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REVIEW

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Nutrition and feed strategies for sustainable swine production in China

Abstract China is the largest swine producer in the world. Although the China swine industry has made great progress in the past, it faces many problems according to the requirement of sustainability. This article summarizes the current situation and problems of the swine industry in China and proposes nutrition and feed strategies for the sustainable development of swine production with emphasis on available practical approaches and future research focuses.

Keywords swine production, sustainability, nutrition and feed, strategy, China

1 Current situation of swine production in China

1.1 Total output

China has a long history in swine production and rich resources in swine breeds. As reported, the history of swine production in China has lasted for about 6000 years. There are totally 126 pig breeds in China, 66 of which are described in the book of Records of Swine Breeds of China. By far, the output of slaughter pigs and pork has ranked the first in the world. It has been increasing gradually since 2000 (Table 1). In 2006, pork output amounted to 5.197×10^7 tons, accounting for 50.1% of the global total. The amount of pork per capita amounted to 40 kg while in 2007, the ultimate national pork output was 4.700×10^7 tons, with a 10% decrease compared to the year before, which resulted from various reasons, especially from the incidence of Porcine Reproductive & Respiratory Syndrome (PRRS).

1.2 Productivity

Although the total output of pigs and pork ranks the largest in the world, Chinese swine productivity is still very low (Table 2). One of the main reasons for the low productivity is due to the small-sized farm feeding (Table 3). Over half of the pigs are produced from farms with an annual capacity of less than 10 pigs, and this size of farms accounts for 94.48% of the total pig farms. For these small-sized farms, advanced techniques concerning breeding, nutrition and feeding, health care, housing and management cannot be easily applied in practice. For example, only 20% of pigs are currently produced by feeding complete compound feed in China.

1.3 Pork eating quality and safety

Sixty percent to seventy percent of pork is from the hybrid between native Chinese breeds and high-lean foreign breeds, with 30%–40% from the crossbreed of Duroc×Landrace×Yorkshire (DLY). Since the native breeds are excellent in meat quality in terms of tenderness, juiciness, slender muscle fiber, marbling, and eating flavor, Chinese pork quality is normally excellent. However, these advantages of high pork quality tend to be decreased since the proportion of pork from DLY or specified high-lean commercial lines is gradually increasing. In contrast, Chinese pork safety is not as excellent as eating quality. Existing problems include the following.

1.3.1 Drug residues, mainly antibiotics residue

This issue comes from feed and disease control. Some antibiotics are still legally allowed to be used as feed additives. The amount of antibiotics used as pharmaceuticals is still high due to the high pressure of pig infectious disease control.

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Table 1 Output of swine production in China from 2000–2005

item	2000	2001	2002	2003	2004	2005
no. of slaughter pigs (10000 heads)	52673.3	54936.68	56684	59200.5	61800.7	66098.6
no. of inventory pigs (10000 heads)	44681.5	45743	46291.5	46601.7	48189.1	50334.83
output of pork (10000 tons)	4031.4	4184.5	4326.6	4518.6	4701.6	5010.612

Note: The data came from National Bureau of Statistics of China, 2006.

Table 2 Comparison of China pig productivity with developed countries

item	China	developed countries
piglet survival rate/%	<90	>95
weaning age/d	28–35	17–21
bodyweight at weaning/kg	5–6	5–7
age to market/d	160–170	140–155
bodyweight at market/kg	100–110	110–125
carcass weight/kg	70–80	85–100
marketing rate/%	120–130	150–160
feed conversion rate (FCR) (G-F pigs)	2.8–3.0	2.5–2.7
FCR (whole herds)	3.5–3.8	2.8–3.0
litters per sow per year	1.8–2.0	2.2–2.4
market pigs per sow/head	15–17	20–22

