characteristics such as higher density and easier pelleting. Most importantly, the product exhibits enhanced flowability.

Bio-Refining

Until recently, all product going into a dry-grind ethanol production facility has essentially become DDG/S through the process. Now, three fully-commercialized dry-grind facilities have implemented true dry-milling operations in front of the ethanol facility. The whole corn is milled into several fractions which can then be directed into several different production streams (Figure 10).

The "endosperm" stream – actually, a "corn-starch-enriched" stream is what ends up in the fermenter. That is, some of the bran and some of the germ – the non-fermentables – are removed from the whole kernel before fermentation. The advantages to ethanol production are fairly obvious. What is less obvious are the changes to the resultant co-product.

The co-product – marketed under the trade name Dakota Gold HP – is actually a true DDG. It has very high levels of protein (and amino acids, obviously) along with lower levels of fat and phosphorus. Research indicates that the energy value is quite good (Table 3). This is probably due to the removal of the bran fraction which dilutes the ME in "normal" DDG/S.

As the corn is milled prior to fermentation, the "germ enriched" fraction also becomes available as a feedstuff for animal production. The product is marketed as Corn Germ Dehydrated (according to the AAFCO definition). As expected this product is high in fat and phosphorus. As the germ fraction contains the most desirable proteins in the corn kernel, the amino acid profile is quite desirable in spite of a fairly low crude protein level. As the product has not

been "steeped" (as in a wet-mill), these protein fractions contain all the soluble fractions. Also, as this corn has not been through fermentation, the oil is in its "native" state.

There are two other bio-refining processes currently under development. Quality Technology International is currently building a corn fractionation facility on an existing ethanol plant (Lohrmann, 2006). The process used is known as HydroMilling™ and is, essentially, a wet-mill type process. Although not yet completed, the company is currently advertising a number of products which will be available from this production facility – namely, high-protein type products which will be targeted at the non-ruminant livestock industries.

Renessen is currently building a pilot plant attached to a small ethanol production facility (Jakel, 2006). Although not yet in production, the Renessen process seems to be similar to the dry-milling process previously described and is being marketed alongside a proprietary corn product. The end-products are claimed to be similar to those from the dry-milling process previously described.

"Oil from Syrup"

One final new technology that deserves mention is the "oil from syrup" process. At least two companies are introducing technology to the ethanol industry for removing the oil from the syrup process stream prior to drying into DDG/S. The uses for this oil are obvious: biodiesel, primarily, and feed, secondarily. Although not yet in wide-spread operation, the process is easy to implement and is quite inexpensive to operate.

Nutritionists are cautioned to note that the resulting DDG/S will be lower in fat.

Conclusion

The fuel ethanol industry is experiencing explosive growth in both volume and technology. The DDG/S from this production will be fed. Although the swine industry has been slow to adopt the use of DDG/S in the past, there is a tremendous opportunity for exploiting the plentiful resource in the future. Care should be taken to become intimately familiar with the specific product being fed.

References

Allee, G.L., R.W. Fent, and S.X. Fu. 2005 Determination of the metabolizable energy concentration of different corn byproducts of ethanol production. Univ. of MO – Columbia. Dakota Gold Research Assoc. Rept # 0503.

Allee, G.L. and R.W. Fent. 2005. Evaluation of the bioavailability of phosphorus in distiller's dried grains with solubles (DDGS) when fed to pigs. Univ. of MO – Columbia. Report to Dakota Gold Research Assoc. Rept # 0503.

B&A. 2005. Broin and Associates. Sioux Falls, SD. Internal Report – Unpublished.

Batal, A.B. and N.M. Dale. 2006. True metabolizable energy and amino acid digestibility of distillers dried grains with solubles. J App Poultry Res 15:89.

Cook, D.R., N.D. Paton, and M.L. Gibson. 2005. Effect of dietary level of distillers dried grains with solubles (DDGS) on growth performance, mortality, and carcass characteristics of grow-finish barrows and gilts. Midwest Amer. Soc. Anim. Sci. meeting, Des Moines, IA.

DGRA. 2003, 2004, 2005. Dakota Gold Research Association. Sioux Falls, SD. Internal Reports – Unpublished.

Ergul, T., C. Martinez Amezcua, C. Parsons, B. Walters, J. Brannon, and S.L. Noll. 2003. Amino acid digestibility in corn distillers dried grains with solubles. Poult. Sci. Assoc. meeting, Madison, WI.

Gibson, M.L. and K. Karges. 2005. Overview of the ethanol industry and production of DDG/S: A nutritionist's perspective. Multi-State Poultry Feeding and Nutrition Conference. May 23 – 25, Indianapolis, IN.

Gourley, G., and J. Lampe. 2005. Effect of distillers dried grains and solubles formulated for % NDF on the growth and carcass performance of pigs. Swine Grafix Enterprises, Webster City, IA. Dakota Gold Research Assoc. Rept # 0507

Hill, G.M., J.E. Link, M.J. Rincker, K.D. Roberson, D.L. Kirkpatrick, and M.L. Gibson. 2005. Corn dried distillers grains with solubles in sow lactation diets. Midwest Amer. Soc. Anim. Sci. meeting, Des Moines, IA.

Jakel, N. 2006. Fractionation of specialty corn for ethanol fermentation and production of high protein DDGS. Distillers Grains Technology Council, May 18 – 19, Louisville, KY.

Lohrmann, T. 2006. Alternative co-products from a new HydroMilling™ fractionation process. Distillers Grains Technology Council, May 18 – 19, Louisville, KY.

NRC – Swine. 1998. Nutrient Requirements of Swine. Tenth Revised Edition. National Academy of Sciences.

Robinson, P.H. 2004. Nutritive value of distillers grains. Dept. of Anim. Sci. Univ. of CA – Davis. Dakota Gold Research Assoc. Rept # 0301

Schasteen, C.S., J. Wu, G. Yi, C. Knight, C. Parsons, J. Li, and D. Li. 2005. True digestibility of amino acids in raw and heat-treated soy products: comparison of values obtained with cannulated pigs, cecectomized roosters and an *in vitro* IDEA™ Assay. Midwest Amer. Soc. Anim. Sci. meeting, Des Moines, IA.

