Diet and Health Interactions in Swine

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Introduction

Providing adequate consumption of all essential nutrients is central to maintaining good health of pigs. Animals that are fed properly are more resistant to many bacterial and parasitic infections, which may be partially due to better body tissue integrity, increased antibody production, improved immunity to diseases, or other factors. Additionally, proper nutrition is essential for rapid recovery from all diseases [1]. Optimal herd health requires that all parts of a production program fit together in a complementary system. Herd health programs can be fully effective only if pigs have adequate nutrition, while nutrient utilization can only be optimized if pigs have high health status. High health status increases productivity and efficiency, but also increases nutrient requirements. Therefore, diet and health are intricately connected and dependent upon each other.

Objective

The objective of this document is to provide a review of the connections and relationships between nutrition and health of pigs. It is our hope that the reader will better understand:

- How health and immune status affects nutrient partitioning and nutrient requirements
- Effects of nutrient deficiencies and toxicities on swine health
- Toxins and antinutritional factors of common feedstuffs fed to swine
- Potential implications of improved health provided by some feed ingredients

Metabolic Influence of the Immune System on Nutrient Requirements

Understanding the interactions between nutrition and the immune system is crucial for adjusting nutrient allowances and dietary formulations to optimize production efficiency. Historically, most nutrition research associated with the immune system has focused on optimizing the immune response. It has been only recently that we have begun to understand the influence of the immune system on growth and nutrient requirements.

Physiological changes resulting from an immune challenge

The immune system acts as a sensory organ to detect the presence of antigens (e.g., bacteria, viruses, pesticides, foreign proteins) in the body and to communicate this information to the rest of the body, resulting in a series of behavioral, cellular, and metabolic changes that influence growth and nutrient requirements [2]. Fortunately, animals possess an elaborate immune system that functions to contain or destroy antigens before life-threatening changes occur. In general, the response of the immune system to an antigen is initiated by a release of a series of cytokines, which serve as messengers and activate the cellular (i.e., phagocytic) and humoral (i.e., antibody) components of the immune system. Cytokines also lower voluntary feed intake, and increase core body temperature and body heat production [3].

Nutrient repartitioning

Nutrients are diverted away from productive functions (i.e., lean tissue growth) and toward nutrient demands of the immune system as a result of immune challenge, including vaccination. These metabolic changes increase basal metabolic rate which increases carbohydrate utilization and subsequently increases the energy requirement. Tissue growth rates and body protein synthesis are reduced so that more body proteins can be degraded and contribute to the body's defense for fighting invading antigens. An immune challenge decreases protein synthesis and increases protein degradation rates as a result of reduced feed intake [3] and to meet the increased need for nitrogen to synthesize immunological products. These changes in amino acid utilization have been shown to lower the amino acid requirements for lysine, methionine + cystine and arginine in chicks, presumably because of less demand for these amino acids for lean tissue growth and a different amino acid profile required for the production of immune products [4]. The net results of these metabolic adjustments are reduced body growth rate, less efficient utilization of feed for growth, and potentially fatter carcasses.

Photo courtesy of National Pork Board

Research studies have shown clearly that high health status pigs eat more feed, grow faster and more efficiently during each stage of production, and produce carcasses that have a greater amount of lean and less fat than conventional pigs. An example of the magnitude of differences in growth performance and carcass composition between SEW and conventionally raised pigs is shown in Table 1 [5]. Because less nutrients are needed to support the immune system of SEW pigs compared to pigs with average health status, more nutrients are needed for meeting the greater capacity for muscle tissue growth. In fact, SEW pigs required 2 to 6 grams more lysine intake per day at various body weights to maximize gain/feed in this study (Table 2).

In addition to the increased requirement for dietary amino acids of high health pigs, other nutrients are also required in greater amounts. Dietary fat calories support greater growth rate and efficiency of dietary ME utilization than starch calories in pigs experiencing either moderate or high levels of antigen exposure [6]. Addition of niacin, pantothenic acid, riboflavin, B12 and folacin above estimated requirements resulted in up to 21 and 19% faster growth rates and 10 and 6% less feed required per unit of weight gain in pigs experiencing a moderate and high level of antigen exposure, respectively [7]. Pigs with high antigen exposure appear to have a greater need for one or more of the antioxidant vitamins (vitamins A, E, C). The immune system produces toxic free radicals, which are enhanced by cytokines, to assist in killing foreign organisms. However, because of the potential detrimental effects of cytokines and free radicals on pig performance, and the higher amounts produced by pigs subjected to high antigen exposure, the requirement for these antioxidant vitamins was increased to ameloriate the effects of the higher production of free radicals and cytokines [8]. Dietary available phosphorus needs for 14 to 60 lb pigs were 1.7 times less for pigs with high antigen exposure compared to moderate antigen exposure pigs [9], likely related to the reduced lean growth of pigs exposed to high antigen levels.

