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# Environmental Sustainability and Social Desirability Issues in Pig Feeding*

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**ABSTRACT :** Feeding pigs used to be a means of managing domestic resources that may otherwise have been wasted into valuable animal protein. Feeding pigs thus was a form of husbandry. Following recent rapid industrial development, pig rearing has changed from extensive to intensive, but this transformation has been associated with major concerns. The concentration of large amounts of pig manure in small arrears is environmentally hazardous. Moreover, high densities of animals in intensive production systems also impose a health threat for both animals and humans. Furthermore, the use of growth promoters and preventive medicines for higher production efficiencies, such as in-feed antibiotics, also induces microbial resistance thus affects human therapeutics. In addition, consumers are questioning the ethics of treating animals in intensive production systems. Animal welfare, environmental and bio-safe issues are re-shaping the nature of pig production systems. Feeding pigs thus involves not only the consideration of economic traits, but also welfare traits and environmental traits. Thus, a focus on technological feasibility, environmental sustainability and social desirability is essential for successful feeding operations. Feeding pigs now involves multiple projects with different sustainability goals, but goal conflicts exist since no pattern or scenario can fulfill all sustainability goals and the disagreements are complicated by reduced or even no use of in-feed antibiotics. Thus it is difficult to feed pigs in a manner that meets all goals of high quality, safe product, eco- and bio-sustainability, animal welfare and profit. A sustainable pig production system thus requires a prioritization of goals based on understanding among consumers, society and producers and needs to view from both a local and global perspective. (**Key Words** : Pig Feeding, Environmental Sustainability, Social Desirability)

## INTRODUCTION

The judicious use of domestic resources to cultivate or produce of plants and animals is known as husbandry. The use of pigs as converters, rather than scavengers, to transform farm left-over or kitchen swill to favorable animal products not only provides organic fertilizer for crops, but is also beneficial for nutrient management, and undoubtedly constitutes husbandry. Pigs under such a minimum waste system of conventional agriculture are traditionally kept in small herds as a sideline source of farm revenue. Following industrial developments and economic growth, pig rearing has rapidly industrialized and changed from extensive to intensive due to greater demands for animal-derived food consumption. The increase in real incomes of consumers and in urbanization has led pork to be produced in intensive systems, thus lowering the cost of production through economies of scale. Industrial pig production is capitally and technologically intensive, and is also highly labor efficient. It drives trade in feed grains and other feed resources, and thus is detached from land in terms of feed supply and waste disposal. Consequently, pig production is fairly transportable, since it is not restricted to highly specific geographic locations (grain producing areas) or climate conditions (temperate environments). The application of controlled environment measures has enabled pig production in a range of disfavoring regions (tropical and subtropical) around the world. Therefore, pig husbandry has evolved into commercial pork production through the adoption of modern technologies of animal science, and knowledge of finance and commerce, to meet the consumption needs of urban consumers with high disposable incomes.

Conversely, industrial systems of pig production cause some substantial concerns. The concentration of large quantities of pig manure in small areas is hazardous to the environment. This problem is aggravated by the expansion

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of metropolitan areas, and the placing of production near large cities to allow good market access. High densities of animals in intensive production systems also impose a constant health threat for both animals and humans. The use of growth promoters and preventive medicines for higher efficiencies, such as in-feed antibiotics, also induces microbial resistance, and consequently affects human therapeutics through horizontal gene transfer or survival niche movement. Some swine exotic diseases also significantly increase the risk of zoonoses. Moreover, consumers, who have been benefited by the low cost and secure supply of industrial production, are questioning the ethics of raising animals in intensive systems, and are increasingly willing to pay more for similar products with ethical as well as ecological values. Environmental issues, animal welfare and safety are particularly important in the knowledge-based economy, and have moved animal production beyond the singular goal of providing animal products and maximizing profit.

Environmental, bio-safe and animal welfare issues are changing pig production systems, requiring effective management of resources such as water, soil, air and biomaterials from microbials to feed materials, along with respect for animal rights. Therefore, feeding pigs is not only a consideration of economic traits such as growth rate, lean percent, feed efficiency and litter size, but also environmental traits (e.g. less excretion of N and P) and welfare traits (e.g. little stereotypies, maternity, fitness and disease resistance). Producers seeking a fair income for their current work and investment are facing challenges, because feeding pigs should not only be environmental friendly and biologically safe, but also be accommodate social ethics. Hence, the technological feasibility, environmental sustainability and the social desirability are essential for successful operations.

