Nutritional Strategies for Enhancing Meat Quality

Muhammad Waqar[1,*], Muhammad Nauman[2], Hamza Ayub[3] and Muhammad Waqas[4]

[1]Department of Poultry Production, University of Veterinary and Animal Sciences, Lahore Pakistan
[2]Faculty of Veterinary Sciences, University of Veterinary and Animal Sciences Lahore, Pakistan
[3]Department of Fisheries and Aquaculture, University of Veterinary and Animal Sciences Lahore, Pakistan
[4]Department of Animal Nutrition and Nutritional Diseases, Faculty of Veterinary Medicine, Ondokuz Mayıs University, Samsun, Turkiye
*Corresponding author: mwaqarvet@gmail.com

Abstract

Meat from animal sources is a vital source of protein, offering health benefits, affordability, and production efficiency. Advances in genetic selection and nutritional strategies have significantly improved meat quality and production efficiency. However, modern production practices are often associated with challenges such as bacterial and parasitic infections, heat stress, and the consumption of mycotoxins and oxidized oils, which can negatively affect meat quality and body composition. The nutritional interventions have demonstrated considerable potential in addressing these challenges. Modulating dietary components such as energy, crude protein, amino acid levels, and fiber have been shown to enhance meat quality and optimize body composition. Additionally, supplementing diets with bioactive compounds such as vitamins, probiotics, prebiotics, exogenous enzymes, phytobiotics, and organic acids has improved meat quality and composition. Simultaneously, there is growing consumer demand for healthier meat products with reduced levels of potentially harmful components, such as salt, nitrates, nitrites, and N-nitrosamines. Incorporating dietary components and natural bioactive compounds has facilitated the production of safer, higher-quality meat products. These strategies address nutritional deficiencies, minimize toxic compounds, and preserve the sensory quality and safety of poultry meat. This review highlights innovative nutritional approaches to enhance poultry meat quality, ensuring a sustainable and health-focused production system.

Keywords: Bioactive compounds, Poultry, Ruminants, Fish, Dietary components, Meat quality, Meat composition

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Introduction

Meat is broadly defined as the skeletal muscle and associated tissues obtained from animals, encompassing the edible parts removed from the carcasses of domestic livestock such as cattle, pigs, sheep, goats, and poultry, as well as farmed game and small wild game (Regulation, 2004). Processed meat products undergo treatments such as dehydration, fermentation, curing, and smoking, resulting in physical and chemical transformations that distinguish them from fresh meat (Regulation, 2004; Simonin et al., 2012). Among the various types of meat, poultry has emerged as a globally preferred and economical protein source due to its affordability, high-quality protein content, low fat, and beneficial omega-3 fatty acid concentrations, which support vascular health (Betti et al., 2009; Daniel et al., 2011). The global poultry industry has witnessed exponential growth, with production outpacing other meat sources such as pork, beef, and sheep. In 2023, poultry meat production was projected to surpass 139 million metric tons, reflecting a nearly 3% increase compared to 2022, driven by countries like Brazil and the United States (Barbut & Leishman, 2022). Consumption trends also reveal the rising prominence of poultry, with global per capita consumption reaching 14.7 kg in 2019, exceeding other meat sources (OECD, 2020; Whitton et al., 2021). This surge in demand is attributed to population growth, evolving consumer preferences, and increased health consciousness, particularly in Asia and Western countries (Tripathi et al., 2019; Panea & Ripoll, 2020). Innovations in genetic selection and nutrition programs have significantly enhanced broiler production efficiency, with modern broilers reaching weights of approximately 3.3 kg at 42 days with a feed conversion ratio of 1.55 (Cobb-Vantress, 2022). However, these advancements have also introduced challenges related to meat quality, such as reduced water-holding capacity, myopathies, and undesirable texture and flavor (Petracci et al., 2015; Escobedo del Bosque et al., 2022). The rapid growth and intensive farming practices in modern poultry production have heightened concerns about food safety, animal welfare, environmental sustainability, and meat quality. Issues such as feed costs, disease outbreaks, heat stress, and mycotoxins pose significant challenges to the industry, influencing meat composition and consumer acceptance (Choi & Kim, 2020). Given the increasing consumer demand for high-quality, sustainable, and safe poultry products, research has shifted focus toward optimizing nutrition strategies, genetic improvements, and management practices. Nutrition, in particular, plays a pivotal role in influencing broiler meat quality and body composition (Mir et al., 2017; Yue et al., 2024). Numerous studies have highlighted that altering feed nutrient composition and adding bioactive substances such as probiotics, prebiotics, exogenous enzymes, vitamins, essential oils, polyphenolic compounds, and organic acids can effectively improve both the body composition and meat quality of broiler chickens (Choi et al., 2023).

