Low protein diets for pigs: where are we going?

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ABSTRACT
Objective: To update the trends of advantages and disadvantages of using low-protein diets (LPD) for fattening pigs, as well as providing information on the direction of LPDs in future research.
Approach: The advantages and disadvantages of reducing dietary crude protein (CP) in the diet with supplementation of synthetic amino acids (AA) have been reported in recent years, in order to generate a sustainable swine industry.
Results: The reduction of CP in diets for fattening pigs saves protein ingredients, decreases not only nitrogen excretion but also feeding costs, without affecting growth performance compared to traditional diets.
Implications: The good response of reducing the amount of CP in pig diets is not unique; there are also unwanted effects in the pigs' response to be considered. Therefore, the use of LPD for pigs needs further research to analyze the use of feed additives that maintain of improve the productive response and/or to avoid their negative effects on pork.
Conclusions: There are advantages and disadvantages of feeding pigs with LPD; however, there is the need to study the issue focusing on the reduction of the cost of feed and the protection of the environment from nitrogen excretion.

Keywords: Amino acids, Crude protein, Productive performance, Pigs.

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INTRODUCTION

In pig production, dietary crude protein (CP) content is reduced when the requirements for essential amino acids (EAA) and total nitrogen are met. In pigs, the dietary protein requirement is essentially to cover the amino acid (AA) requirements [1, 2]. In pig feed, the use of diets based on corn-soybean meal is frequent; however, due to the nature of corn, the lysine content is limited. Therefore, this traditional diet has high CP levels to meet the lysine requirements for pigs [3]. High protein diets (HPD) led to excesses of both essential amino acids (EAA) and nitrogen excretion in feces and urine. This not only reduces the efficiency of nitrogen use, but also leads to disadvantages: for example, protein fermentation in the large intestine damages intestinal health [2, 4].

Reducing dietary CP by 2 to 4 percentage units as recommended by the NRC (1998) and meeting requirements with synthetic amino acids (SAA) has been shown to increase nitrogen use efficiency, improve intestinal health, reduce feed costs and nitrogen excretion, without compromising pig growth and performance [5]. For example, in studies where LPDs were used with the addition of the four commercially available synthetic amino acids (L-lysine, DL-methionine, L-threonine and L-tryptophan), which are the first four limiting EAAs in standard corn-soybean meal diets, the productive response was similar [3]. The NRC (2012) nutrient requirement for pigs removed the recommendations for CP and replaced it with a total nitrogen requirement [6]. If the total nitrogen requirement from NRC (2012) is multiplied by the coefficient of 6.25, the CP level is 2 to 4 percentage units lower than that recommended in the previous NRC (1998) [2, 4]. However, one of the variables of greatest concern when pigs are fed LPD is the higher amount of carcass fat compared to those fed typical high protein diets (HPD) [7]. Therefore, the objective of this review was to update trends with the advantages and disadvantages of using low protein diets (LPD) for fattening pigs, as well as to provide information on the direction of LPD in future research.

APPROACH

Advantages:

Nitrogen excretion

Nitrogen excretion is the main criticism in pig production due to the negative impact on the environment, since manure contributes ammonia (NH_3) that damages ecosystems and generates unpleasant odor in farms [8]. The excess of other AAs in the standard diet in CP is broken down into nitrogen, and this surplus of nitrogen is excreted in urine as urea [9]S. An effective approach to decrease nitrogen emission is to reduce the CP content in the diet and add SAAs to cover the protein requirement of the pig. Based on the concept of ideal protein, the LPDs improve the efficiency of nitrogen utilization without affecting its digestibility and retention [10].

The results indicate that LPDs reduce water intake and urine urea nitrogen excreted [9]. Regarding plasma urea nitrogen, the main and final nitrogen product of protein catabolism, a lower concentration was also detected in pigs fed with LPDs compared to traditional protein diets [8, 11].

The odor of pig production units is bothersome to the neighboring human inhabitants. This odor is the result of anaerobic fermentation of indigestible proteins present in pig manure. Reducing CP in the diet decreases odor emission. It was reported that odor emission levels were significantly reduced by 31 and 33% for diets with 16 and 13% CP, respectively, compared to diets with 19% CP [2].