Table 1. Growth performance and carcass composition of high health (SEW) pigs and average health, conventionally raised pigs (Williams, 1996)[5]		
	High Health (SEW)	**Average Health (Conventional)**
Feed Intake, lbs/day		
13-60 lbs BW	2.15	2.00
60-247 lbs BW	5.80	5.56
13-247 lbs BW	4.88	4.62
Daily Gain, lbs/day		
13-60 lbs BW	1.49	1.17
60-247 lbs BW	2.10	1.75
13-247 lbs BW	1.90	1.59
Gain/Feed		
13-60 lbs BW	0.70	0.59
60-247 lbs BW	0.36	0.32
13-247 lbs BW	0.39	0.34
Hot carcass wt., lbs	177.7	175.5
10th rib backfat, in.	1.00	1.16
Loin muscle area, sq. in.	6.14	5.23
Dissected muscle tissue, lbs	100.0	93.4
Dissected fat tissue, lbs	44.2	52.2

Table 2. Estimated lysine intakes (g/day) required to maximize gain/feed in high health (SEW) pigs and average health, conventionally raised pigs at various body weights (Williams, 1996)[5]		
Body weight, lbs	**High Health (SEW)**	**Average Health (Conventional)**
15	7.9	5.7
55	18.8	15.6
70	17.1	14.1
132	21.9	16.1
194	19.9	16.8
225	19.3	16.1

Other Nutritional Effects from Immunological Stress

Lipid and fatty acids

Fatty acids have been shown to regulate cytokine production and synthesis as well as release of prostaglandins. In particular, omega-3 fatty acids have been a main focus of research due to their demonstrated ability to modulate infection and inflammation [10]. The release of proinflammatory cytokines resulting from immune stimuli is reduced by dietary omega-3 fatty acids in many species, and it has been postulated that conjugated linoleic acid improves growth by inhibiting the production of PGE2 [11], a potent catabolic inflammatory mediator. However, a different study evaluated the effect of selected fat sources and found no detrimental effect of providing diets with high linoleic acid levels or advantage of providing omega-3 fatty acid enriched diets to immune challenged growing pigs [12].

Minerals

Serum copper concentrations increase while serum iron and zinc concentrations decrease during immunological stress. Iron is required by bacteria for growth; and unless iron in the body is bound by a protein (e.g., transferrin or lactoferrin), susceptibility to infection is increased [13]. In order to avoid the risk of infection, iron is quickly removed from circulation and made nutritionally unavailable to bacteria and parasites. To prevent further immunological stress, dietary iron concentrations should not be increased during immunological stress.

Effects of Nutrition on Minimizing the Risk of Immune Challenge

Energy

The direct effects of feed (energy) intake on specific immune events are largely unknown. Since vitamin, mineral, and amino acid deficiencies or imbalances depress feed intake, it is difficult to interpret data on nutritional effects and immunocompetence. Both heat and cold exposure reduce passively acquired immunity in newborn pigs which is likely due to reductions in colostrum intake.

Protein

Antibody-mediated immune responses are not substantially affected by moderate protein deficiencies. However, several specific amino acids have been associated or involved with metabolism or synthesis of products that provide protective properties in the body against disease pathogens, and thus a significant deficiency in these may be expected to diminish animal health long-term. For example, sulfur amino acids have been shown to enhance antioxidant status via glutathione synthesis. Arginine is a substrate for nitrous oxide synthesis, which stimulates growth hormone synthesis and increases numbers of helper T cells [14]. Glutamine is a precursor for glutathione, is a nutrient for immune cells, and improves gut barrier function [15]. It is probably more important to study how infectious disease progression can affect the nutritional status of the host.

Vitamin E and selenium

When vitamin E and/or selenium are added to nutritionally adequate swine diets, there is generally an increase in the ability of pigs to synthesize antibodies. Supplemental selenium and vitamin E have been shown to increase resistance of sows to MMA [16,17].

Iron

Although results are variable among studies, iron imbalances (levels either too high or too low) increase susceptibility to a number of bacterial and parasitic infections.

Vitamin A

Animals that are fed diets deficient in vitamin A have been shown to not eat well, resulting in reduced intake of essential nutrients and poor growth [18]. Additionally, vitamin A supports the functional integrity of epithelial tissues, and a deficiency may cause a reduction in mucous secretion in the respiratory tract leading to penetration of bacteria. Vitamin A deficiency likely increases susceptibility of animals to infection not only through compromised membrane composition, but also has been shown to greatly reduce synthesis of antibodies and antibody-forming cells in the spleen.