## ENVIRONMENTAL SUSTAINABILITY

### Life cycle assessment

New incentives and policies for ensuring the sustainability of agriculture and ecosystem services are crucial to ensure that food meets the growing demand without compromising environmental integrity and public health (Tilman et al., 2002). Feeding pigs involves multiple environmental projects, and involves two major sustainability issues: eutrophication or acidification, and global warming or energy consumption. The environmental impact of pig production can be described as a life cycle. A comprehensive set of programs focusing on sustainable pig production should employ the life cycle assessment (LCA) to promote production patterns. The fundamental principle of the LCA is to follow the product through its entire life cycle from extraction of raw materials to final disposal or recycling. LCA is a tool to assess the environmental impacts of product systems and services, accounting for the emissions and resource usage during the production, distribution, use and disposal of a product (ISO 14045, 1999). It also includes methods for grouping different emission based on the extent of the environment impact caused when released. The effects of eutrophication and global warming, which are mainly based on input-output analysis by LCA approaches, are utilized as indicators to inform policy making, select areas of action, identify the most sustainable methods, advise consumers and evaluate the effectiveness of sustainable consumption or production measures, when considering sustainable consumption and production. This assessment can help producers to reduce the environmental impact of a product during its life cycle, such as in pig production, addressing the energy in feed formulation and consumption when rearing a pig herd, as well as the environmental load linked with the disposal or treatment of pig manure.

The environmental impact of pig production in a life cycle perspective has previously been described (Basset-Mens and van der Werf, 2005). High nitrogen utilization is generally agreed to be the most important measure for reducing hazards of acidification and eutrophication in a pig production system. The European Union's Nitrate Directive (91/676/EC), which permits a maximum of 170 kg N/ha to be applied to cultivated land each year to keep the N concentration of surface water below 50 mg nitrate/L, indicating that a manure surplus in particular N surplus is considered as an threat to water quality.

Reducing N loss from the farm must begin with proper animal feeding and management to reduce N excretion. A low-protein pig diet has been recommended to improve the environmental performance, and can be achieved by including a large quantity of synthetic amino acids (Han and Lee, 2000; Han et al., 2001). Indeed, lowering the dietary crude protein level from 16% to 12%, and supplementing the diet with crystalline lysine, tryptophan and threonine, could significantly decrease the level of N excretion, provided that growth performance and lean tissue gain are similar in growing pigs whether they are housed in a thermal-neutral or heat-stressed environment (Kerr et al., 2003).

Several general strategies of nutrition and feed management besides amino acid supplementation exist to reduce nutrient excretions and odors from pig manure. Avoiding excessive overages of dietary P, balancing diets on the basis of available P, and use of phytase, are practical for reducing the level of P in manure (Knowlton et al., 2004). Use of reduced or organic forms of Cu, Zn, Fe and Mg decrease excretion of these minerals in manure. Maintaining the proper acid-base balance and buffering in the diet can significantly lower odorous compounds.

Additionally, adding acidifying Ca salts to the diet rather than $CaCO_3$ could lower urinary pH, and consequently decrease ammonia emission by 26 to 53% (q.v. Sutton and Richert, 2004).

Effluent from pig farms also contains large quantities of electrolytes, creating additional difficulties. A high electrical conductivity ranges from 2,000 to 6,000 μs/cm, depending on the amount of flush water used in cleaning, was recorded from a family-based small production unit. This level far exceeds the maximum limit of 750 μs/cm, 25°C for crop irrigation. Two periods of irrigation with maximum conductivity allowance generally build up a soil limit of 4,000 μs/cm at which can retard crop growth (Yu et al., 2005). Channeling the pig farm effluent into irrigation system is therefore detrimental to crop field, and rice paddy may be the most vulnerable crop due to continuous wetting. Attempts to minimize electrolyte content in pig excreta to reduce conductivity by dietary modification have not been successful. Decreasing dietary protein content by 20%, and mineral supplements by 40% (Ca, P and other salts), would reduce nutrients supply close to maintain level of pigs. However, this level could only decrease waste water conductivity by 30%, leaving it well beyond the irrigation allowance (Yu et al., 2005). The conductivity is significant, especially in areas where pig feeding and crop growing often co-exist in integrated farming systems within a small close community. An independent watercourse is undoubtedly a burden if it becomes a prerequisite for feeding pigs.