Recent studies [8, 11, 12] have been conducted to employ nitrogen sources more efficiently in pig production. First [1], the inclusion of α-ketoglutarate in a LPD with 17% CP improved productive performance in weaned piglets. Second, another nitrogen source that has been used to improve the response to a LPD is ammonia. With the addition of ammonia, nitrogen is rapidly absorbed but is poorly used for urea synthesis; however, with LPD for pigs it is used as a nitrogen source to increase the synthesis of Alanine, Citrulline

and Glutamine, amino acids important for growth in pigs [8]. In sum, when the CP in the diet is reduced, pigs need an alternative nitrogen source to synthesize these metabolites, so future research will evaluate several nitrogen sources.

The intestinal microbiota is important in the digestive physiology and metabolism of pigs. Fermentation of undigested dietary proteins is associated with increased growth of coliform bacteria. Therefore, the source, quality and level of dietary protein influence gut microbial communities [11]. The influence of dietary CP levels on intestinal microbiota populations was studied in weaned piglets, since the bacterial composition structure of growing or finishing pigs was relatively stable. In a study with weaned piglets, a LPD decreased Enterobacteriaceae in feces [2,11].

Similar to the reduction of nitrogen excretion in pig farms, studies have also evaluated nitrogen sources with the aim of improving intestinal microbiota using LPDs. For example, the inclusion of α-ketoglutarate in a LPD improved gut microbiota not only by increasing the population of beneficial bacteria, *Bacteroides* and *Bifidobacterium*, but also by reducing the population of *Escherichia coli* and the amount of ammonia in the cecum. As a result, research to improve the intestinal microbiota with LPDs is expected to be a topic to develop in the near future [13].

Reduction of unpleasant odors

Crude protein (CP) in pig diets provides the animal with essential amino acids, nitrogen (N) and sulfur (S) for optimal growth and development. In a typical pig diet, due to the digestibility of feed nutrients in ingredients and the price of amino acids (AA), the CP content is often supplied in excess, which is excreted, estimated to be between 40 and 60% for N and between 50 and 75% for S in the diet [14, 15].

Excess nutrients are deposited in the feces and digested anaerobically. The main odors emitted during manure storage and transport off farms are: volatile fatty acids (VFAs); phenolic compounds; indole compounds; and volatile sulfur compounds (VSCs) [16,17]. The origins of these compounds in pig feed are related with the CP content. Consequently, reducing the loss of these nutrients in an economical manner is an important issue for the pig industry, since odor emissions are an environmental nuisance in rural communities [18].

Odor control technologies in animal production fall into four categories. First, management inside the farm (separation of urine from feces, adsorbents used as bedding additive, and indoor environment/manure surface spraying agent). Second, manure management (semi-permeable membrane coating, reactor composting, mulching and acidification). Third, end-of-pipe measures for air treatment (wet purifying of farm exhaust air and air biofiltration). Fourth, dietary manipulation (diet with low crude protein and enzyme additives in feed) [18]. Depending on availability and price, synthetic AAs are used to reduce CP levels in pig diets, without affecting productive performance [2].

The use of AAs to reduce CP is an example of innovative technology where pig producers do not need to upgrade facilities or change management practices, but only reformulate diets and use existing infrastructure to reduce emissions. Diets with lower CP

content are effective in decreasing N excretion and NH_3 emissions but results in reducing odor/odorants in manure are inconsistent [19].

Early research focused on dietary impacts on fresh fecal and urine compositions, while later studies focused on dietary impacts of aged manure on air [20]. The level of CP in pig diets influences both manure properties and odor emissions. In sum, the chemical characteristics of manure from pigs fed low CP diets have lower manure pH, total solids, total N, and total S, with reduced concentrations of NH_3, VFA, and phenolic compounds. Emissions of NH_3, BCFA, phenolic compounds, and total odor are decreased in pigs fed LPDs. Emissions of NH_3, phenolic compounds, and total odor are reduced in pigs fed low CP diets [21,22]. Pigs fed a diet with low CP of 15% showed lower production of odorous compounds than the group of animals fed a 20% CP diet and this result is associated with changes in bacterial communities, especially their effect on protein metabolism [15].

Low protein diets used in pig feeding to reduce unpleasant manure odors is a novel topic, where good results have been observed when using a diet formulation for pigs under the concept of ideal protein; however, it is necessary to continue evaluating different sources and levels of protein in the diet, as well as the combination of these diets with the sources and levels of sulfur in pig feed [21,22].