Table 3 Pig-feeding farm size in China in 2006

size (annual sale of slaughter pigs, head)	no. of farms		total annual output	
	amount	percentage/%	×10000 head	percentage/%
1–9	101963901	94.48	34773.06	52.87
10–49	4815474	4.46	12094.52	18.39
50–99	851429	0.79	5899.85	8.97
100–499	249016	0.23	5863.93	9.07
500–2999	33844	0.03	3647.70	5.55
3000–9999	3388	0.00	1741.97	2.65
10000–49999	911	0.00	1418.12	2.16
>50000	30	0.00	235.84	0.36
total	107917993	100.00	55774.99	100.00

1.3.2 Heavy metal residues

Since pig farms are very small, the hygiene quality of feed raw ingredients and mineral additives and drinking water cannot be monitored. Some feeds or water with high heavy mineral contents are still used for pig consumption. Another reason is that high rate copper sulphate and arsenicals are widely utilized as growth promoters.

1.3.3 Pesticide residue problem

Here, pesticide residue comes from crops and plant feeds. Although pesticides containing phosphorus and chlorine have been prohibited for two decades, they still exist in soils due to their slow degradation.

1.3.4 Mycotoxin residue

It is investigated that major feed ingredients and commercial feeds are easily contaminated with moulds under the weather, particularly during late spring, summer and fall. Mycotoxins ingested by animals can be residued in meat.

1.4 Environmental pressure

Animal agriculture is one of the main environmental polluters in the globe since the rate that animals convert nutrients from feeds into edible food is as low as 15%–20%. For example, a pig from weaning to 100 kg bodyweight can consume a total of 8 to 9 kg of nitrogen, of which less than 3 kg can be deposited in the tissue, the remaining 5 to 6 kg is excreted. The utilization rate of plant-origin phosphorus is only 20%–30%, while that of inorganic minerals is even less than 10%. The volatile metabolites such as volatile fatty acids, phenolic compounds, indoles and sulfurets circulate in the air, resulting in offensive odors.

Therefore, the main pollutants of animal agriculture are nitrogen, phosphorus, trace minerals and offensive odors. The larger the size of pig farms is, the more serious the environmental pollution is. Fortunately, China animal agriculture is based on very small size or family basis; the actual environmental pollution is not serious. The pressure, however, is getting higher and higher since the intensive feeding of animals develops fast.

1.5 Feed resources

Even though the China feed industry has developed rapidly and the total commercial feed output has reached over 100 million tons, coverage of commercial complete feed for pigs is less than 20%. Majority of pigs are produced by feeding feed ingredients and roughage.

The shortage of feed resources, especially high-quality feed ingredients such as corn, soybean meal, fish meal, and milk products is becoming serious day by day with the development of intensive animal agriculture in China. On the contrary, by-products from animal and plant origins are very abundant. There are large amounts of plant by-products produced in the processing industries, including rice byproducts (rice bran, rice hull, rice bran meal, rough rice, broken rice), wheat byproducts (wheat bran, wheat middling and reddog), oil seed meals (rapeseed meal, cottonseed meal, sesame meal, peanut meal, sunflower meal, palm meal), and other byproducts (DDG, DDGS, molasses, sugar beet lees, sugar cane lees). The annual output of cottonseed meal, rapeseed meal, DDG and DDGS reaches 6, 3 and 15 million tons, respectively.

By-products from animal source include blood meal, feather meal, leather meal, meat and bone meal, and meat meal. There are nearly 0.5 million tons of blood meal and 0.3 million tons of meat and bone meal each year.

Nutritive values of by-products vary considerably. Data of nutrient contents and bioavailabilities are not complete and accurate. Some contain anti-nutritional factors. As a result, only a very small proportion of by-products is used as swine feed, with the majority wasted.

1.6 Swine health

Swine diseases are always a big problem for the swine industry. The main diseases occurring in the swine production in China include hog cholera, pasteurellosis of pigs, swine colibacillosis, porcine reproductive and respiratory syndrome (PRRS), enzootic pneumonia, piglet paratyphus, pig transmissible gastroenteritis (TGE), pig circovirus (PCV), pseudorabies.