Spiehs, M.J., G.C. Shurson, and M.H. Whitney. 1999. Energy, nitrogen, and phosphorus digestibility of growing and finishing swine diets containing distiller's dried grains with solubles. J. Anim. Sci. 77:188 (Suppl. 1).

Whitney, M.H., M.J. Spiehs, G.C. Shurson, and S.K. Baidoo. 1999. Apparent ileal amino acid digestibility of corn distiller's dried grains with solubles produced from new ethanol plants in Minnesota and South Dakota. J. Anim. Sci. 77:188 (Suppl. 1)

Stein, H.H., C. Pedersen, and M. Boersma. 2004. Amino acid and energy digestibility in ten samples of dried distillers grain with solubles by growing pigs. Report to Dakota Gold Research Assoc.

Stein., H. 2005. Energy and nutrient digestibility of distillers grains from various sources for growing pigs. Distillers Grains Technology Council, May 18 – 19, Louisville, KY.

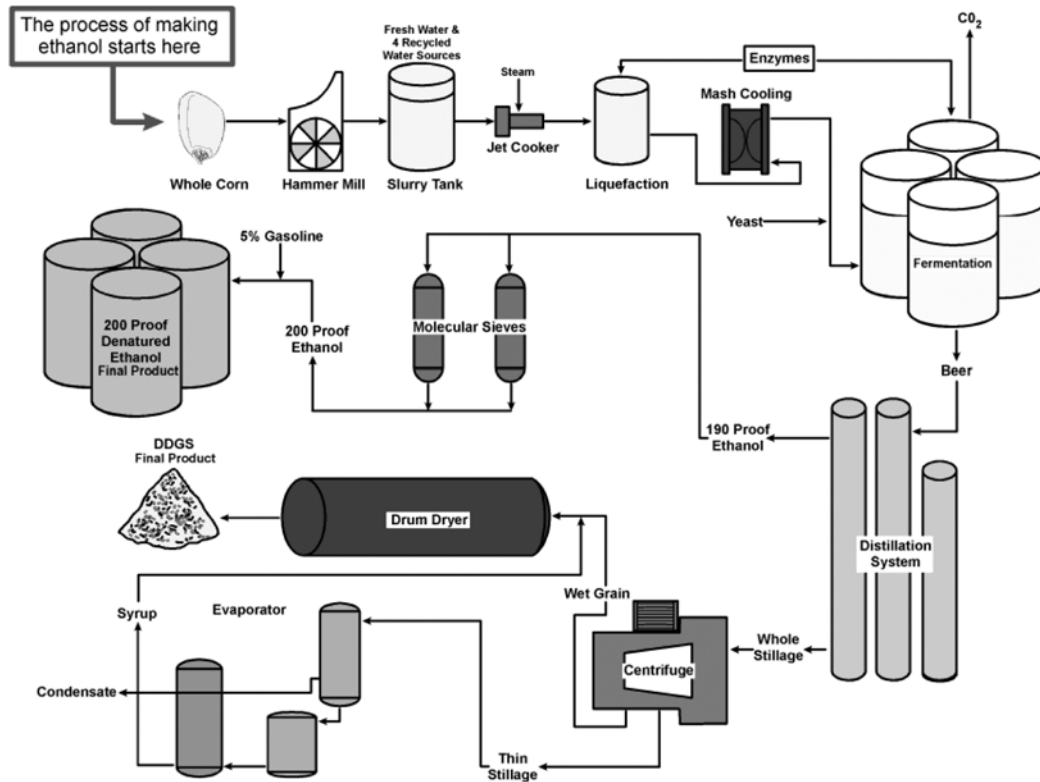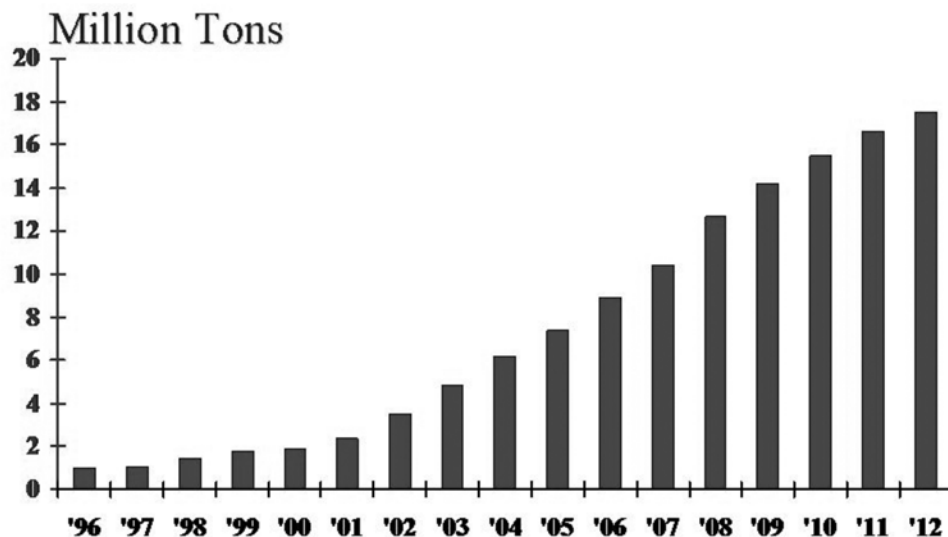Figure 1. The Dry-Grind Ethanol Process. Broin, 2006.

Figure 2. Growth of DDG/S Production – USA. ACE, 2006.

DDG/S Production 1996 – 2012

* Adapted from CMC, '05

Table 1. DDG/S Source-to-Source Variability[1]. Robinson, 2004.

| | Source | |
Nutrient	Industry-wide	Dakota Gold
Crude Protein	30.1 ± 2.6	30.7 ± 1.2
Fat	11.5 ± 3.5	11.9 ± 0.7
ADICP	28.9 ± 11.7	8.2 ± 2.3
Phosphorus	0.88 ± 0.14	0.70 ± 0.10

[1] Mean ± SD

Table 2. ME (kcal/kg) of DDG/S for Swine. Spiehs, et. al. (1999).