Problems with pig farming in Yucatan: current conflict

Pork importing countries are: China, Japan, Mexico, South Korea, and the USA. The main exporting countries are: the European Union, USA, Canada, Brazil, and Mexico. According to the Agrifood and Fisheries Information Service (SIAP, 2021) [23], breeding of 18.8 million pigs was reported, with a production of 1,652,262 tons, which placed Mexico in 13th place in the world, with a value of 961 million dollars. The state of Yucatán is the third national producer of pork due to the large number of pig farms. There are all sizes, from very small to mega-farms with more than 30,000 pigs, many of which generate environmental and social problems; therefore, there is a great movement against pork production in the Yucatan Peninsula [24].

Arguments of the movement against pig farming in Yucatán

The Yucatan Peninsula is a place of great natural and cultural wealth, both characteristics preserved for many years thanks to the care of civil society. A general characteristic of the state of Yucatán is that it has no surface bodies of water (rivers or lakes). The scarcity of surface water is due to the fact that the soil in this region is shallow, resulting in the formation of underground rivers and cenotes. The Yucatan Peninsula is the richest reservoir of fresh underground water in Mexico. This resource is the source of drinking water for the different activities of its population.

During recent decades, pork production in Yucatán has increased. Pig farms are an important source of pollution, as pigs produce a huge amount of feces. The main pollutants are: ammonium (NH_4), nitrites (NO_2) and nitrates (NO_3). The farms do not comply with the maximum permissible limits of pollutants in residual discharges into water and national assets (NOM-001-SEMARNAT-1996 for the protection of aquatic life) [25], as established in NOM-127-SSA, which dictates the recommended limits for human

use and consumption. Therefore, the movement against pork production in Yucatán proposes to adopt the international recommendation; that is, that there be one pig for each hectare of land, and not to issue more permits for the establishment of pig farms in certain municipalities [26].

Arguments of the pro-pig farming movement in Yucatán

Pork production in Yucatán is one of the most prestigious in the country, since it is recognized for its high genetic quality production. Yucatán is self-sufficient in pork production; it is the third largest national producer of pork. Yucatán is one of the entities in the country that supplies the largest export tonnage to countries such as China, Japan, South Korea, the United States, Canada and Chile, and also supplies the entire Mexican southeast, thanks to its high quality standards. In Yucatán there is international experience in the marketing of pork and in the management of farms, since it has a privileged location and it is a growing activity [27].

The millenary importance of pork in the state is transcendental in the gastronomy of the emblematic dishes of Yucatec cuisine; for example, cochinita pibil, which is a dish with added value for tourism. Pig farming in Yucatán is an important source of employment, since 7,000 families, who live mainly in rural areas, depend directly on this sector, which has registered sustained growth in recent years. Likewise, pig farms in Yucatán are not located in Natural Protected Areas (NPA). Livestock activity in the Yucatan Peninsula only represents 0.67% of the water discharge. The establishment of biodigesters is a common practice of pig farmers in Yucatán [23, 26, 27].

LPD in pigs: a real alternative for pig farming in Yucatán

The main issues to improve sustainability in pork production in Yucatán are to reduce nitrogen and phosphorus excretion into the environment [24, 27]. Because of the importance and extent of phosphorus excretion in pork production, this will be a pending issue for the authors for a future review. In this article, the problem was only mentioned in relation to nitrogen excretion, with a current issue in Mexico such as pork production in Yucatán [24, 26].

In the controversy in Yucatán, both sides, for and against pork production, have solid arguments to maintain their position. However, neither of them mentions the formulation of LPDs as a real and scientifically supported alternative to reduce nitrogen excretion in pork production in Yucatán [24, 26, 27].

Currently, five synthetic EAAs (lysine, methionine, threonine, tryptophan, and valine) are used, which allows nutritionists to formulate diets with low levels of crude protein. According to the review by Rocha *et al.* (2022) [28], there is a minimum level of CP in the diet that does not affect the productive performance of pigs, which is different for each stage of production. When the average daily gain and feed efficiency were considered, respectively, these levels were estimated to be 18.4 and 18.3% of CP in diets for weaned piglets. For growing pigs, 16.1 and 16.3% and for finishing pigs 11.6 and 11.4% of CP.

Reducing dietary CP is a solution to reduce N excretion and ammonia emissions, which are problems in pork production. According to Cappelaere *et al.* (2022) [29], the use of

LPD linearly reduces total N excretion, in urine, feces and ammonia emissions by 8.2, 10, 3.2 and 10%, respectively, per percentage point of CP reduction. Likewise, nitrogen efficiency in LPDs improves by 1.6% per percentage point of CP reduction in pig diets. Therefore, the positive impacts of CP reduction and the decrease in N excretion in pig production is a novel topic with a trend of continuous innovation to generate sustainable and practical production to solve current problems [12, 30].