Zinc

Zinc serves as an essential cofactor for over 70 enzymes [18]. Additionally, a number of nutrients and hormones affect the expression of specific genes when interacting with zinc. Because of the key role zinc plays in cell turnover, a deficiency weakens immunity by impairing antibody synthesis and thus increasing susceptibility infections.

B-complex vitamins

B-complex vitamins, in particular pantothenic acid, pyridoxine, and riboflavin, improve resistance to infection and disease [18]. Deficiency of one or more of these vitamins has been shown to lead to a dramatic reduction in antibody synthesis. There is almost no reserve for the water-soluble B vitamins, so daily intake of these micronutrients is essential.

Vitamin C

Vitamin C, or ascorbic acid, is a powerful water-soluble antioxidant that plays a key role in immune cell function. Vitamin C is not a dietary essential nutrient for pigs, unlike primates, because swine have the enzyme L-gulonolactone oxidase to synthesize ascorbic acid from carbohydrate sources like glucose and galactose. Vitamin C protects cells from lipid peroxidation and increases the fluidity of cell membranes, thus enhancing the immune response [19]. Protection against extracellular free radicals increases structural integrity of cells and tissues. In macrophages, vitamin C also increases phagocytosis, chemotaxis, and cell adherence, all of which are important in immune cell function [20].

Nutrient deficiencies

Nutrient deficiencies rarely occur in pork production operations today because of our increasing understanding of nutrient requirements of pigs under various production conditions as well as our ability to estimate nutrient content, digestibility and bioavailability of ingredients used in swine feeds. However, occasional deficiencies do occur as a result of feed formulation or manufacturing errors as well as under unique circumstances of high productivity, low feed consumption, or other compounding circumstances.

In general, energy, amino acid, and water (macro nutrients) deficiencies can be observed quickly because there is limited nutrient storage in the body and pigs have a relatively high requirement for these nutrients to support daily needs. Vitamin and mineral deficiencies generally are not observed until a longer period of time has elapsed because many of these nutrients are stored in the body and are mobilized to compensate for deficiencies in nutrient intake. Table 3 summarizes general effects of energy, protein and essential fatty acid deficiencies on swine health and performance. Table 4 summarizes specific mineral deficiency diseases, while vitamin deficiency diseases are summarized in Table 5 [21].

Table 3. Clincal Signs of energy, protein and essential fatty acid deficiencies in swine[a]

Nutrient	**Energy**	**Protein level**	**Protein Quality (essential amino acids)**	**Essential Fatty Acids**
Deficiency Sign				
Slow growth	X		X	X
Reduced appetite		X	X	X
Poor hair and skin conditions		X	X	X
Lameness				
Diarrhea				
Impaired reproduction	X	X		
Offspring dead or weak		X		
Weakened bone structure				
Other (see codes below)	1	2,3	3	4

Code:
1 Reduced fatness in proportion to body weight
2 Anemia
3 Poor feed efficiency; overfat carcass
4 Loss of hair; scaly, dandruff like dermatitis, especially of feet and tail

[a]Source: Adapted from Reese and Miller (2006) [21].

Table 4. Signs of mineral deficiency diseases

Elements	**Deficiency Disease**
Calcium, Phosphorus	Rickets, Osteomalacia
Magnesium	Tetany
Iron, Copper	Anemia
Copper, Potassium	Ataxia
Zinc	Parakeratosis
Iodine	Hypothyroidism
Manganese	Perosis
Selenium	Hepatosis dietetica, Nutritional muscular dystrophy, Micro angiopathy, Edema

Source: Reese and Miller (2006) [21]