The incidence of various diseases tends to be increased and results in considerable economic losses. The number of pigs dying of various diseases in China normally accounts for 8%–10% of total death; one third of the death from diseases is caused by hog cholera. The swine industry suffered the most serious challenge from infectious diseases in 2007. The prevalence of PRRS caused 5% and 7% decrease of the total population of sows and finishers, respectively, compared to the year of 2006. Economic losses reached 10 billion RMB Yuan.

2 Basic requirements for sustainability of swine production

With the continuing increase of the Chinese population and the progress of society and the economy, great changes will be needed in swine production to achieve sustainability (Zhang et al., 2003). Sustainable development means coordinated and harmonious development of swine production with other social components such as population, economy, natural resources and environment (Ma and Xu, 2003; Liu, 2007). Swine production is neither a limiting factor nor a negative factor for the development of any other components of society. The key features for the changes of China swine production can be expected as follows.

(1) Total pork yield needs to keep increasing to meet the need of the increasing population. The production system, therefore, will be transferred from family basis or very small-sized farms to intensive production and large-sized farms. Only in this case can advanced science and technology be applied to improve yield and productivity.

(2) Pork eating quality should be improved to the extent that it is close to the pork produced by traditional feeding system.

(3) Pork eating safety must be guaranteed to protect people's health and meet international consumption standards. This goal is most difficult to be realized because it is associated with a revolution of the production system and quality control technology during the production process to eliminate residues of all risk factors such as antibiotics, drugs, metals, pesticides and mycotoxins.

(4) Resource utilization should be high enough to avoid the competition of animals with humans for grains and edible food. Feed resources will mainly depend on domestic resources instead of imports. By-products should be utilized more efficiently to reduce the amount of grains used as animal feed and reduce environmental pollution by the by-products.

(5) Environment friendship is the fundamental requirement for sustainable pig production. All the pollutants

including excretions, disposals, noise, and odors must be controlled to as minimum as possible, and must be treated to reach the environmental disposal standard before entering the environment.

(6) Health care and biosafety issues are the main concerns of future pig production. Swine are one of the main transmitters of epidemic pathogens. Some diseases such as foot-and-mouth disease are zoonosis. Health care and disease control program are extremely important to guarantee biosafety for animal and human health.

3 Nutrition and feed strategies for sustainable swine production

Animal nutrition and feed science is the key theoretic subject for animal agriculture. It plays an important role in the aspects of improving utilization efficiency of natural resources by animals, influencing environmental quality by regulating nutrient intake and excretion by animals, and ensuring animal health and eating quality of animal products for humans. Swine production, as in other animal production, cannot develop sustainably without the progress of science and technology of animal nutrition and feed science. Based on the current knowledge and the predicted development of animal nutrition and feed science, the following strategies will be emphasized to realize the sustainability of swine production.

(1) Study nutrient metabolism at molecular level and establish the accurate and dynamic nutrient requirements for the specific genotypes, growth stages, production levels, and feeding systems of pigs at various circumstances.

(2) Study and understand the relationships between nutrition and pig health and pork eating quality in order to establish and apply nutritional technologies for improving disease resistance of pigs and pork quality.

(3) Study chemical compositions and nutrient bioavailability of current feed resources, especially by-product resources in order to set up a precise database of feedstuffs for pigs.

(4) Formulate diets based on bio-available nutrients rather than total nutrients to accurately meet the nutrient need of pigs.

(5) Study and apply ideal amino acid balance pattern on the basis of bioavailability to reduce dietary crude protein level, improve protein utilization, and lower nitrogen excretion.

(6) Develop new feed and feed additive resources by biotechnology. Produce and apply bio-feeds and bio-feed-additives.

(7) Study and optimize feed processing facilities and technology and feeding systems (phase feeding, liquid feeding) to improve pig performance and feed conversion efficiency.