	Exp. 1	Exp. 2	Mean
Grower	4,707	2,983	3,845
Finisher	4,191	3,428	3,810
Mean	4,449	3,206	3,828
NRC			3,032

Table 3. ME (kcal/kg) values for Swine. Allee, et. al. (2005).

Ingredient	NRC	DGRA
Corn	3,842	3,864
DDG/S	3,032	3,940
Dakota Gold HP	--	4,049

Figure 3. Corn Protein – Crop Years '03/'04 → '04/'05. DGRA.

Corn Protein
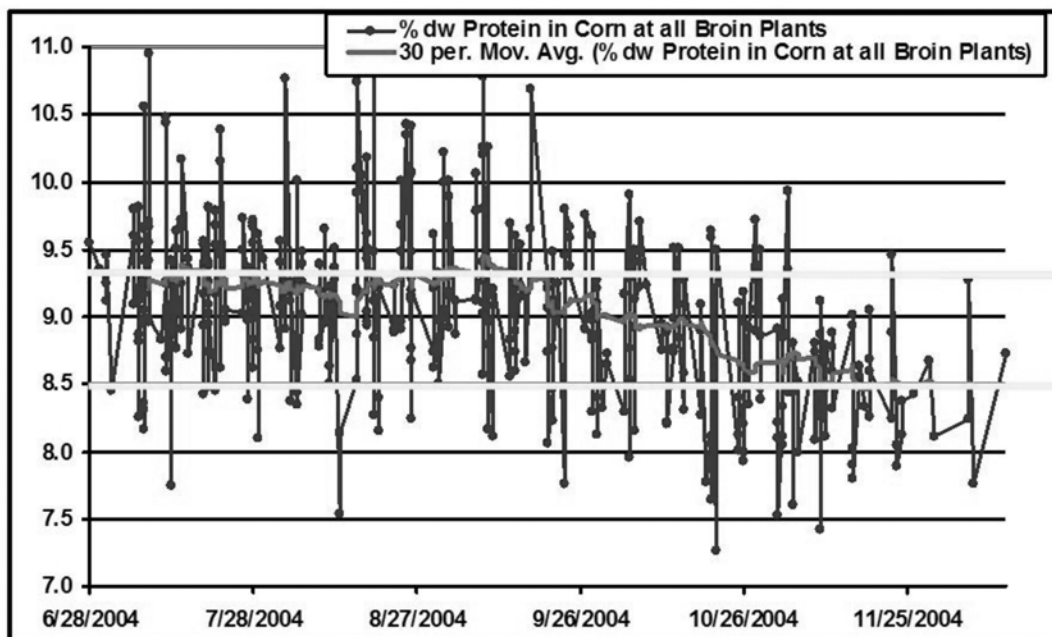### New Crop Transition: '03 –'04 → '04 –'05

Table 4. Variation in DDG/S Lysine between Crop Years. DGRA.

Crop Year	Mean	S.D.	n
'03 – '04	0.96	0.20	> 500
'04 – '05	0.94	0.12	> 200
'05 – '06	0.95	0.13	> 200

Table 5. Lysine (%) and Digestibility Coefficients (%) of DDG/S – Various References.

Source	Total LYS	Digest. Coeff.	Digest. LYS
NRC	.62	47	.29
"Old"[1]	.68	0	.00
MN / SD[1]	.83	53	.44
SD – Low Digest.[2]	.68	44	.30
SD – Hi Digest.[2]	.85	63	.54

[1] Whitney, et. al. (1999)
[2] Stein, et al. (2004)
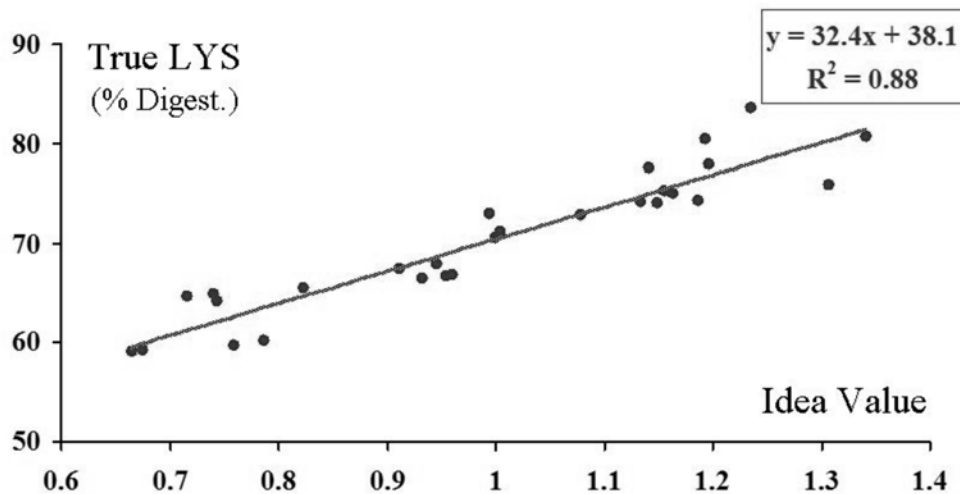
Table 6. Hunter Color Scores and Digestible Lysine.

Color	Hunter L*	Hunter b*	Digestible LYS, %
Dark[1]	41.8	32.9	0.38
Light[1]	53.8	42.8	0.65
Dark[2]	50.4	7.41	0.18
Light[2]	60.3	25.9	0.66

[1] Ergul, et. al. (2003)
[2] Batal & Dale (2006)

Figure 4. IDEA™ value vs True Lysine Digestibility – DDG/S. Schasteen, et. al., 2005.