Table 5. Vitamin deficiency diseases[a]	
Vitamin	**Deficiency Diseases**
Vitamin A	Unsteady gait, Incoordination, Trembling, Spasms, Paralysis, Eye lesions, Reduced growth, Estrus failure, Fetal resorption, Fetus deformities
Vitamin D	Rickets, Osteomalacia, Poor growth, Stiffness, Lameness
Vitamin E (and/or Selenium)	Muscular dystrophy, Hepatosis dietetica, Sudden death of fast growing pigs, Icterus, Difficult locomotion, Peripheral cyanosis, Dyspnea, Weak pulse, Hepatic necrosis, Degenerative myopathy, Edema, Yellow discoloration of adipose tissue, MMA syndrome in sows, Spraddled rear legs in baby pigs, Gastric ulcers, Infertility, Suseptibility to swine dysentery, Poor skin condition
Vitamin K	Impaired blood coagulation, Low prothrombin levels, Increased clotting time, Hemorrhaging
Thiamin	Decreased appetite and body weight, Vomiting, Slow pulse, Subnormal body temperature, Nervous signs, Postmortem heart changes, Sudden death due to heart failure, Anorexia
Riboflavin	Decreased growth, feed consumption, and feed efficiency; Anorexia; Rough hair coat; Dermatitis; Alopecia; Abnormal stiffness; Unsteady gait; Scours; Ulcerative colitis; Inflammation of anal mucosa; Vomiting; Cataracts; Light sensitivity; Decreased immune response; Discolored liver and kidney; Degenerating ova; Degenerating myelin of sciatic and brachial nerves; Premature parturition; Increased stillborn pigs; Anestrus; Cessation of ovarian cyclicity; Hairless newborn pigs
Niacin	Loss of appetite, Retarded growth, Weakness, Digestive disorders, Diarrhea, Stomatitis, Normocytic anemia, Achlorhydria, Exfoliate type dermatitis, Hair loss, Degeneration of nervous system, Inflammatory lesions of gastrointestinal tract, Reduced resistance to bacterial infection
Pyridoxine	Poor appetite, Slow growth, Mycrocytic hypochromic anemia, Dermatitis, Epiletic-like convulsions, Faaty liver, Diarrhea, Rough hair coat, Scaly skin, Brown exudate around eyes, Demyelination of peripheral nerves, Suncutaneous edema, Excessive nitrogen excretion, Increased urinary xanthurenic acid and kynurenic acid
Pantothenic acid	Locomotor disorder of rear legs "goose stepping," Paralysis, Scaly skin and thin hair, Brown secretion around eyes, Dermatosis of shoulder and ears, Necrotic enteritis, ulceration and hemorrhages in the large intestine, Bloody feces, Fatty liver degeneration, Enlarged adrenals, Enlarged heart, Complete reproductive failure
Biotin	Reduced growth and feed conversion; Alopecia; Dry, rough dermatitis with brown exudate; Ulceration of the skin; Inflammation of oral mucosa; Hindleg spacity and cracking of soles and top of hooves; Lameness; Impaired reproduction
Folic acid	Deficiency can be induced by feeding sulfa drugs, Reduced growth, Macrocytic anemia, Leucopenia, Listlessness, Diarrhea, Suboptimal reproductive performance of sows
Vitamin B_{12}	Loss of appetite, Variable feed intake, Dramatic growth suppression, Rough skin and hair coat, Vomiting, Diarrhea, Microcytic normochromic anemia, High netrophil and low lymphocyte counts, Nervous disorders, Thymus and spleen atrophy, Liver and tongue enlargement, Reduced litter size and baby pig survival, Abortions, Low birth weights, Fetal deformities, Late estrus, Fewer corpora lutea and embryos
Vitamin C	Weakness; Fatigue; Dyspnea; Bone pain; Skin, muscle, adipose tissue, and some organ hemorrhaging; Leg weakness
Choline	Unthriftiness, Poor conformation (short legs, pot-belly), Lack of coordination, Loss of joint rigidity, Fatty liver, Spraddled legs of newborn pigs, Reduced conception rate and litter size of sows

[a]Adapted from Reese and Miller (2006) [21]

Nutrient Toxicities

Continuous long-term feeding of minerals at the maximum tolerable levels may cause adverse effects. Maximum tolerable levels of minerals and vitamins are affected by the age of the animal. Generally, young pigs are more susceptible to nutrient toxicities than older sows or boars. Furthermore, the multiple mineral interactions as well as mineral-vitamin interactions influence the maximum tolerable levels. Table 6 summarizes mineral toxicity diseases, and Table 7 lists the maximum tolerable level of dietary minerals for swine [21]. Vitamin toxicity diseases are not well defined or documented because of the high order of magnitude of supplementation (4 to 10 times the requirement) to achieve a vitamin toxicity status for most vitamins (Table 8) [22]. Because of the high improbability of feeding toxic levels of most vitamins under practical conditions, vitamin toxicity diseases are not listed. Vitamin tolerance is defined as the absence of deleterious effects of vitamin intakes above those needed to prevent nutritional deficiency disorders (National Research Council, 1987).

Health Related Properties of Some Selected Feed Ingredients

Selection of feed ingredients may play a role in the overall health and performance of pigs apart from the nutrients that a particular ingredient may contribute to the diet. The ingredient may improve the health status of the pig or help the pig endure stressors associated with disease. On the other hand, some feed ingredients may compromise the pig's ability to perform optimally in the presence of stressors induced by disease or the environment. Some ingredients serve a dual role in that they are important sources of required nutrients to swine diets and they more directly influence the pig's ability to cope with disease and other stressors.