Dietary carbohydrate manipulations have recently attracted significant interest, because it can not only reduce environmental impact by lowering ammonia emission from manure, but also act as a prebiotic, allowing it partially to replace in-feed antibiotics. Including fermentable carbohydrates in diets has reduced the ratio between urinary N and fecal N, reducing emission because fecal N is less easily degraded to ammonia. Additionally, slurry pH is also reduced, which further decreases the potential for urease activity and ammonia volatilization (q.v. Nahm, 2003). A linear relationship was found between the intake of dietary nonstarch polysaccharides and ammonia emission. For each 100g increase in the intake of the nonstarch polysaccharides, the slurry pH fell by about 0.12, and ammonia emission decreased by 5.4%. Practically, the use of raw potato starch rather than cornstarch in the diets of growing pigs lowered ammonia emission by 13% (Lenis and Jongbloed, 1999).

Resistant potato starch also led to a dose-dependent reduction of skatole in the gut content from 134 μ/g dry matter (controls) to 4.8 μ/g in the treated group. Back fat skatole concentrations were decreased from 159 to 20 ng/g fat and belly fat concentrations from 64 to 16 ng/g fat (Losel and Claus, 2005) and significantly improved odor control from pig facilities (Willig et al., 2005). Furthermore, fermentable carbohydrates are showing considerable promise as dietary agents capable of increasing bacterial populations considered advantageous to host health or, alternatively, in suppressing those that may promote pathogenesis (Crittenden et al., 2002). Therefore, selecting appropriate carbohydrate sources is beneficial for both N emission and animal health, as well as for public health, because it reduces the use of in-feed antibiotics to manage colonic problems.

**Priority of impact attributes**

The impacts on the environment attributes of pig production also include energy consumption and related environmental parameters (Su et al., 2003). Feed production has a large impact on the overall environment system, and contributes more than animal rearing *per se* to the environmental burden. Thus, raw materials selection during diet formulation determines the environmental impact, because each material used differs in energy required to produce. A Swedish study (Strid Eriksson et al., 2005) revealed that the impact parameters of pigs fed on a diet based on imported soybean meal were 6.8 MJ, 1.5 $CO_2$-eq, 0.55 $O_2$-eq, and 24 $SO_2$-eq per kg gained. However, changing the diet to a formulation based on Swedish produced peas and rapeseed cake led to lower parameter values of 5.3 MJ, 1.3 $CO_2$-eq, 0.55 $O_2$-eq and 25 $SO_2$-eq per kg gained. Their study indicates that high levels of peas rather than soybean meal should be suggested to Swedish pig producers to reduce energy use and global warming potential. By contrast, the same set of input data creates an opposite conclusion of minimal acidification and eutrophication are focused and locally produced peas should be avoided from pig diet in Sweden due mainly to the increasing use of fertilizers to produce crops locally (Strid Eriksson, 2004). This dilemma also applies to inclusion of synthetic amino acids into pig diet, possibly reducing eutrophication but also increasing energy use as well as cost. Thus, an environmental impact priority e.g. eutrophication and acidification verses global warming and energy use should be made before an appropriate production system could be operated.

Quality and safe pork product are currently also emphasized and indoor pig production with specialized integration is essential for the production system. Certified production (e.g. HACCP) can only be achieved using well-controlled operations, where the hosing environment as well as diet formulation and distribution are controlled to maximize nutritional and hygienic values. Animal health is also monitored, and preventive medical treatment is used. The subsequent slaughtering and packing should be clearly also effectively regulated to certify product quality and safety. Such a product-quality scenario inevitably has a higher environmental impact than the eco-friendly system of efficient use of feed resources (Stern et al., 2005). By contrast, if animal welfare is the major concern, then animals should have outdoor opportunities, be able to access to a paddock, and be raised in groups to avoid re-ranking and fighting. Strategic feeding is applied with diets diluted with forages to increase the feeding time. Mental enrichments by providing stimuli (e.g. bedding, toys) are also encouraging, and maternal traits are also important for selection and breeding. The management practice should be chosen to achieve high hygienic feed quality and a healthy physical environment for the herd. This animal welfare scenario shows an in-between environment impact among systems of quality ensuring and efficient use of resources, but has the highest production cost because of larger space needed required to produce animals (Stern et al., 2005).