IDEA Value vs True LYS
Poultry – DDG/S*

$y = 32.4x + 38.1$
$R^2 = 0.88$

* Schasteen, Wu, Parsons, MWASAS '05

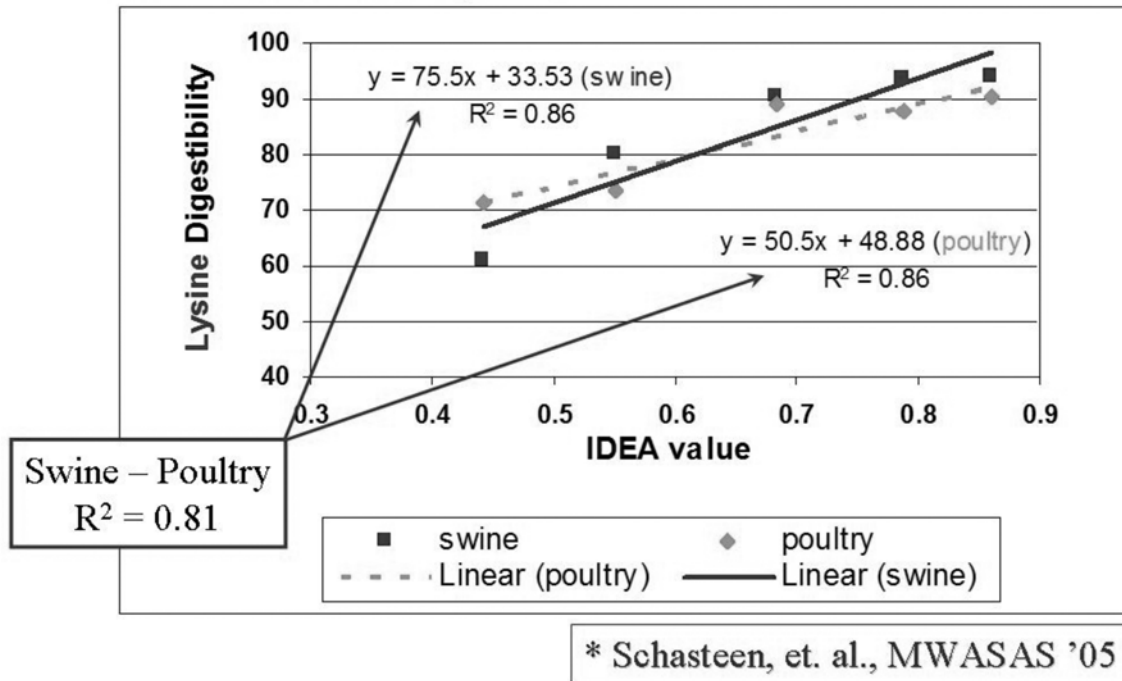Figure 5. IDEA™ Value vs. True LYS Digestibility – SBM. Schasteen, et. al., 2005.

Table 7. Fatty Acid Profiles. NRC & DGRA.

Item	Corn[1]	DDG/S[2]
C16:0	11	13
C18:1	24	29
C18:2	59	51
$\Omega 3$	0.7	2
$\Omega 6$	58	52
Unsat:Sat	6.5	4.6
Iodine Value	125	110
Free Fatty Acids	0 ?	10

[1] NRC
[2] DGRA

Figure 6. Performance Summary. Cook, 2005.
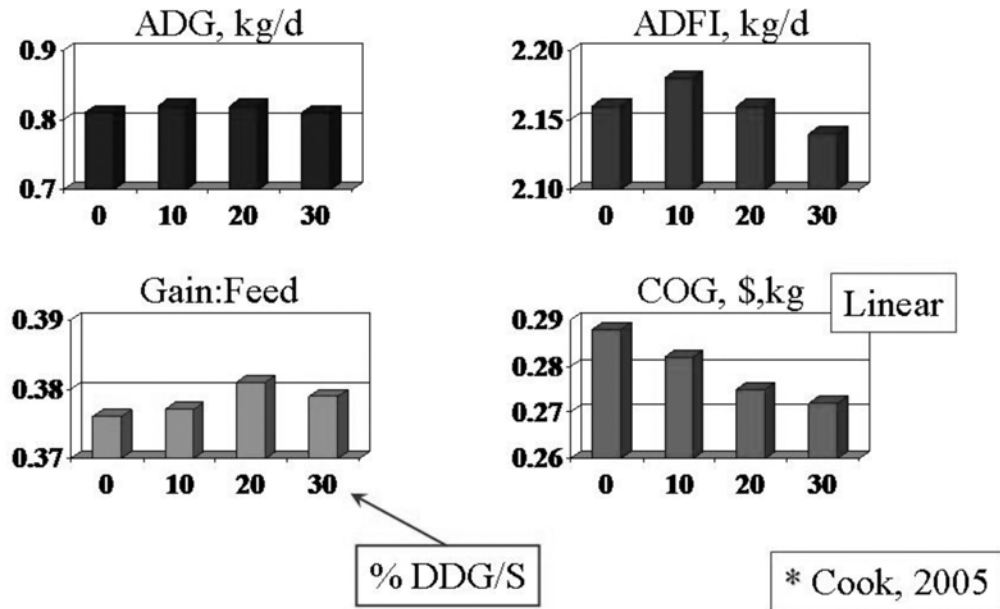
Figure 7. Performance Summary. Cook, 2005.
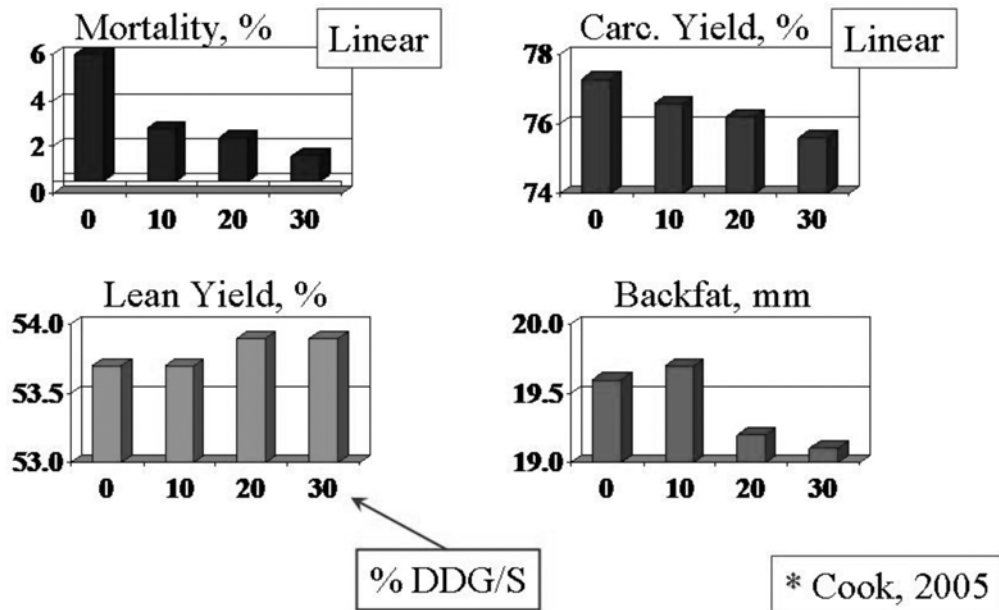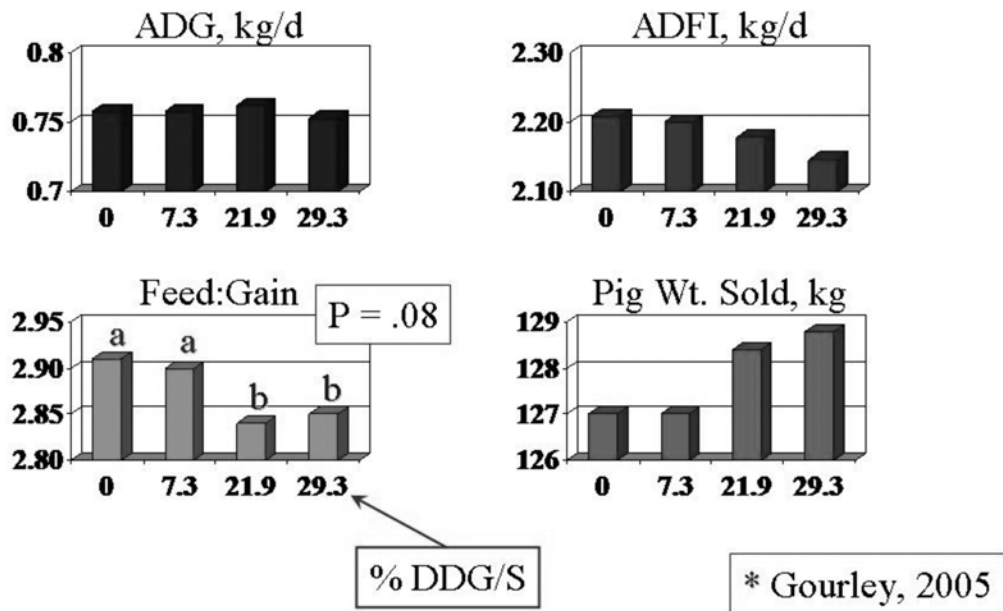
Figure 8. Performance Summary. Gourley, 2005.