Spray dried porcine plasma (SDPP)

Spray dried porcine plasma is used in diets to enhance feed intake and growth rate of newly-weaned pigs. The magnitude of growth response is greater for younger (10 to 16 days), more immature pigs compared with older pigs (> 21 days) at weaning. In addition to being a concentrated source of highly digestible amino acids, SDPP seems to offer some immunological protection to the young pig. The beneficial effects of SDPP appear to result from the immunoglobulin fraction [23,24]. The immunological protection provided by SDPP appears to elicit a greater performance response in immune-stimulated pigs compared with high health pigs [25]. The exact mechanism for the consistent improvement in voluntary feed intake and pig performance is not known. However, these findings suggest SDPP provides some non-specific immunological protection to newly-weaned piglets that typically are weaned at a time when protection from colostral antibodies is waning and their own immune system has not fully matured.

Table 6. Mineral toxicity diseases[a]

Element	Toxicity Disease
Calcium	Parakeratosis (Zn interaction)
Copper	Icterus, Anemia (Fe, Se interaction)
Iron	Rickets, Nutritional Muscular Dystrophy (P, Se interaction)
Selenium	Alkali disease (As interaction)
Sodium	Hypertension (K interaction)
Zinc	Arthritis, gastritis (Cu interaction)
Arsenic	Erythema, ataxia (Se interaction)
Cadmium	Anemia, dermatitis (Fe, Zn interaction)
Cobalt	Anemia (Fe interaction)
Fluorine	Enamel hypoplasia, hyperostosis (Ca, P interaction)
Lead	Ataxia, anemia (Fe interaction)
Mercury	Ataxia, cyanosis, polyuria (Se interaction)
Aluminum	Rickets (P interaction)

[a]Reese and Miller (2006) [21]

Table 7. Maximum tolerable levels of dietary minerals for swine[a].		
Element	**Dietary Level**	**Comments**
Aluminum	200 ppm	Derived by extrapolation from other species. As soluble salts of high bioavailability. Higher levels of less-soluble forms found in natural substances can be tolerated.
Arsenic, inorganic	50 ppm	
Arsenic, organic	100 ppm	
Barium	20 ppm	Derived by extrapolation from other species. As soluble salts of high bioavailability. Higher levels of less-soluble forms found in natural substances can be tolerated.
Bismuth	400 ppm	Derived by extrapolation from other species.
Boron	150 ppm	Derived by extrapolation from other species.
Bromine	200 ppm	
Cadmium	0.5 ppm	Level based on human food residue considerations.
Calcium	1 %	Ratio of calcium to phosphorus is important.
Chromium chloride	1,000 ppm	Derived by extrapolation from other species.
Chromium oxide	3,000 ppm	Derived by extrapolation from other species.
Cobalt	10 ppm	
Copper	250 ppm	
Fluorine	150 ppm	As sodium fluoride or fluorides of similar toxicity. Fluoride in certain phosphate sources may be less toxic.
Iodine	400 ppm	
Iron	3,000 ppm	
Lead	30 ppm	Levels based on human food residue considerations.
Magnesium	0.3 %	Derived by extrapolation from other species.
Mercury	2 ppm	Levels based on human food residue considerations.
Molybdenum	20 ppm	
Nickel	100 ppm	Derived by extrapolation from other species.
Phosphorus	0.9 %	Ratio of calcium and phosphorus is important.
Potassium	2 %	Derived by extrapolation from other species.
Selenium	2 ppm	
Silver	100 ppm	Derived by extrapolation from other species.
Sodium chloride	8 %	Unlimited access to water required at this level
Strontium	3,000 ppm	
Tungsten	20 ppm	Derived by extrapolation from other species.
Vanadium	10 ppm	Derived by extrapolation from other species.
Zinc	1,000 ppm	Supranutritional levels up to 3000 ppm from zinc oxide sometimes included in young pig diets for growth promotion.

[a]Reese and Miller (2006) [21]

Table 8. Vitamin tolerances of pigs[a]		
Vitamin	**Upper Safe Level**	**Comments**
Vitamin A	4x to 10x requirement	Toxic effects at 10x to 1000x requirement
Vitamin D	4x to 10x requirement (>60 d feeding period) 100x requirement (<60 d feeding period)	Vitamin D3 is 10x to 20x more toxic than vitamin D2.
Vitamin E	1,000 to 2,000 IU/kg diet 75 IU/kg of body weight/day	
Vitamin K (menadione)	1,000x requirement	
Vitamin C (ascorbic acid)	10 ppm	
Thiamin	1,000x requirement	
Niacin	350 mg/kg of body weight/day	
Riboflavin	10x to 20x requirement	100x requirement may possibly be tolerated
Pyridoxine (B6)	1,000x requirement	
Folic acid	Not established	
Pantothenic acid	20 ppm	
Biotin	4x to 10x requirement	
B_{12}	500x requirement	
Choline	2,000 ppm	

[a]National Research Council, 1987 [22]

Spray dried egg protein

Spray dried egg proteins are similar to SDPP in that they provide a highly digestible source of essential amino acids to the pig. Spray dried egg proteins have not been studied extensively. Early studies indicate a variable response of newly-weaned pigs to spray dried whole egg (SDWE). Designer egg proteins, harvested from eggs of hens immunized against common swine diseases, results in an ingredient containing specific immunoglobulins against those diseases, but more research is needed to evaluate the effectiveness of these products.

