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Nutritional strategies for designer pork and lean meat production: An overview

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Abstract

Pork is the second most consumed meat globally, and its quality is largely influenced by intramuscular fat (IMF) content and fatty acid composition. While IMF enhances sensory attributes such as flavor, juiciness, and tenderness, modern genetic selection for leaner carcasses has reduced IMF levels, negatively affecting pork quality. Designer pork has emerged as a strategic approach to improve nutritional value by modifying fatty acid profiles and enhancing beneficial nutrients without increasing subcutaneous fat. Various nutritional interventions, including manipulation of dietary protein, fats, conjugated linoleic acid (CLA), vitamins, and minerals, play a crucial role in improving pork quality, lipid stability, and shelf life. Additionally, strategies targeting postmortem metabolism and fat quality help optimize meat characteristics. Despite challenges such as high production costs and consumer acceptance, designer pork and lean meat production offer significant health, economic, and sustainability benefits, aligning with the growing demand for functional and healthier meat products.

Keywords: Designer pork, fatty acid composition, intramuscular fat, lean meat production, nutritional strategies

1. Introduction

Pork is the second most-consumed meat worldwide, and its production is expected to increase steadily in the coming years ^[1]. The quality of pork is largely influenced by intramuscular fat (IMF) content and its fatty acid composition, which significantly affect sensory attributes such as flavour, juiciness, and tenderness, as well as consumer health. It is widely recognized that an adequate level of IMF enhances sensory quality, whereas excessively low fat content results in less palatable meat. However, pork is also a major source of dietary fat, and its consumption may contribute to an imbalance in fatty acid intake among modern consumers, potentially leading to adverse health effects.

In recent decades, genetic selection aimed at reducing subcutaneous fat in pigs has inadvertently led to a substantial decline in IMF levels (below 2.5%) in commercial crossbred pigs. This reduction has negatively impacted the sensory quality and overall acceptability of pork. To address this issue, various strategies have been developed to increase IMF content without increasing subcutaneous fat, thereby improving fat partitioning and overall meat quality ^[2].

In this context, the concept of designer pork has gained importance. Designer pork refers to meat that has been modified to possess specific desirable attributes, such as improved fatty acid profiles, reduced unhealthy fat content, or enhanced levels of beneficial nutrients like omega-3 fatty acids and selenium. Similarly, lean meat production focuses on reducing excess fat deposition while maintaining muscle growth and meat quality. These approaches fall under the broader category of designer or functional foods, which are conventional foods enhanced with health-promoting properties and are increasingly valued for their role in disease prevention and health promotion.

1.1 Why Designer Pork?

The development of designer pork is driven by increasing concerns regarding the nutritional quality of conventional pork. Compared to chicken and beef, pork generally contains a lower proportion of unsaturated fatty acids in its intramuscular fat. Moreover, a high intake of saturated fatty acids, along with an imbalanced ratio of n^{-6} to n^{-3} polyunsaturated fatty acids, has been associated with the development of various health disorders, particularly cardiovascular diseases. In recent years, there has been growing public awareness and concern about the relationship between meat consumption and the risk of coronary heart disease and atherosclerosis. Therefore, improving the fatty acid profile of pork through the concept of designer pork has become an important strategy to enhance its health value and consumer acceptability.

1.2 Advantages of Designer Pork and Lean Meat Production

Designer pork and lean meat production offer significant nutritional, economic, and environmental advantages. These products can be enriched with beneficial nutrients such as omega⁻³ fatty acids while reducing saturated fats, thereby improving their nutritional value and promoting better health by lowering the risk of obesity and cardiovascular diseases. They can also be tailored to enhance sensory qualities like flavour, juiciness, and tenderness, increasing consumer acceptability.

In addition, such products have higher market value and can fetch premium prices, benefiting producers economically. Lean meat production also supports sustainability through efficient resource use and reduced environmental impact, while advancements in breeding techniques may improve animal welfare. Furthermore, increasing consumer awareness of healthy diets has boosted demand for such products. Designer pork also holds potential as a functional food, with improved shelf life and opportunities for developing specialized markets like low-fat and health-enhanced meat products.