Environment, product health and animal welfare each focus on one aspect of sustainability, and sometimes conflict with each other. Therefore, the environment sustainability of pig feeding should vary in its meaning, structure and approaches, based on location, economic and social conditions. Eutrophication and acidification are important factors in a large production unit, so controlling the emission of N and other substances is the top priority. Thus, phase feeding and efficiently used slurry should be adopted. A family production unit in rural areas may orientate to the quality-safety pattern, although it has the highest value for energy use, global warming potential, chemical use and surplus nutrients. A welfare system appears to be essential for units close to metropolitan areas. It should be noted that feeds selection, diet formulation, and feeding strategies differ between systems, and thus affecting pork quality (Olsson and Pickova, 2005). That is different production systems may have different market niches, resulting in different breeding goals such as for socially important traits (Kanis et al., 2005). No feeding pattern or management system has yet been found to fulfill all sustainability goals of pig production, and the disagreements could be further complicated by public health requirements, such as compulsory reduction or non-use of in-feed antibiotics.

## SOCIAL DESIRABILITY

### Reducing antibiotic-resistance threats

Although markedly enhancing growth performance, antibiotic use in intensive pig production has contributed to the development and persistence of multidrug-resistant bacteria (Cromwell, 2002; Verstegen and Williams, 2002). Subtherapeutic doses of in-feed antibiotics have been shown to select bacteria for resistance to high concentrations of antibiotics (Aarestrup et al., 2000a, 2000b). Furthermore, antibiotic resistant genes have become highly mobile and their spread has occurred by all known bacterial gene transfer mechanisms (Seveno et al., 2002). Multiple classes of antimicrobial compounds were detected in swine slurry lagoons, nearby surface soil, ground water samples, and pig farm dust (Compagnolo, 2002). The exposure pathway for transfer of resistant organisms from pigs to humans thus has become multiple. Inhalation of air at an intensive production site (Hamscher et al., 2003; Chapin et al., 2005), and drinking nearby ground water have also become pathways (Krapac et al., 2002). Removing antibiotics from pig rations is imperative to minimizing public health concerns associated with intensive pig farming.

A recent increase in the incidence of severe *E. coli*-associated diarrhea in piglets has been observed worldwide. Severe forms of *E. coli* are likely due to the emergence of virulent *E. coli* clones and intensified production systems (Fairbrother et al., 2005). Bacterial resistance to antibiotics and a recent increase in the prevalence and severity of post weaning syndromes have created a hostile environment for pig production. Decreasing subtherapeutic antibiotic use is obligatory; however, producers have a difficult time finding consistently effective substitutes with acceptable costs. For decades, producers have relied on in-feed antibiotics to maintain health and growth of herds raised in sub-optimum sanitary environments and, consequently, many producers believe such antibiotics are a necessity. A sudden withdrawal of in-feed antibiotics typically causes an immediate production loss particularly in subtropical and tropical environments. A great loss in efficiency is primarily due to gastro-intestinal problems in early weaned pigs even when supported by health management plans. Alternative strategies of feeding to the use of in-feed subtherapeutic antibiotics are being developed and extensively reviewed by Adjiri-Awere and van Lunen (2005). Generally, these strategies can be classified as growth promotion or disease prevention-the latter is more urgently needed.

Numerous studies have shown that beneficial effects can be attained through diet modification, including supplementation with prebiotics, probiotics, synbiotics, minerals, organic acids, nutraceuticals and herbs. Feeding pigs with probiotics, or living microorganisms such as lactic acid producers (lactobacilli and bifidobacteria), streptococci, yeast and saccharomyces species, has shown that these microorganisms may be substituted for in-feed antibiotics in high-health nurseries (Kritas and Morrison, 2005). However, in-feed antibiotics have minimal impact on healthy animals under clean conditions (Taylor, 1999). Substituting probiotics for antibiotics requires a practical value, especially in sub-optimum sanity or "dirty" conditions in which in-feed antibiotics are needed and their advantageous effects can be exerted the best.