Dried porcine solubles (DPS)

Dried porcine solubles is the dried residue from hydrolyzed porcine intestines that remains after extraction of heparin. Partial replacement of dried whey with 5 – 6% DPS in diets during the first two weeks postweaning elicited minor improvements in growth rate of nursery pigs [26]. More interesting was the observation that the improvements in growth rate continued and were of greater magnitude during the subsequent two weeks when all pigs were fed a common diet without DPS. The mechanism for this delayed response is unclear, but possibly DPS hastens maturation of the gut which enhances the pig's ability to digest feed. Potential immunological benefits of DPS have not been investigated.

Rendered animal by-products

Meat and bone meal, meat meal, and other rendered animal by-products are discriminated against because some swine industry professionals perceive an increased risk of disease introduction to swine production units. Risk of salmonella introduction via meat meal has been argued to be far less than cereal grains and soybean meal because meat meal is produced under strict quality control standards and it is included in diets at relatively low levels [27]. Ingredients of plant origin can be a vehicle for salmonella infection due to contamination with bird and rodent droppings.

Soybean meal

Soybean meal is a staple in the diet of pigs raised in North America. Soybean meal is a relatively inexpensive source of essential amino acids that balances the amino acid deficiencies of the primary dietary energy source, cereal grains. Unfortunately, these benefits are tempered by antinutritional factors present in soybeans. These antinutritional factors include: protease inhibitors, hemagglutinins, goitrogens, saponins, estrogens, cyanogens, oligosaccharides, and antigenic factors [28]. The antigenic factors are particularly troublesome to newly-weaned pigs. Young pigs experience a delayed hypersensitivity to storage proteins present in soybean meal [29]. Intestinal villi become shorter and club-like in appearance as a result of the antigenic response to soy proteins [30]. These changes presumably reduce surface area of the intestinal mucosa which likely has negative effects on the gut's ability to absorb nutrients.

An antigenic response to the diet may predispose the newly-weaned pig to gastrointestinal disease. In pigs challenged with pathogenic E. coli, feeding a diet that contained antigenic proteins caused diarrhea in 100% of the pigs [31]. However, no diarrhea was observed when contemporary pigs were fed the same diet that had been enzymatically hydrolyzed to reduce its antigenicity. If susceptibility to E. coli is increased when feeding an antigenic diet to newly-weaned pigs, one may hypothesize that susceptibility to other pathogenic organisms may also be increased. It is not practical or economical to avoid soybean meal in diets for pigs fed to slaughter weight because of delayed hypersensitivity to the diet. Consequently, pigs must be introduced to soybean meal at some point. Current research and understanding appear to indicate that providing some low level of soybean meal in the first postweaning diet is useful to acclimate the pig to dietary soybean proteins.

Dried Distillers Grains with Solubles (DDGS)

A growth performance and carcass composition trial conducted on a commercial farm [32] demonstrated a linear reduction in mortality percentage from 6.0 % to 1.6% when dietary DDGS level was increased from 0 to 30% in a corn-soybean based diet fed to growing pigs from 93 lb to market weight. There are a number of compounds that may be present in DDGS that may affect the immune status of pigs. Distiller's by-products contain residual yeast cells and yeast cell components. It has been estimated that approximately 3.9% of the dry weight of DDGS is contributed from yeast cell biomass [33]. Beta-glucans, mannan-oligosaccharides, chitin, and proteins are biologically important fractions of yeast cell walls, with many of these compounds capable of stimulating phagocytosis [34]. Yeast cells also contain nucleotides, glutamate and other amino acids, vitamins and trace minerals which may also play a role in the immune system when fed to pigs.

One disease trial reported that feeding diets containing 10% DDGS reduced the prevalence and severity of intestinal lesions when pigs were challenged with Lawsonia intracellularis, the causative agent of porcine proliferative enteropathy, or ileitis [35]. Feeding antimicrobials in the diets also reduced the length and severity of lesions, but no additive effects of feeding DDGS and the antimicrobials was observed. These results suggest that dietary inclusion of DDGS may aid young growing pigs in resisting a moderate ileitis challenge similar to an approved antimicrobial regimen, although results from two other trials [36,37] indicate that under more severe challenges, DDGS may not be effective.