(8) Study the metabolism and residue or excretion mechanism of feed-origin unsafe factors such as antibiotics, drugs, toxins, heavy metals, pesticides, and antinutritional factors to quantify the relationship between the factors and pig health or pork eating safety, setting up prewarning and predicting technology.

(9) Study the patterns of feed mould and nutrient oxidation, understand the influences of mycotoxins and oxidatives on pig health and performance, and establish nutritional anti-mould and anti-oxidation manipulations.

The issues of pig health, performance, resource utilization, pork quality, environment pollution can be well solved by the above strategies. However, none of the above aspects are clearly and completely understood up to now. There is a long way to go for China's swine production to realize sustainability. Some of the aspects are described in more detail as follows.

3.1 Nutrient metabolism and requirement

Understanding nutrient metabolism and its efficiency in animal body at the molecular level is the prerequisite to improve nutrient utilization efficiency. However, the interaction between the animal body and nutrition is an extremely complex process involving multi-organ physiology with molecular mechanisms on all levels of regulation (genes, gene expression, proteins and metabolites). Animal nutrition science will never reveal such a complex metabolic process if it focuses only on traditional research contents and methodology. Therefore, animal nutrition must be transferred from traditional population level into the individual and molecular level to elucidate the molecular mechanisms for physiological functions performed by nutrients and the individual difference at the same nutrient allowances. This is the fundamental basis to figure out nutrient recommendations for a group or an individual of animals. Nutrigenomics, a new field in the study of the interaction between nutrients and genes, provides powerful approaches to unravel the complex relationship between nutritional molecules, genetic polymorphisms, and the biological system as a whole (David et al., 2005; Irène Corthésy-Theulaz et al., 2005). China animal nutritionists should keep pace with the global scientific development to solve the nutrition-related problems of animal agriculture.

The current nutrient requirements for swine are established mainly based on the optimum growth performance. As shown in Fig. 1 (Chen, 2001), with the increasing of nutrient allowance, pig growth rate enhances and reaches a plateau at B level. However, when nutrient allowance reaches a level, further increase would reduce marginal utility of growth efficiency, and dramatic increase of environmental loading although the absolute growth rate continues to rise. Obviously, taking all the three factors of pig performance, environmental risk and resource

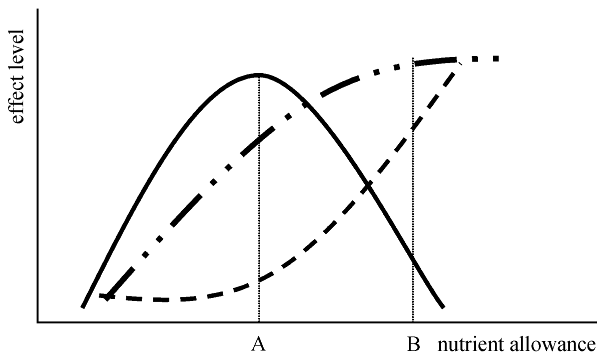

Fig. 1 Relationship of nutrient allowance with pig performance and environmental risk

Note: ——— represents marginal utility of growth performance,
– · · – · · – represents absolute growth rate,
– – – – – represents environmental loading.

utilization into account, the reasonable nutrient recommendation is not B, which is the current recommendation. Therefore, the current nutrient requirements for swine need to be refined and re-evaluated.

Nutrient requirements are influenced by many factors such as genetics, management, environment and even nutrient origins (Yang, 1993). The future task for nutritionists is to integrate and quantify all the influencing factors and establish a dynamic requirement model. NRC (1998) sets a good example.

3.2 Nutrition and pig health

There is a very close relationship between nutrition and pig health. The underlying mechanisms include the following:

(1) 80% diseases are associated with immune system and immunity. Nutrition can influence the development and immunity of the immune system. Reasonable levels of nutrition can improve immunity and resistance to diseases and stress.