Additionally, not all probiotic strains are effective and there exists considerable strain-to-strain variations in characteristics relevant to probiotic efficacy within bacterial species. A special strain may be more effective or more specific-for example, the *B. lactis* strain of HN019 is effective in decreasing severity of rotavirus-induced diarrhea in weaning piglets. By feeding HN019, Shu et al. (2001) demonstrated that the content of fecal rotavirus and *E. coli* could not only be lowed, but blood leukocyte phagocytic and T-lymphocyte proliferate responses, as well as gastro-intestinal tract pathogen-specific antibody titers were elevated in weaning pigs. Therefore, the protective effect of HN019 is likely via a mechanism accounting for enhanced immune-mediated protection and inter-microbial competition with pathogens for intestinal attachment sites. Probiotic strains may be wholly or partially reliant on more than one mechanism for protection against gastro-intestinal pathogens.

Interest in probiotics has been fuelled in recent years by an increasing number of animal and human studies demonstrating the beneficial effects of probiotic cultures on numerous health conditions, including reduced atopic eczema symptoms and severity and duration of gastro-intestinal infections, particularly rotavirus infections (Doron and Gorbach, 2006). Probiotics may not be consistently successful; however, when bacterial cell numbers are inadequate, contaminated or aged, bacterial cultures lose their efficacy and instability of intestinal fermentation. Pig producers often find that studies are not applicable under actual intensive production units as many factors affect probiotic survival in feed preparations. Well-known factors such as pH, temperature, and oxygen, variations in starter cultures (Shihata and Shah, 2002), prebiotics, oxygen scavengers (Dave and Shah, 1998), water activity and sugar concentrations (Shah and Ravula, 2000) all dramatically influence probiotic survival during storage and feeding. Consequently, effectiveness can vary among farms, places and times and seasons. A dynamic program of probiotic feeding is required for practical use and should be based on studies with well-defined strains and/or products, animals from well-defined backgrounds in randomized, well-controlled trial designs with appropriate numbers to calculate significance. These conditions are essential for conducting clinical trials that have results of practical value.

Inclusion of nondigestible or fermentable carbohydrates in pig diet is a practical approach for controlling ammonia and reducing nitrogen excretion as mentioned earlier. However, equally important, fermentable carbohydrates reportedly have significantly affected monogastric animals by encouraging proliferation of select groups of colonic miroflora (Brown et al., 1997). A number of non-digestible oligosaccharides, which have been shown to selectively promote proliferation of bifidbacteria in the colon, and are recognized as prebiotics. For example, fructo-oligosaccharides (FOS) and galacto-oligosaccharides are specific nutrient sources beneficial to microorganisms and, when ingested in small quantities, can effectively stimulate preferential growth, although not exclusively of lactobacilli and bifidobacteria (Tzortzis et al., 2005). Other prebiotics frequently mentioned are gentio-oligasaccharides, isomalto-oligosaccharides, xilo-oligosaccharides, soybean oligo-saccharides, in addition to lactulose, lactosucrose and inulin. In early weaned pigs, supplementation with FOS and lactobacillus significantly improved weight gain and feed efficiency (Estrada et al., 2001). When infected with Salmonella typhimurium, 2-day-old piglets did not develop diarrhea when fed a diet containing 7.5 g/L FOS (Correa-Matos et al., 2003). The effectiveness of these prebiotics in monogastric animals depends on initial concentration of indigenous prebiotic species and intra-luminal pH (Duggan et al., 2002). Prebiotic oligosaccharides are currently utilized as functional food ingredients for human use and thus, their use in animal feed is cost-prohibitive.

Non-digestible carbohydrates, including resistant starches (RS) and fiber-like non-starch polysaccharides (NSP), which have also shown promise as prebiotics (Brown et al., 1997), beneficially modify intestinal function of weaning piglets and other mono-gastric animals. Not all starch is digested and absorbed in humans and pigs. Resistant starches, named for their resistance to amylolysis, occur in many foods, e.g., whole grains and seeds, raw potatoes and green bananas. Relatively high starch concentrations have been detected in terminal ileum and large bowel of pigs fed diets containing different starches (Brown et al., 1997; Bird et al., 2000). Studies of pigs fed various starches have demonstrated that RS is a significant substrate for large bowel microflora, and that excretions of bifidobacteria ingested orally were higher than in those consuming normal starches (Brown et al., 1997).