2. Different Nutritional Strategies for Designer Pork Production

For designer pork production different type of nutritional manipulation is required, that mainly include:

- Postmortem Metabolism and Pork Quality
- Intramuscular Fat Content
- Pork Fat Quality
- Lipid and Colour Stability
- Miscellaneous

2.1 Postmortem Metabolism and Pork Quality

Different nutritional strategies for the improved postmortem metabolism and pork quality are mainly include,

- Glycogen manipulation in carcass
- Tryptophan
- Magnesium
- Creatine

a. Glycogen manipulation in carcass

Glycogen manipulation in the carcass is a key factor influencing postmortem pork quality. High muscle glycogen levels at the time of slaughter lead to increased lactic acid production, resulting in a rapid decline in pH (5.8–6.0) and the development of pale, soft, and exudative (PSE) pork. In contrast, low muscle glycogen levels reduce lactic acid

accumulation, increase the ultimate pH, and result in dark, firm, and dry (DFD) pork. Therefore, controlling muscle glycogen reserves prior to slaughter is essential for optimizing meat quality.

Several methods are used to regulate glycogen levels, including preslaughter feed withdrawal, which helps manipulate muscle glycogen reserves and improve fresh pork colour and water-holding capacity (WHC). Fasting pigs for 16 to 36 hours before slaughter has been shown to reduce glycogen concentrations in the longissimus dorsi muscle, increase both initial and ultimate pH values, and produce darker meat with improved WHC. Additionally, feeding glycogen-reducing diets containing high levels of fat (17–19%) and protein (19–25%) with very low carbohydrate content (less than 5%) can further help in managing glycogen levels and enhancing pork quality.

b. Tryptophan

Supplementation of swine diets with the amino acid tryptophan plays an important role in improving pork quality by modulating animal behaviour and stress response. Tryptophan enhances serotonin production in pigs, which helps to reduce aggression and stress levels. As a result, circulating cortisol concentrations are lowered, minimizing stress-induced metabolic changes before slaughter. This ultimately leads to a reduced incidence of pale, soft, and exudative (PSE) pork, thereby improving overall meat quality.

c. Magnesium

Shortly after slaughter, the oxygen supply to muscle tissues ceases, and anaerobic metabolism (glycolysis) becomes the primary pathway for maintaining energy and muscle function. When postmortem glycolysis is accelerated in a still warm carcass, it results in excessive lactic acid accumulation, a rapid decline in pH, and ultimately the development of pale, soft, and exudative (PSE) pork. Magnesium plays a significant role in mitigating these effects by reducing glycolytic rates triggered by stress hormones such as catecholamines. Supplementation of magnesium in pig diets, even for a short period before slaughter, has been shown to improve the water-holding capacity (WHC) of fresh pork. Additionally, both short- and long-term magnesium supplementation can enhance the colour of fresh pork, contributing to improved overall meat quality.

d. Creatine

Creatine, synthesized from the amino acids arginine, glycine, and methionine, plays a vital role in energy metabolism by being phosphorylated to form phosphocreatine, which serves as a rapid energy reserve for ATP production, particularly in active muscle tissues. Supplementation with creatine monohydrate increases antemortem muscle phosphocreatine levels, thereby sparing muscle glycogen and reducing the risk of pale, soft, and exudative (PSE) pork. Furthermore, elevated creatine levels in muscle can delay postmortem anaerobic glycolysis, leading to reduced lactate accumulation and a slower decline in pH after slaughter, ultimately contributing to improved pork quality.

2.2 Dietary Effect on Intramuscular Fat Contents

Intramuscular fat (IMF), also known as marbling, is a key determinant of pork palatability, as it significantly influences sensory attributes such as flavour, juiciness, and tenderness. An IMF content ranging between 2.5 and 3.0% is generally

considered optimal for ensuring consumer acceptability of cooked pork. Therefore, maintaining and manipulating IMF levels through appropriate nutritional and management strategies is essential for improving overall meat quality. IMF content can be manipulated by,

- Dietary Protein and Amino Acid Effects on Pork IMF
- Fats and oils
- Conjugated Linoleic Acid (CLA)
- Vitamin A Supplementation

a) Dietary Protein and Amino Acid Effects on Pork IMF

Dietary protein and amino acid levels play a significant role in regulating intramuscular fat (IMF) deposition in pigs. Feeding diets deficient in protein or essential amino acids has been shown to increase marbling by enhancing IMF content. Specifically, reducing crude protein (CP) and/or lysine levels in swine diets can significantly elevate IMF levels. Studies have reported that lowering CP levels in grower and finisher diets can increase IMF content by 13.7 to 176.5%, while reducing dietary lysine in growing-finishing pigs can result in an increase of 66.7 to 136.8%. However, prolonged reduction of CP in the diet may negatively affect feed efficiency and growth performance. In contrast, short-term reduction of CP levels for about 5–6 weeks has been found to increase IMF without causing adverse effects on overall animal performance.