The addition of AA to reduce the amount of CP is an example of innovative technology where pig farmers in the Yucatan Peninsula do not need to modernize facilities or change management practices, but only reformulate diets and use existing infrastructure to reduce emissions [28, 29] . The use of LPDs will help reduce pollution from nitrogen excretion, and will ensure sustainability in this area of Mexico. This will happen with the collaboration of producers, government, civil society and the scientific community.

Disadvantages:

Productive performance

Productive performance, which includes daily gain (DWG), daily feed intake (DFI), and feed efficiency (FE), is the first factor to evaluate LPDs and also a simple indicator to determine their performance [10, 31, 32]. Reducing CP by 3 percentage units in the diet within the NRC (1998) requirement, with the addition of the first four limiting amino acids (LAA), resulted in a similar productive performance compared to traditional growing-finishing pig diets [33]. However, conflicting results have been reported on the response to a reduction greater than 3 percentage units of CP. For example, productive performance was reported to be reduced when the level of CP decreased more than 3 percentage units [34].

To improve the productive response, it is necessary to include the following limiting AAs in typical corn-soybean meal diets: valine (Val) and isoleucine (IIe) [33]. When growing pigs (25-50 kg LW) are fed LPD, Val is more limiting than IIe, while Ile becomes the limiting AA for finishing pigs (75-125 kg) [3]. Reduction of more than 6 percentage units in the level of CP is possible when supplementing the diet with all EAAs without affecting the productive performance in pigs, implying that non-essential amino acids (NEAAs) were not limiting in LPDs for growing and finishing pigs [36]. Poor performance in pigs fed with very low protein diets is due to deficiency in intact protein or excess of free AAs. Therefore, the inclusion of protein-bound AAs (intact protein) was reported to be more effective in maintaining nitrogen retention and body protein homeostasis than free AAs [32,35]. Therefore, the use of LPDs is still an unfinished issue if the aim is to reduce CP by more than 4 percentage units. Future research indicates that the addition of di- and tri -peptides hydrolyzed from intact protein is a viable option to improve digestive enzyme activities and, therefore, productive performance.

Carcass quality

It is debatable whether LPDs added with SAAs affect carcass characteristics. The relationship between carcass weight and pre-slaughter live weight is not affected by the reduction of the dietary CP level. However, a constant increase in dorsal fat thickness and

reduction in the *Longissimus* muscle area at slaughter was found with LPDs for growing and finishing pigs [3].

Three things are considered responsible for these results: 1) More energy is required for the excretion of excess AAs in a high protein diet. In contrast, LPDs are closer to the ideal AA ratio, so the energy needed for N excretion is lower; thus, there is more energy for adipose tissue synthesis. 2) The weight of the liver, intestine, kidney and pancreas increases in pigs fed with a high protein diet; as a result, energy requirements for maintenance increase. 3) The higher proportion of cereals in the LPD contributes a high content of available starch that is more efficient for fat deposition compared to AAs [7, 36].

To avoid the negative effects of LPDs on carcass characteristics, many studies have been carried out. First, the inclusion of some functional AAs with potential to reduce excessive body fat, for example: leucine, arginine, glutamine, glutamate and proline. Second, the system of formulating diets based on net energy to substitute digestible or metabolizable energy. Third, covering the nitrogen needs in the diet with sources of rapid absorption but low urea synthesis. Fourth, the use of growth promoters that reduce fat synthesis [36].

Where are we going?

Future research will focus on identifying and testing feed additives that maintain and/or improve the productive response of finishing pigs fed with LPDs supplemented with SAAs, such as phytobiotics, prebiotics, probiotics and enzymes, among others [10, 12, 32]. It will also focus on testing different sources of nitrogen/protein apart from the protein from the most commonly used (main) ingredients in pig diets. And finally, on the effect of both feed additives and different nitrogen sources on the microbial populations of the gastrointestinal tract of pigs and their productive response.

CONCLUSIONS

The practical application of LPDs is a recommended strategy in pig production, not only to reduce feed costs and nitrogen excretion but also to effectively improve intestinal health with a better microbiota. However, if one wishes to reduce CP by more than 3 or 4 percentage units, productive performance can be negatively affected. More research is required on the addition of EAAs in order not to affect the response of pigs. Likewise, it is necessary to use the net energy system in diet formulation, to provide this nutrient in amounts closer to the requirements of pigs, with which leaner carcasses could be obtained.

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