Interest in RS as a prebiotic developed from the appreciation that consumption of large amounts of RS led to a time-dependent shift in fecal and large-bowel profiles of short-chain fatty acids (SCFA), primarily acetate, propionate and butyrate as end-products of colonic fermentation. Butyrate is the major energy source for colonocytes, whereas propionate is largely taken up by the liver and acetate enters peripheral circulation and metabolized by peripheral tissues. Specific SCFA may reduce risk of developing gastrointestinal disorders and it is likely that some or all of the effects of RS are through the actions of SCFA (Wong et al., 2006). Interest is increasing regarding prebiotic potential; for example, in children with acute diarrhea, adding amylase-resistant starch to glucose oral rehydration shortened diarrhea duration compared with that achieved with a standard treatment (Raghupathy et al., 2006). In weaning piglets feeding a diet based on cooked rice (high in RS) supplemented with either animal or plant protein lowers the incidence and severity of diarrhea with a consequent reduction in mortality (Montagne et al., 2004). This finding is of particular interest for pig producers in Far Eastern regions where low-cost locally grown rice is readily available. Suitably processed rice may be a useful feed option for pig herds in which post weaning colibacillosis is endemic and resistant strains of *E. coli* are present.

Both FOS and RS raised fecal bifidobacteria numbers by roughly equal amounts when fed separately to pigs. In a human study, these increases are of a generally similar order to those reported for prebiotics such as FOS (Tuohy et al., 2001). When fed FOS and RS together, an increase exceeding individual increases suggests that they operate through different mechanisms. Furthermore, FOS and RS maintain colonies in pigs when probiotics supplementation ceases. Thus, when pigs were fed a control diet, fecal bifidobacteria numbers declined rapidly following probiotic withdrawal. However, this decline was much slower than that in those fed either FOS or RS. When FOS and RS were consumed together, no decline existed in fecal numbers (Brown et al., 1997). Maximal effectiveness may be achieved when preparations could be a mixture of FOS and RS, as these agents seem to have additive effects. Also, combining several probiotic bacteria will achieve stronger effects and this effect was the same as combing different prebiotic (oligosaccharides and RS). Thus, to formulate synbiotics (probiotic with prebiotics) can be likened to an art as different environments require different strategies. Availability or the source of RS, selection of probiotic strains, palatability considerations, manufacturing (pelleting), storage, etc., all render formulating a new generation of carbohydrate-manipulated diets complex.

Fermentable carbohydrate in certain circumstances is detrimental rather than beneficial to pigs. For example, the incidence of pig dysentery can be largely reduced with a low NSP diet (Pluske et al., 1996, 1998). This reduction is simply because colonization by spirochaetes is highly related to dietary NSP concentrations, while incidence of dysentery was also reduced when diet included low RS (Durmic et al., 2002). Further studies are now required, given the diverse nature of carbohydrate substrates and the SCFA patterns produced by their fermentation. Studies are also required to quantify the health benefits of prebiotics and synbiotics and their interactions in different feeding environments.

Luminal acidification as reflected by low fecal pH is a positive response to diet containing probiotics, prebiotics or synbiotics feeding. Additionally, maintaining intestinal luminal pH at approximately 4.5 is necessary to support proliferation of beneficial bacteria and exclude gut pathogenic. This low luminal ph is particularly important for weaning piglets as they suffer environmental and psychological stressors during transit and develop a high gastric pH when milk diet is replaced by dry feed and, thus, are at high risk of developing diarrhea (Kim et al., 2005). Directly adding organic or inorganic acid to weaning diet or drinking water is an alternative approach to providing a favorable acid environment and it has been shown to improve feed efficiency and enhance growth performance in piglets (Franco et al., 2005).