Figure 9. Performance Summary. Gourley, 2005.
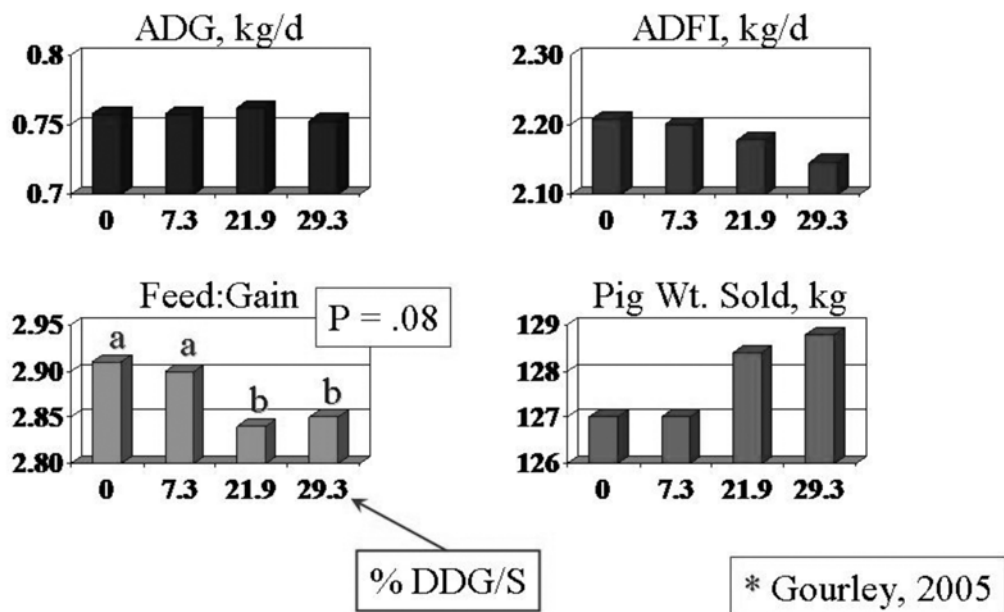
Figure 10. Bio-Refining & Ethanol Production Process. Broin, 2005
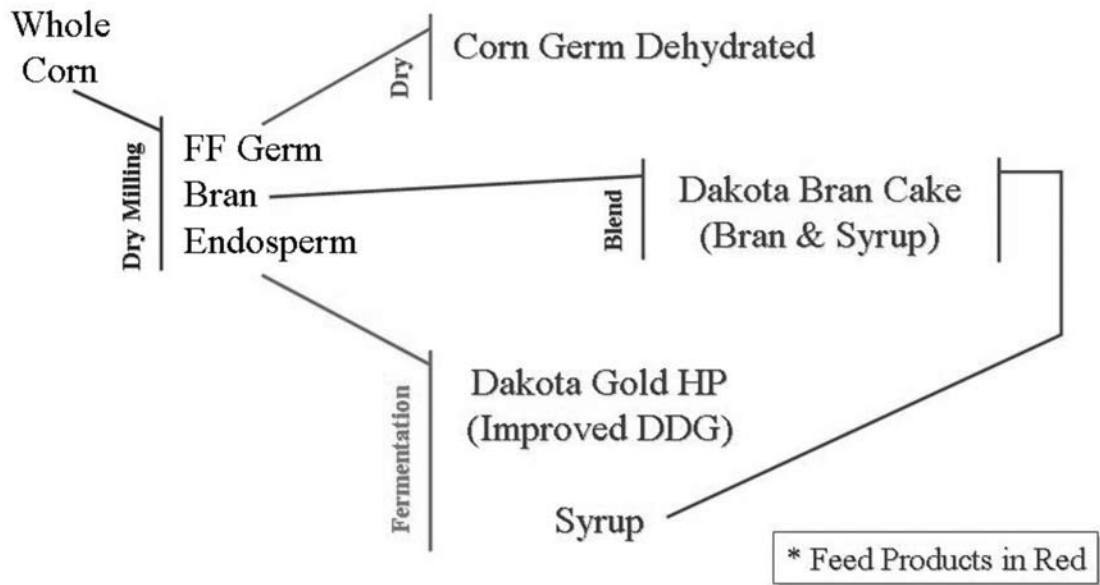
DDGS: Energy and nutrient content and digestibility