b) Fats and oils

Dietary fat sources have a significant influence on intramuscular fat (IMF) content and marbling in pork. Feeding diets supplemented with vegetable oils such as sunflower or canola oil has been reported to reduce marbling scores in lean meat. In contrast, the inclusion of animal fat sources, such as beef tallow, can enhance intramuscular fat deposition. For instance, pigs fed diets containing approximately 5% beef tallow have shown an increase of about 25% in IMF content, thereby improving marbling and potentially enhancing meat quality.

c) Conjugated Linoleic Acid (CLA)

Conjugated linoleic acid (CLA), a fatty acid naturally present in ruminant meat and milk, is known for its potential protective effects against cancer and cardiovascular diseases. Dietary supplementation of CLA in pigs has been shown to improve meat quality by increasing lean meat marbling scores and intramuscular fat (IMF) content. Studies in rodents have also demonstrated that synthetic CLA can reduce overall carcass fat while increasing lean mass and potentially improving feed efficiency. In pigs, CLA supplementation has been reported to decrease body fat by 6.2–25% and increase lean mass by 2.3–9.7%. In some cases, inclusion of 5% dietary CLA resulted in an increase in muscle marbling by 1.12%. Additionally, CLA has been found to improve the firmness and saturation of backfat and pork bellies, likely due to its inhibitory effect on enzymes involved in the conversion of saturated fatty acids to monounsaturated fatty acids.

2.3 Dietary Effect on Pork Fat Quality

Pork fat quality can be manipulated by main 3 ways,

- Dietary fat source and pork fat quality
- Dried distillers' grain byproduct
- Conjugated Linoleic Acid

(a) Dietary fat source and pork fat quality

Dietary fat sources play a critical role in determining pork fat

quality, particularly in terms of firmness and fatty acid composition. Increased consumption of polyunsaturated fatty acids (PUFA), especially when linoleic acid content exceeds 15%, can lead to the development of soft fat in pork. Feeding pigs diets rich in linoleic acid, commonly found in certain plant oils, also contributes to softer pork fat and bellies. This soft fat condition creates several challenges, including difficulties in carcass handling and processing, reduced bacon yield, an opaque and less appealing appearance, decreased shelf life, and potential rejection by both domestic consumers and export markets. In contrast, the inclusion of animal fat sources in diets does not negatively affect fat and belly firmness to the same extent as plant-based oils. It is estimated that 50–60% of the variation in pork fat fatty acid composition can be attributed to the type and level of dietary fat included in the feed, highlighting the importance of dietary manipulation in maintaining optimal pork fat quality.

(b) Dried distillers' grain byproduct

Dried distillers' grains (DDG), a common byproduct of industries such as ethanol production, contain approximately 10–15% crude fat and are characterized by a high proportion of unsaturated fatty acids. When included at high levels in pig diets, DDG can significantly increase the polyunsaturated fatty acid (PUFA) content of pork fat. This often results in the development of soft and pliable pork bellies, which are considered undesirable due to their negative impact on processing quality and product acceptability. Therefore, careful regulation of DDG inclusion levels in swine diets is necessary to maintain optimal fat quality in pork.

(c) Conjugated Linoleic Acid (CLA)

Supplementation of conjugated linoleic acid (CLA) in pig diets influences pork fat composition by increasing the proportion of saturated fatty acids (SFA), particularly palmitic and stearic acids, in both fat and muscle tissues. This shift in fatty acid profile contributes to improved fat quality, as higher SFA levels are associated with increased firmness of pork fat and fresh bellies, thereby enhancing processing characteristics and overall product quality.

2.4 Dietary Modifications on Lipid and Colour Stability

It is mainly done by supplementation of,

1. Vitamin E
2. Vitamin C
3. Magnesium
4. Vitamin-Trace Mineral Removal

a. Vitamin E

Vitamin E (α -tocopherol) is a potent antioxidant that plays a crucial role in maintaining cell membrane integrity and preventing lipid oxidation, particularly during refrigerated storage and retail display of pork. Among various nutritional strategies, vitamin E supplementation in the diets of growing-finishing pigs is one of the most extensively studied approaches for improving pork quality. Feeding pigs with an additional 100–200 mg/kg of dl- α -tocopherol acetate has been shown to effectively delay the onset of lipid oxidation in fresh whole-muscle cuts, ground pork, as well as precooked and cured pork products. Overall, supranutritional supplementation of vitamin E within this range enhances the oxidative stability of pork, thereby improving shelf life and product quality^[3].

b. Vitamin C

Vitamin C functions as an antioxidant and has been investigated for its role in improving pork quality. Supplementation of ascorbic acid prior to slaughter, particularly within four hours, has been reported to produce darker and redder pork, which may enhance visual appeal. However, studies indicate that both short-term and long-term supplementation of vitamin C do not have a significant effect on overall pork color stability or water-holding capacity (WHC), suggesting limited impact on these quality attributes under typical feeding conditions.