The practice of diet acidification by adding organic acids in excess of 2.7 kg per ton is becoming more popular as a method of reducing feed pH and controlling enteric pathogens in growing pigs. At such high acid levels, palatability becomes a problem for weaning piglets-they reluctant to eat dry feed and avoid acidified diets when given a choice. Adding 1.2% of K-diformate to acidify piglet diet does not decrease feed intake or negatively affect piglet dietary preferences (Ettle et al., 2005). Notably, minimizing the addition of alkaline compounds such as calcium bicarbonate or protein from fish and milk products helps to optimizes the benefits of diet acidification resulting from decreasing buffering effects (Kornegay et al., 1994; Hardy, 1999).

Other compounds, including botanicals, nutracenticals and anti-microbial peptides, have been proposed as alternatives to in-feed antibiotics, and, although not yet applicable, have generated promising results. Some herbs are valued for their medicinal properties, flavor or aroma. It has been suggested that many plant extracts and spices act as immuno-modulators when administered in low doses and show great promise as feed additives to replace current antimicrobial agents. Garlic, ginseng, and oregano are frequently used as general tonics in alternative human medicine and, thus, are of limited use for animals due to availability and cost (q.v. Adjiri-Awere and van Lunen, 2005). Investigations of the medical values of herbs, although often using pigs as experiment animals, usually have minimal practical use for pig production. Identifying the active compounds and ingredients in plant extracts with the most potent antimicrobial action and growth-promoting efficacy is essential before these compounds can be commercially produced and applied in animal production.

Development of novel anti-infection agents to cope with the antibiotic-resistance threat is urgently needed in human and animal medicine. A source of compounds considered promising is the large number of gene-encoded antimicrobial peptides in animals and plants. These peptides are also termed bacteriocins and are constitutively produced or synthesized following infection or injury. Mammals have a large variety of antimicrobial peptides that function as natural innate barriers suppressing microbial infection, or, in some instances, they act as integral components in response to inflammation or microbial infection (Brogden et al., 2003). These peptides have board-spectrum activity against a wide range of microorganisms, including Gram-positive and Gram-negative bacteria, protozoa, yeast, fungi and viruses (Reddy et al., 2004). The so-called epithelial defensins that are produced by Toll receptors once the bacteria are recognized are actually comparable with antibiotics (Ganz, 2003).

In pigs, more than a dozen distinct anti-microbial peptides have been identified, some of which include defensins. These peptides are naturally present in the gastro-intestinal tract and act as a common mechanism of host defense (Zhang et al., 2000). High (20-200 μg/ml) concentrations of porcine β-defensin are expressed in the dorsal tongue (Zhang et al., 1999), and are synergistic with other porcine antimicrobial peptides against *E. coli* and multidrug-resistant salmonella. Some bacteriocins are in commercial production; for example, nisin is used to control bacterial spoilage in heat-processed, low-pH food worldwide; lactoferrin along with some probiotics is employed as health food supplement. However, use of purified or recombinant bacteriocins in animal rations is unlikely in the foreseeable future simply because these are not cost-effective. Immuno-modulation to enhance *in vivo* expression, synthesis and release of bateriocins is likely a feasible approach.

**Animal welfare**

Intensive animal production systems are also criticized for poor animal treatment. These debates focus on how farm animals live and housing and feeding conditions. These concerns are reflected in current legislation and regulations (e.g., space allowance) that will have a considerable impact on pig production and will modify the feature of pig rearing facilities and management tools, thereby increasing pig production costs. To resolve confinement-related animal welfare problems, providing an environment that suits animal needs is the predominant approach. Therapeutic practice is also involved, including the use of chemicals, nutritional therapy and other treatments to effectively suppress undesirable behavior associated with product quality assurance programs. For instance, synthetic maternal pheromones are utilized to reduce fighting and stimulate feeding behavior, thereby improving the well-being of early-weaned piglets (McGlone and Anderson, 2002). Supplementing diet with antibiotics was also a therapeutic approach as it enhances pig health and welfare; however, this practice has been criticized due to concerns about antibiotic resistance.