Hans H. Stein
Department of Animal Sciences
University of Illinois
Urbana IL 61801
217 333 0013
hstein@uiuc.edu

Summary

The concentration of gross energy in distillers dried grain with solubles (DDGS) is greater than in corn. However, because of a lower digestibility of energy in DDGS than in corn, there is no difference in the concentration of digestible and metabolizable energy between DDGS and corn. The apparent and standardized ileal digestibility of amino acids in DDGS does vary among sources but, with the exception of lysine, the variability is no greater than what has been reported for other feed ingredients. Lysine in DDGS may be damaged if excessive heating is used during the drying process, which in turn leads to a low digestibility of lysine. Based on the wide range of digestibility values for lysine in DDGS, it is likely that some ethanol plants do overheat DDGS and destroy some of the lysine in the product. The digestibility of phosphorus in DDGS is approximately 56%. This value is greater than in corn. Therefore, if DDGS is included in the diet, less inorganic phosphorus is needed.

Key words: Amino acids, Digestibility, Dried distillers grain with solubles, Energy, Phosphorus, Pigs

Introduction

Distillers dried grain with solubles (DDGS) is increasingly being included in diets fed to swine. Barley, wheat, sorghum, or corn may be used in the production of ethanol and the resulting DDGS is characterized by the grain that was used. However, even when the same grain is used, variability in the chemical composition of DDGS may be observed (Cromwell et al., 1993; Spiehs et al., 2002). This variability is likely caused by differences in the effectiveness of fermentation, differences in drying temperatures, or differences in the quantities of solubles that are added to the distillers dried grain. Because the product has gone through heat treatment, there is a risk that the digestibility of some amino acids, and lysine in particular, may be reduced because of Maillard reactions (Chromwell et al., 1993). If this is the case, then the variability in concentrations of digestible lysine will increase compared with the variability of total lysine in DDGS.

Pigs have requirements for digestible contents of nutrients such as amino acids and phosphorus and they need energy for maintaining basic body functions. The concentration of energy and digestible nutrients in a feed ingredient, therefore, determine the value of this ingredient in diets fed to swine. During recent years, several experiments have been conducted to measure the concentrations of digestible energy and nutrients in DDGS if fed to swine. It is the objective of the current contribution to summarize these results.

Energy concentration and digestibility

The average concentration of gross energy in 10 samples of DDGS was measured by Pedersen et al. (2006) at $5,434 \pm 299$ kcal GE per kg dry matter (DM). This value is greater than in corn. However, the digestibility of energy in DDGS is lower than in corn and the measured concentration of digestible (DE) and metabolizable (ME) energy in the 10

sources of DDGS was 4,140 ± 205 and 3,897 ± 210 kcal per kg DM, respectively. These values were not different from the DE and ME that were measured in corn (Table 1). These numbers concur with average values of approximately 4,220 kcal DE and 4,040 kcal ME per kg DM that were measured in two sources of DDGS (Hastad et al., 2004). Based on the chemical composition of a large number of samples of DDGS, values for DE and ME in DDGS of approximately 3,990 and 3,750 kcal per kg DM, respectively, were calculated (Spiehs et al., 2002). Thus, both measured and calculated values are significantly greater than current estimated values for DE and ME in DDGS of 3,441 and 3,032 kcal per kg DM, respectively (NRC, 1998). Because the DE and ME in DDGS are similar to corn, no energy adjustments in diet compositions are needed if DDGS is included in diets formulated to pigs.

Amino acid concentration and digestibility

The concentration of amino acids in DDGS has been reported in several publications (NRC, 1998; Spiehs et al., 2002; Fastinger and Mahan, 2006; Stein et al., 2006). The concentration of most amino acids in DDGS is 3 to 4 times greater than in corn (Table 2). If calculated as a percentage of crude protein, the concentration of most amino acids in DDGS protein is similar to that in corn protein. The exception to this rule is the dispensable amino acid glutamate, which is present in DDGS protein in a quantity that is lower than in corn protein (Table 2). The reason for the relatively low concentration of glutamate in DDGS may be that yeast cells prefer to use glutamate as an energy source. The yeast that was used in the fermentation of corn to produce ethanol may, therefore, have utilized some of the glutamate in corn, leaving a smaller amount in DDGS protein.