(2) Recent studies in our lab indicate some nutrients at certain intake levels can increase the antibody titers to specific pathogens such as cholera, PCV, PRRS.

(3) Nutritional programs have significant effects on the micro-ecology and functions of the digestive tract, which is the first, largest and most important barrier for health.

(4) There is an interaction between nutrition and disease-resistant genes. Nutrition can modulate the expressions of these genes and influence disease resistance.

(5) Mycotoxins and reactive oxygen species (ROS) are two powerful immunity suppressors. Nutritional approaches can alleviate their negative effects on immunity.

Disease-resistant nutrition is a new branch of animal nutrition. The study and application are extremely important for pig health, performance, feed utilization, and pork safety under the current production conditions and systems in China. Due to its recent emergence, the concerned knowledge is still inadequate. The following aspects should be emphasized for research.

(1) Quantify the relationships between nutrient intake and immunity, with focus on protein, amino acids, trace minerals and vitamins; establish the requirement profile for maximum immune functions.

(2) Study the micro-ecological effects of macronutrients (proteins, carbohydrates and lipids), with focus on histology, microbial population, nutrient digestibility and absorption in small and large intestines.

(3) Study the molecular mechanisms for the differences among pig breeds for disease resistance. Identify and clone specific genes and study the interaction between nutrient and gene expression.

(4) Study molecular immune mechanisms for specific infectious diseases and the interactions with nutrition. Establish nutritional approaches for improving defense to the diseases and maximizing protective efficacy of vaccines.

(5) Develop new feed additives, antibiotic alternatives, functional premix and complete feed products which can improve immunity, inhibit bacteria, prevent mycotoxin and ROS production, and modulate the intestinal environment.

3.3 Utilization of local feed resources

China has a large amount of byproduct feed resources with a very low utilization rate for animal feed. The seasons include variation of chemical compositions, containing anti-nutritional factors, poor palatability and lack of nutrient bioavailability. To solve the problem, animal nutritionists should take the following strategies.

(1) Determine chemical compositions of by-product feeds, including nutrients and anti-nutritional factors.

(2) Evaluate nutrient bioavailability, establish an accurate database of available nutrient contents for all feed ingredients.

(3) Further study and improve methodology for feed evaluation, refine the protocols for rapid and accurate evaluation.

(4) Inactivate or detoxify the anti-nutritional factors or natural toxins by cost-effective processing technology.

(5) Modify chemical nature and nutritional profiles and bioavailability by integrating modern biotechnology and animal nutrition theory to make bio-feed ingredients of balanced nutrient profile, less anti-nutritional factor, higher nutrient bioavailability, better palatability (Harinder and Gerrit, 2005).

(6) Optimize the manner and proportion to use the by-products in pig feeding to improve their feeding values.

3.4 Nutrition management for environment protection

Because of the poor quality of protein sources, high content of feed phytin and poor production environmental conditions, pig diets in China normally contain high levels of protein, total phosphorus and growth promoters, such as copper sulphate, zinc oxide, and arsenicals to keep good performance, resulting in excessive excretions of organic matter, nitrogen, phosphorus, and minerals (Wang, 2007). The key task for intensive swine producers in China is to reduce excretions of these nutrients as much as possible as well as maximize pig performance. The practical nutritional approaches are listed as follows.

(1) Formulate diets on the basis of digestible amino acids and ideal protein model.

(2) Apply crystalline lysine, methionine, threonine and tryptophan to balance at least 5 essential amino acids, which can reduce 3%–4% of dietary crude protein.

(3) Use protease feed additives to pre-digest poor quality of protein sources such as rapeseed meal, cottonseed meal, feather meal, and blood meal.

(4) Ferment protein sources by probiotics such as lactobacillus, feed yeast, bacillus bifidusm to improve protein quality and palatability.

(5) Utilize enzyme preparations of decomposing non-starch polysaccharides in plant feeds such as xylanase and β-glucan enzymes to improve energy utilization and reduce the excretion of organic matter.