Other Feed Ingredients with Health-Promoting Properties

Many other feed ingredients may provide health promoting properties. For example, lactose (provided via dried whey or other dairy source) is a substrate for Lactobacillus spp, enhancing growth of the beneficial bacteria and thus potentially aiding weanling pig health by competitively inhibiting the colonization of other pathogenic bacteria in the gut. Fish meals and oils contain omega-3 fatty acids that have been shown to positively influence health of humans and pigs in many ways. Many of these types of ingredients are often included in the diets of young, newly-weaned piglets at a time when they are subjected to a number of immunological and other stressors while immune system function is still developing. More information is provided in PIG Factsheets 07-01-08 (Nursery Swine Nutrient Recommendations and Feeding Management) and 07-07-09 (Composition and Usage Rate of Feed Ingredients for Swine).

Natural Toxins in Feedstuffs

Many common feedstuffs contain naturally-occurring anti-nutritional factors that may impair pig performance. Although their presence is undesirable, knowledge of these factors allows nutritionists to formulate diets that correct the negative impacts. Table 17 is a summary of natural toxins found in grains, tubers, and protein supplements.

Table 17. Natural toxins found in feedstuffs fed to swine	
Feedstuff	**Toxin(s)**
All grains	Phytate, mycotoxins
Rye, triticale	Trypsin inhibitors, ergot
Milo	Tannins
Buckwheat	Fagopyrin
Potatoes	Solanum alkaloids
Cassava	Cyanogenic glycosides
Soybeans	Trypsin inhibitors, lectins, goitrogens, saponins, phytate, mycotoxins
Cottonseed	Gossypol, tannins, cyclopropenoid fatty acids, mycotoxins
Rapeseed	Glucosinolates, tannins, erucic acid, sinapine
Linseed meal	Linatine, linamarin
Field beans	Trypsin inhibitors, lectins
Lupins	Alkaloids

Phytate

Phytate is a naturally occurring compound (phosphorus + inositol) in many grains that contain phosphorus of low availability to the pig and may account for as much as 80% of the total phosphorus in grains. Chemical analysis overestimates the phosphorus available to the pig. Phytate combines with other minerals (e.g., zinc, iron, and manganese) which reduces their availability, and the presence of calcium increases the problem. These adverse effects can be partially overcome by supplementing the diet with the enzyme phytase which effectively liberates a portion of the phosphorus from phytate. Alternatively, the diet can be supplemented with additional calcium, phosphorus and zinc.

Saponins

Saponins are commonly found in legumes such as alfalfa, soybeans, chickpeas, and beans, and impair pig performance due to bitter taste and irritating effect on the lining of the mouth and gut.

Estrogens

Zearalenone is an estrogenic mycotoxin occasionally found in corn. Alfalfa, clover, and soybeans can also produce coumestrol which is an estrogenic like substance.

Tannins

Tannins elicit their negative effects by binding to proteins and inhibiting protein digestion. Tannins also are present in soybeans, faba beans, sunflower seeds, sorghum and alfalfa and reduce palatability. They can be removed from these feedstuffs, but the process is not cost effective. Plant breeders have or are developing hybrids with lower tannin content to reduce these negative effects.

Trypsin inhibitors

Trypsin inhibitors are present in soybeans that have not been properly heat processed as well as in alfalfa, rye and barley. Heating soybeans for 15 minutes at a temperature of 212°F will effectively render them inactive in soybeans. Trypsin inhibitors manifest their anti-nutritional effects by binding to protein digesting enzymes (trypsin and chymotrypsin) to render them inactive and decrease protein digestibility.

Glucosinolates

Glucosinolates are present in rapeseed, mustard and turnips. Glucosinolates reduce palatability and impair function of the thyroid gland. Low glucosinolate varieties of rapeseed, called canola, have much lower levels of glucosinolates and erucic acid.

Mycotoxins

Mycotoxins are produced by specific molds under specific environmental conditions. Many naturally occuring mycotoxins have been identified, but only a few have been shown to cause significant, detrimental health and performance problems in swine fed contaminated plant based feedstuffs. The maximum tolerable levels and signs of mycotoxicosis in swine are shown in Table 18 [38]. It is important to remember that the presence of molds in grains does not automatically indicate mycotoxin presence. If clinical signs of mycotoxicosis are observed in the animal, it is important to collect a grain or feed sample and send it to a laboratory to determine the presence and level of the suspected mycotoxin(s). Analytical tests for mold spore counts are of little or no value.