c. Magnesium

Magnesium plays an important role in improving pork quality by acting as a cofactor in the activation of antioxidant enzymes such as superoxide dismutase. Dietary supplementation of magnesium has been shown to enhance the stability and visual quality of pork. For instance, the longissimus dorsi muscle (LM) from pigs fed diets containing 350 mg/kg of magnesium exhibited less discoloration even after seven or more days of retail display compared to meat from non-supplemented pigs. Additionally, magnesium supplementation has been associated with increased muscle pH, improved visual colour scores, and reduced lightness values, contributing to better overall meat quality. Supporting these findings, D'Souza *et al.* (1999)^[4] reported that feeding pigs 40 g of a purified magnesium source for five days resulted in significant improvements, including a reduction in lightness (L*) by 2.6 units and a decrease in drip loss by 1.7%, indicating enhanced water-holding capacity and colour stability.

d. Removal of trace minerals and vitamins

Reducing the inclusion of vitamins and minerals, particularly during the final month of the finishing period, can be an effective strategy to lower production costs and minimize the excretion of phosphorus and other mineral elements into the environment. Studies have indicated that the complete removal of vitamins and trace minerals during the late-finishing phase does not adversely affect key pork quality traits such as colour, marbling, or firmness. Therefore, this approach can be adopted as a cost-effective and environmentally sustainable feeding practice without compromising meat quality.

2.5 Miscellaneous Nutrients

a. Chromium

Chromium is known to potentiate the action of insulin and may play a significant role in enhancing lean tissue deposition in pigs. Pettigrew and Esnaola (2001)^[3] reviewed 27 studies on chromium picolinate supplementation at a level of 200 ppb and reported notable improvements in carcass traits, including a reduction in average backfat thickness by 1.5 mm, an increase in carcass lean percentage by 1.5%, and an expansion of loin eye area by 2 cm². Further studies conducted on market-weight hogs suggest that the effectiveness of chromium supplementation may depend on dietary energy levels, with positive responses observed under high-energy diets and negative or minimal effects under low-energy conditions. Supporting this, Shelton *et al.* (2003)⁵ found that chromium supplementation increased loin eye area by 4.5 cm² in pigs fed high-energy diets, whereas a decrease of 2.87 cm² was observed under low-energy diets. However, in a subsequent experiment, the increase in loin eye area with high-energy diets was not statistically significant, indicating

variability in response to chromium supplementation.

b. Betaine

Methionine is an essential amino acid that plays a critical role not only in protein synthesis but also as a methyl group donor in various metabolic processes, including DNA and choline synthesis. Betaine serves as an alternative methyl donor, helping to regenerate methionine and contributing to the maintenance of osmotic balance in cells. The inclusion of betaine in swine diets has shown potential to improve carcass characteristics by enhancing leanness and, in some cases, growth performance. However, responses to betaine supplementation can be variable, as reported by Lawrence *et al.* (2002)⁶, who observed that factors such as gender may influence outcomes, with barrows generally exhibiting more favourable responses compared to gilts.

3. Challenges Faced by Designer Pork and Lean Meat Producing Industries

The development and commercialization of designer pork and lean meat products face several challenges that can limit their widespread adoption. One of the primary constraints is the high cost of production, as advanced breeding technologies, genetic modifications, and specialized feed formulations significantly increase overall expenses, making it difficult to compete with conventional meat products. In addition, consumer acceptance remains a major concern, as apprehensions regarding genetic modification, perceived unnatural production methods, and scepticism about health claims may hinder market penetration.

Regulatory hurdles further complicate the situation, as strict frameworks governing genetically modified organisms (GMOs) and novel production technologies can delay product approval and increase compliance costs. Moreover, designer meat products often cater to niche markets, resulting in limited demand and reduced scalability compared to conventional meat products. Global market expansion is also challenging due to variations in regulations, consumer preferences, and economic conditions across different countries, which complicate production, distribution, and marketing strategies.

4. Conclusion

Designer pork production offers an effective approach to improving pork quality by optimizing intramuscular fat (IMF) and fatty acid composition through targeted nutritional strategies. Supplementation with nutrients such as vitamins, minerals, amino acids, and functional compounds enhances meat quality, including flavor, tenderness, color, and shelf life. These strategies also help produce healthier pork with improved lipid profiles, meeting consumer demand for functional foods. However, challenges such as high production costs, regulatory issues, and consumer acceptance remain significant barriers. Overall, designer pork and lean meat production provide a promising pathway for producing high-quality, nutritious, and sustainable meat products.

Conflict of Interest

Not available

Financial Support

Not available

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