(6) Improve the utilization of phosphorus from plant feeds by using phytase. For corn-soybean-meal diet, 0.1%–0.2% of available phosphorus can be saved by supplementing 500–1000 IU phytase per kg diet.

(7) Supplement diets with probiotics to modulate inner-environment of gastrointestinal tract, promote the growth and reproduction of beneficial microbes, and improve feed digestibility and absorption.

(8) Apply phase feeding to meet accurately the nutrient requirements for specific physiological stages. There should be 3 stages for young pigs from weaning to 20 kg bodyweight and 5 stages for growing-finishing pigs from 20 to 110 kg bodyweight.

(9) Replace inorganic trace minerals in the diets with organic trace element salt to reduce mineral excretion. Various products of amino acid chelates and organic acid salts of minerals are already available on China markets.

(10) Control or eliminate the use of high level of copper sulphate, zinc oxide, and arsenicals as growth promoters. Instead, use Chinese herbal medicines or plant extracts as alternatives.

Nitrogen and phosphorus excretions can be reduced up to 50%, with minerals to 80%, organic matter to 30% by the above strategies. Nutritionists should continue to study how to further improve the utilization efficiency of nutrients which are the main environmental pollutants, and develop new theories, new technologies and new products to minimize the excretions of nutrients into the environment.

3.5 Pork quality and safety

Pork quality means normal eating quality. It is a complex quality trait controlled by multi-genes. Although nutrition is closely related with pork quality (Chen et al., 2002, Song et al., 2007), genetic modification either by traditional crossbreeding or by modern gene engineering is the most efficient approach to improve pork quality (Zhong, 2001). For China, this is not an urgent problem. However, eating safety is much more important and urgent than eating quality. To solve the safety problems listed above, the following strategies can be taken for practice.

(1) Control seriously the hygienic quality of feed ingredients and feed products. Strengthen the detection and monitor the hygienic parameters such as heavy metals, pesticides, mycotoxins, pathogens, and drugs.

(2) Improve the storage conditions for feed products to prevent feed mould, feed spoilage, and infections by insects and pathogens.

(3) Monitor quality of drinking water for pigs to prevent excessive intake of unsafe substances from water.

(4) Prohibit feed additives with detrimental potential on human health and environment such as antibiotics, arsenicals, and high level of copper sulphate. Alternatively, use additives with less detrimental impact on human health and the environment such as herbal extracts, probiotics, organic mineral salts and organic acids (Zhang et al., 2002).

(5) Strengthen health care program for pigs, prevent infectious diseases to reduce the amount of antibiotics for treating the diseases, and reinforce nutritional regime and management to improve the resistance to diseases.

(6) Apply HACCP system for feed industries and pig farms to improve management during the whole production process.

3.6 Animal scientists should strengthen the researches on the following aspects.

(1) Pre-warning and predicting theories and techniques for pork safety to set up a dynamic predicting model

(2) Disease-resistant nutrition theories and techniques to establish a "Nutrition-based Health" system to prevent disease incidences

(3) New cost-effective feed additives as the alternative of antibiotics, arsenicals, high level copper and zinc salts

4 Conclusions

The China swine industry has made great progress in the past decade. The number of pigs and the amount of pork produced rank the first in the world, accounting for over 50% of the world total. However, according to the requirements of sustainability, the China swine industry still has many problems mainly including very-small-sized feeding farms, low productivity, low resource utilization, poor pork eating safety, great health challenge and increasing environmental pressure, which are beyond nutrition and feed science. Many nutritional strategies, however, are indeed available to solve, at least partially, these problems. Nutritional scientists should keep researches on nutrient metabolism and requirements, disease-resistant nutrition theory and techniques, feed resource utilization and nutritional value evaluation, pork quality and safety, and nutritional approaches for environmental protection. Only by depending on the great progress in these fields can animal nutrition and feed science play a greater role for the sustainability of the swine industry in China.

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