Table 18. Maximum tolerable level of mycotoxins commonly found in swine feeds[a]

Mycotoxin	Maximum Tolerable Level	Comments
Aflatoxins (B1, B2, G1, G2)	< 20 ppb for human use, dairy feed, feed for immature animals < 100 ppb for breeding swine < 200 ppb for finishing swine (>120 lbs body weight)	Carcinogenic. Immunosuppressant. Acute signs: anorexia, depression, ataxia, epistasis. Chronic signs: reduced feed efficiency, reduced milk production, icterus, decreased appetite.
Zearalenone	< 1 ppm for young growing pigs < 2 ppm for breeding herd < 3 ppm for finishing pigs and young and old boars	Estrogenic effects. Swollen vulvas, vaginal or rectal prolapses in prepubertal gilts. Enlarged uterus, swollen or twisted uterus, shrunken ovaries. In boars, testes atrophy, enlarged mammary glands, decreased fertility.
Deoxynivalenol (vomitoxin)	< 5 ppm on grain and grain by-products. DON contaminated feedstuffs should not exceed 20% of the diet. (< 1 ppm in complete feeds)	Reduction in feed consumption and weight gain are inversely proportional to concentration of DON. High concentrations cause feed refusal and vomiting.
T-2 toxin	< 1 ppm	Potent immunosuppressive agent that directly affects immune cells and modifies immune response as a consequence of other tissue damage. Frequent defecation, vomiting, weight loss and feed refusal.
Fumonisin	Not established < 5 ppm (extrapolated from horse data)	Carcinogenic in laboratory tests using rats. Associated with pulmonary edema in pigs.
Ochratoxin	< 200 ppb has been associated with kidney damage in swine	Ochratoxin A is most common and potent. Reduction in growth, feed efficiency, increased mortality, liver and kidney damage.
Ergot	< 200 ppb	Vertigo, staggers, convulsions, temporary posterior paralysis, eventual death. Decreased peripheral blood supply. Reduced growth, tail loss, reduced reproductive efficiency of sows.

[a]Feedstuffs Reference Issue (1997) [38].

Fat Addition to Swine Diets and Air Quality

Air quality in swine confinement facilities is important for worker and pig health. Dust is a primary pollutant in swine confinement facilities. The primary origin of dust in confinement swine housing is from feed [39,40]. Several studies have shown that adding soybean oil or fat to pig diets reduces the amount of airborne dust in swine confinement buildings [41,42,43]. Based on these results, it is well accepted that adding 1% fat to the diet markedly reduces airborne dust, and up to 3% supplemental fat will further reduce airborne dust levels in swine confinement facilities. Soybean oil is a more effective dust suppressor when added to complete feed after grinding than when adding it to the corn before grinding, and that feed storage does not reduce the dust suppressing effects of soybean oil added to the feed [44]. It is difficult to place an economic value on the dust suppression benefits of adding supplemental fat to swine diets, but understand that air quality is extremely important for worker health and respiratory health of the pigs.

Diet Form and Pig Health

Physical form of feed can play an important role in pig performance and health. Diet particle size and pelleting are the most important factors that affect pig nutrition and health in the U.S. By reducing diet particle size, improvements in growth rate and feed conversion are commonly observed [45,46,47]. In general, for every 100 μm in particle size above 600 μm, feed:gain is increased by 1.3% [48]. However, feeding finely ground diets have negative effects on gastrointestinal health. Results from several research studies have shown that pigs fed finely ground diets have a higher incidence in stomach lesions than pigs fed more coarsely ground feeds [49,50,51]. This appears to be caused by increased acidity and pepsin digestive enzyme activity in the relatively unprotected esophageal region of the stomach. Researchers have also demonstrated that feeding finely ground feed increases the Salmonella prevalence in pigs [52,53]. Despite the potential negative effects of feeding finely ground feed to pigs, pork producers continue to feed diets with average particle size of 700 to 800 μm because of consistent improvements in nutrient digestibility, improved growth rate and feed conversion, and reduced manure production.

Pelleting

Pelleting of complete feeds helps eliminate bridging problems in bins and feeders for diets with small average particle size, reduces dustiness, and prevents segregation of ingredients [54]. Finely ground feed is commonly used to make pelleted diets and as a result, feeding pelleted diets have been shown to increase growth rate and feed conversion compared to pigs fed meal diets. However, fine grinding may also increase the incidence of gastric ulcers and stomach keratinization [48,49,55]. Feeding meal diets has been shown to reduce the number of pigs testing positive for Salmonella [52,53], and reduce coliform bacteria in the stomach and cecal contents [53] compared to pigs fed pelleted diets.

Non-Nutritive Feed Additives and Pig Health

Additives are included in the diet because they enhance the pig's well being in ways other than providing necessary nutrients. Many of these feed additives elicit their positive effects of pig health and performance by altering the microbiota of the gastrointestinal tract. There is no "silver bullet" when it comes to dietary additives and their ability to prevent disease: what works on one farm may not work on another. Additionally, other factors must be considered when determining whether to include a non-nutritive additive in feeds, including physical form of the diet and cost effectiveness. A complete description of different feed additives, their mode of action, and relative efficacy is described in PIG factsheet #07-03-03 (Feed Additives for Swine).

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