Values for apparent and standardized ileal digestibility of amino acids were determined at South Dakota State University in 37 samples of DDGS originating from 36 different ethanol plants in the Midwest (Stein et al., 2005; 2006; Pahm et al., 2006a and b). The diets used to measure the apparent ileal digestibility values in these experiments consisted of 67% DDGS, 27% cornstarch, 1% soybean oil, 3% sugar, and vitamins and minerals. The basal endogenous losses were determined using a protein-free diet and the standardized ileal digestibility values were calculated. The results of the experiments showed

that some variation exist for amino acid digestibility among different samples of DDGS (Table 3). This is true in particular for lysine that is more variable than all other indispensable amino acids in terms of digestibility. The reason for this variation is believed to be that lysine may have been heat-damaged in some of the samples of DDGS, which in turn has lowered the calculated digestibility of lysine in these samples. Further work is needed to identify the reasons for this heat damage and to establish procedures for the production that allow ethanol plants to dry the products without heat damaging it. Nonetheless, the amino acids in DDGS have a medium digestibility and, except for lysine, the variability among different samples is within the normal range of variation found in other feed ingredients. Values for apparent and standardized ileal digestibility in 5 different sources of DDGS also have been published (Fastinger and Mahan, 2006). The digestibility of lysine in these samples varied from 38.2 to 61.5%, thus confirming that lysine is the most variable amino acid in DDGS in terms of digestibility.

Phosphorus concentration and digestibility

The phosphorus concentration in more than 200 samples of DDGS was measured by Spiehs et al., 2002. Results of this worked showed that the average concentration of phosphorus in DDGS is 0.89% (DM basis). However, the value reported by NRC (1998) is only 0.83% (DM basis), and the average phosphorus concentration (DM-basis) in 24 samples of DDGS were measured at South Dakota State University at 0.79% (Stein et al., 2005; 2006; Pedersen et al., 2006). Therefore, there seems to be some variation in the estimated concentration of phosphorus in DDGS.

The apparent total tract digestibility of phosphorus in DDGS was measured in 2 experiments involving a total of 14 samples of DDGS (Stein et al., 2005; Pedersen et al., 2006). On average, an apparent total tract digestibility value for phosphorus in DDGS of 55.9% was reported (Table 4). The corresponding value for corn was 21.5%, which was significantly lower than in DDGS. Previously, the relative availability of phosphorus in DDGS has been reported at 77 and 85% (NRC, 1998; Fent et al., 2004). These values seem high and would suggest that almost all the P in DDGS is digestible to the pig and only little is bound in the phytate complex. However, recent

data suggest that P digestibility may be improved by the addition of microbial phytase to diets fed to pigs (Xu et al., 2006). Microbial phytase is expected to improve P digestibility only if some P is bound in the phytate complex, thus indicating that not all the P in DDGS is available to pigs. Moreover, relative availability values are expected to be greater than values for apparent total tract digestibility and may vary dependent on the availability of phosphorus in the reference source of phosphorus that is used in these experiments. Therefore, the apparent total tract digestibility cannot be calculated from the relative availability data. At this point, therefore, a value of 55.9% for the apparent total tract digestibility of P in DDGS should be used.

The reason for the greater digestibility of phosphorus in DDGS than in corn may be that some of the bonds that bind phosphorus to the phytate complex in corn have been hydrolyzed during the fermentation process in the ethanol plants, which in turn would make more phosphorus available for absorption. As a consequence, if DDGS is included in diets fed to swine, the utilization of organic phosphorus will increase and the need for supplemental inorganic phosphorus will be reduced. This will not only reduce diet costs but also reduce the quantities of phosphorus that are excreted into the manure from the animals.

Fiber concentration and digestibility

The concentration of fiber in DDGS is greater than in corn. Values for ADF and NDF of 17.5 and 37.1% (DM-basis), respectively, have been published (NRC, 1998). These values concur with average values of 16.0 and 42.0% that were measured by Spiehs et al. (2002). Very limited information is available on the digestibility of ADF and NDF by growing pigs. However, unpublished data from South Dakota State University showed that the apparent total tract digestibility of ADF and NDF in DDGS is 65.9 and 63.1%, respectively (Table 4). These values were the average of 4 sources of DDGS. The relatively low digestibility of ADF and NDF and the relatively high concentration of these components in DDGS explain why the average total tract digestibility of DM in DDGS is low compared with corn as shown by Pedersen et al. (2006).

Conclusions

Digestibility values for energy, amino acids, phosphorus, ADF, and NDF have been measured in several sources of DDGS. These values indicate that the concentration of digestible and metabolizable energy in DDGS is equivalent to corn. The digestibility of amino acids in DDGS is not more variable than in other feed ingredients with the exception of lysine that may vary considerably because of heat damage. Therefore, during the production of DDGS, care should be taken not to damage the lysine in the product by excessive heating. Procedures to estimate the degree of heat damage in sources of DDGS are needed.

Because of the relatively high digestibility of phosphorus in DDGS, less inorganic phosphorus is needed in diets containing DDGS. The excretion of phosphorus in the manure from pigs fed diets containing DDGS will also be reduced compared with pigs fed diets containing no DDGS if the inclusion of inorganic P is reduced in diets containing DDGS.

At this point, only limited information is available on the variability in digestibility of energy and nutrients within the same plant over time. This is clearly an area that needs more research.

References

Cromwell, G. L., K. L. Herkelman, and T. S. Stahly. 1993. Physical, chemical, and nutritional characteristics of distillers dried grain with solubles fed to chicks and pigs. J. Anim. Sci. 71:679–686.

Fastinger, N. D., and D. C. Mahan. 2005. Determination of the ideal amino acid and energy digestibilities of corn distillers dried grains with solubles using grower-finisher pigs. J. Anim. Sci. 84: 1722-1728.

Fent, R. W., T. S. Torrance, B. W. Ratcliff, S. X. Fu, G. L. Allee, D. M. Webel, and J. D. Spencer. 2004. Evaluation of the bioavailability of phosphorus in distillers dried grain with solubles (DDGS) when fed to pigs. J. Anim. Sci. 82(Suppl. 1): 254.

Hastad, C. W., M. D. Tokach, J. L. Nelssen, R. D. Goodband, S. S. Dritz, J. M. DeRouchey, C. N. Groesbeck, K. R. Lawrence, N. A. Lenehan, and T. P. Keegan. 2004. Energy value of dried distillers grains with solubles in swine diets. J. Anim. Sci. 82(Suppl. 2): 50 (Abstr.).

NRC. 1998. Pages 110–123 in Nutrient Requirements of Swine. 10th rev. ed. Natl. Acad. Press, Washington, DC.