Feeding pharmacological concentrations of ZnO (2,000-4,000 ppm) to weanling pigs reduced the incidence of diarrhea (Poulsen, 1989) and was considered an approach to improving animal welfare. However, such a high Zn supplementation generated environmental concerns associated with high Zn concentrations in manure (Mantovi et al., 2003). Thus, organic minerals using peptide or amino acid attachments have been suggested as alternatives to inorganic compounds. Supplemental lower concentrations (500 ppm) of Zn from ZnO or several organic sources, however, did not stimulate growth, feed intake, or efficiency (Hollis et al., 2005). Feeding pharmacological Cu is also advantageous to weaning and growing pigs (Davis et al., 2002), as is high dietary Mg to finishing and market pigs (Apple et al., 2005). Yet, again these supplementations generate waste treatment problems.

Supplementary tryptophan is a nutritional therapy aimed at modifying pig behavior (Li et al., 2006). In nursery pigs during weaning and mixing, diets containing high tryptophan (5 g/kg feed) decreased neuroendocrine components of stress and increased gastro-intestinal robustness but behavioral reactivity was not affected (Koopmans et al., 2006). When seeking new methods for improving health and welfare of early weaned piglets, re-evaluation of the current weaning program is worthwhile. All the efforts to improve the well-being of early weaned piglets may not be equivalent to allowing them an extra week of nursing, which may be more beneficial to piglets.

Sows and pregnant gilts often exhibit repeated oral/nasal behavior when limit fed and housed in penned crates. The stereotypies that indicate poor animal welfare can be decreased by feeding high-fiber diets (Meunier-Salaun et al., 2001). This diet has an additional advantage of increasing the number of piglets born (Grieshop et al., 2001). On the other hand, Holt et al. (2006) demonstrated that feeding a high-fiber diet with 40% soybean hulls to gestating sows did not enhance sow welfare by reducing stereotypical behavior or reduce cortisol concentrations. Such a high-fiber diet also reduced digestibility and decreased reproductive performance with fewer pigs born, as compared with that of sows fed a control diet. Moreover, feeding gestating sows twice daily instead of once did not improve their behavior or reproductive performance. The varying response of sows to high dietary fiber diets suggests that many factors influence the efficacy of dietary fiber; the fiber composition of various ingredients is certainly worthy of further investigation.

By definition, dietary fiber comprises a broad spectrum of components. Cellulose and hemicelluloses comprise the principal substrates fermented in the large intestine. Studies using diets with different fermentable carbohydrates would clarify the efficacy of dietary fiber to improve welfare and reproductive performance since, after fermentation, dietary fiber generates readily absorbed short chain fatty acids and beneficially influences animal physiology as mentioned. Feeding high-fiber diets to sows or gilts may generate a larger amount of manure and create additional environment hazards. This environmental effect would not be present if fermentable carbohydrates were responsible for the beneficial effects of high fiber feeding. Greater slurry mass will be compensated by reduced nitrogen excretion, a major effect of fermentable carbohydrates feed. Doing so will allow for intensive application rates of manure to croplands as fertilizer rates are often determined based on nitrogen content.

## CONCLUSION

Today's intensive pig production systems have a relative short history compared with that of the pig as a domesticated animal. The long-time use of extensive systems during the past can be viewed as a thrifty management of resources. However, recent intensive systems that emphasize reducing cost and increasing efficiency though feeding manipulation and performance selection have generated particular environmental and animal welfare problems. Heavy selection pressures under the current intensive pig production may even have exceeded the innate physiological limits of the pig, leading the animal to exhibit pathophysiological changes such as hypertrophic cardiomyopathy (Yang et al., 1997). Domesticated pigs are now used for pork production, as an animal model in biomedical research (Yang et al., 1997), and for future xenotransplantation organs (Yang, 2006). Intensive pig production should adjust to conform to the social demands of environmentally and animal-friendly and to generate a high quality and safe product. Members of the public, in addition to the scientific community, government, producers, consumers, retailer and environmental and/ or animal welfare organizations should be allowed to scrutinize the industry.

Operating a pig production system that meets the desire for high quality, safe product that meets eco- and bio-sustainability and animal welfare concerns while turning a profit, is difficult. Moreover, a number of market segments have different priorities; for example, animal welfare and food safety may be more important than taste and price in one segment than another. Thus, differentiated supply chain designs with distinct and innovative attributes should be implemented. A sustainable pig production system should be based on an understanding derived from dialog among consumers, society and producers and be addressed in terms of local and global perspectives.

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