Pahm, A. A., D. Hoehler, C. Pedersen, D. Simon, and H. H. Stein. 2006a. Amino acid digestibility and measurement of blocked lysine in five samples of distillers dried grains with solubles in growing pigs. J. Anim. Sci. 84(Suppl. 1):285 (Abstr.).

Pahm, A. A., C. Pedersen, and H. H. Stein. 2006b. Evaluation of reactive lysine (homoarginine) as an in vitro procedure to predict lysine digestibility of distillers dried grains with solubles by growing pigs. Abstract # 283 presented at the Midwestern Section ASAS and Midwest Branch ADSA 2006, Des Moines IA.

Pedersen, C., M. G. Boersma, and H. H. Stein. 2006. Digestibility of energy and phosphorus in 10 samples of distillers dried grain with solubles fed to growing pigs. J. Anim. Sci. (In Press).

Spiehs, M. J., M. H. Whithey, and G. C. Shurson. 2002. Nutrient database for distiller's dried grain with solubles produced from new plants in Minnesota and South Dakota. J. Anim. Sci. 80:2639-2645.

Stein, H. H., C. Pedersen, and M. G. Boersma. 2005. Energy and nutrient digestibility in dried distillers grain with solubles. J. Anim. Sci. 83(Suppl. 2): 49 (Abstr.).

Stein, H. H., C. Pedersen, M. L. Gibson, and M. G. Boersma. 2006. Amino acid and energy digestibility in ten samples of dried distillers grain with solubles by growing pigs. J. Anim. Sci. 84:853-860.

Xu, G., G. He, S. K. Baidoo, and G. S. Shurson. 2006. Effect of feeding diets containing corn distillers dried grains with solubles (DDGS), with or without phytase, on nutrient digestibility and excretion in nursery pigs. Abstract # 286 presented at the Midwestern Section ASAS and Midwest Branch ADSA 2006, Des Moines IA.

Table 1. Concentration of energy in corn and 10 samples of distillers dried grain with solubles (DDGS) fed to growing pigs[a, b]

Item Ingredient:	Corn	DDGS			
		Average	Standard deviation	Lowest value	Highest value
Gross energy, kcal/kg DM	4,496	5,434	299	5,272	5,592
Apparent total tract digestibility, %	90.4	76.8	2.73	73.9	82.8
Digestible energy, kcal/kg DM	4,088	4,140	205	3,947	4,593
Metabolizable energy, kcal/kg DM	3,989	3,897	210	3,674	4,336

[a] From Pedersen et al., 2006.

[b] Data are means of 11 observations per treatment.

Table 2. Concentration of crude protein and amino acids in distillers dried grain with solubles (DDGS) and in corn [1]

Item Ingredient:	DDGS		Corn		DDGS:corn
	% of DDGS	% of CP	% of Corn	% of CP	ratio
Crude protein	31.20	100	9.21	100	3.39
Indispensable AA					
Arginine	1.26	4.02	0.43	4.72	2.89
Histidine	0.88	2.81	0.28	3.02	3.15
Isoleucine	1.16	3.73	0.31	3.41	3.70
Leucine	3.54	11.35	1.10	11.93	3.22
Lysine	0.89	2.87	0.28	3.02	3.18
Methionine	0.70	2.24	0.19	2.10	3.62
Phenylalanine	1.52	4.86	0.45	4.85	3.40
Threonine	1.13	3.61	0.35	3.80	3.22
Tryptophan	0.20	0.63	0.05	0.52	4.05
Valine	1.60	5.14	0.45	4.85	3.59
All indispensable AA	11.27	36.11	3.44	37.37	3.27
Dispensable AA					
Alanine	2.01	6.44	0.68	7.34	2.97
Aspartic acid	2.21	7.08	0.63	6.82	3.52
Cysteine	0.79	2.54	0.22	2.36	3.65
Glutamic acid	3.96	12.69	1.80	19.54	2.20
Glycine	1.11	3.57	0.37	4.06	2.97
Proline	2.21	7.09	0.74	8.00	3.00
Serine	1.23	3.93	0.43	4.72	2.82
Tyrosine	1.05	3.36	0.34	3.67	3.10
All dispensable AA	16.19	51.90	5.65	61.36	2.87
All AA	27.81	89.13	9.09	98.73	3.06

[1]Data calculated from Stein et al., 2006.

Table 3. Standardized ileal digestibility (%) of amino acids in 37 samples of DDGS by growing pigs

Item Digestibility:	Average	Standard deviation	Lowest value	Highest value
Crude protein	72.8	5.33	63.5	84.3
Indispensable amino acids				
Arginine	81.1	5.18	74.1	92.0
Histidine	77.4	4.58	70.0	85.0
Isoleucine	75.2	4.77	66.5	82.6
Leucine	83.4	3.85	75.1	90.5
Lysine	62.3	7.61	43.9	77.9
Methionine	81.9	4.12	73.7	89.2
Phenylalanine	80.9	3.94	73.5	87.5
Threonine	70.7	5.26	61.9	82.5
Tryptophan	69.9	6.98	54.2	80.1
Valine	74.5	4.72	65.8	81.9
Dispensable amino acids				
Alanine	77.9	4.46	69.7	85.0
Aspartic acid	68.6	4.75	59.4	75.9
Cysteine	73.1	4.64	65.6	80.7
Glutamic acid	80.4	5.48	67.4	88.3
Glycine	63.5	10.97	46.8	87.0
Proline	74.4	22.12	32.0	125.9
Serine	75.6	5.14	59.6	82.8
Tyrosine	80.9	3.79	74.6	88.9

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Table 4. Apparent total tract digestibility (%) of P, ADF, and NDF in dried distillers grain with solubles fed to growing pigs[1,2]

Item Digestibility:	Average	Standard deviation	Lowest value	Highest value
Phosphorus	55.9	11.0	43.6	68.0
ADF	65.9	1.6	62.4	69.9
NDF	63.1	13.6	53.6	72.8

[1] Values for the digestibility of P are means of 14 samples of DDGS and values for the digestibility of ADF and NDF are means of 4 samples of DDGS.

[2] Unpublished data from South Dakota State University