This book chapter aims to provide a comprehensive summary of the diverse and challenging conditions in modern broiler production affecting meat quality and body composition and the impact of nutritional strategies in mitigating these challenges and enhancing poultry meat quality.

Nutritional Strategies in Poultry to Enhance Meat Quality

Poultry, as a monogastric animal, needs a wide range of nutrients like lipids, carbohydrates, minerals, antioxidants, and enzymes, for proper growth and energy storage. The requirements and nutritional value of the animal's diet determine how well protein accretion and energy storage are balanced.

Energy in diets plays a crucial role in growth rate, fat accumulation, and quality of meat products which in turn influence poultry production. The low-energy diets may help to reduce fat deposition, while the high-energy diets can promote it. High-energy diets lead to depositing more fat in broiler chicks (Rosa et al., 2007), and on the other hand, low-energy diets lead to the production of less fat meat but constrain growth (da Silva Ferreira et al., 2015). Specifications such as growth rate, dressing percentage, and some characteristics of meat may affect these results, and genotype seems to be a major factor (Lipiński et al., 2019).

Protein is vital in muscle synthesis and growth in the diets of poultry, affecting the animal's physical composition and energy value. Low dietary protein has been reported to cause high drip loss in breast meat therefore a proper balanced diet should be encouraged (Chodová et al., 2021). Research has revealed that increased protein concentration in assimilated Indigenous Nigerian guinea fowl enhances carcass characteristics and muscling while decreasing gastrointestinal tract weight, head weight, dressing percentage, and organizer yield (Alabi et al., 2023). Feed inclusion of mulberry leaf powder at a level of 1.50% in White Geese diets improved breast muscle yield, decreased shear force, increased antioxidant background, and overall textural characteristics (Wang et al., 2024).

Amino acids are important in poultry since they act as catalysts in controlling metabolic pathways, antioxidant systems, and enzymatic activity influencing meat quality. Lysine, arginine, and methionine are vital compounds when it comes to enhancing meat quality and a reduction in fat deposit formation. Methionine controls cooking loss and enhances the pH of breast meat while arginine modulates lipogenesis-related genes influencing fat deposition and enhances lean muscle (Wen et al., 2017; Zampiga et al., 2019). Lysine, which is a vital component of amino acid for breast flesh formation enhances more yield of breast meat and less abdominal fat (Oviedo-Rondón et al., 2021).

The n-6: n-3 fatty acid ratio was found to alter immunological outcomes, broiler production results, and meat patterning using omega-3 polyunsaturated fatty acids (PUFAs) broiler chickens (Alagawany et al., 2019). Glutamine supplementation and Omega-3 improve the broiler's daily gains, breast muscle yield, meat quality, antioxidant activity, villous height-to-width ratio in the plasmid, and lowered the MDA concentration, and lowered inflammatory markers (Kishawy et al., 2024). Fish oil supplementation at 2.5% lowered the incidence of fat deposition, the omega-6 to omega-3 fatty acid ratio, and the polyunsaturated to saturated fatty acid ratio but increased drip loss (Zampiga et al., 2019). The feed supplemented with rice bran oil and corticated marama bean meal caused enhanced breast yield, immune organ chocolates, and meat glutathione in broiler chickens and rain-fed abdominal fat yield, meat crude fat, triglycerides, cholesterol, and malondialdehyde levels (Selim et al., 2021).

Heat-stressed broiler chickens need vitamins E and C, which are antioxidants that can decrease heat stress. Some concentrations of vitamin E can enhance the antioxidant potentiality and reduce the lipid peroxidation in the breast muscle of broiler chicken (Pečjak et al., 2022). It was revealed that feed supplementation during the early phase can significantly minimize the impact of woody breast (WB) and shear force issues in broiler chickens (Wang et al., 2020). However, vitamin C supplementation and vitamin E, which are thought to enhance various meat quality attributes in normal-reared broiler chickens, did not have any significant impact on the quality of meat from broiler chickens grown under heat-stress conditions (Zeferino et al., 2016). The present study shows that vitamin A concentrations and period of vitamin A supplementation affect the occurrence and severity of WB and meat yield in broiler chickens probably through, affecting the metabolism of cells in the muscles (Savaris et al., 2021). To promote lean deposition, augmented levels of both vitamins C and chromium improve, ascertained from meat as a medium to be, better quality by raising the proportion of unsaturated fatty acids, lowering saturated fatty acids and fat, and sensation aspect (Nadaf Fahmideh et al., 2023). Supplementation of slow-growing broiler chickens with betaine increases meat redness and yellowness and reduces cooking and drip loss as well as improvement in muscular resilience and tenderness and antioxidant enzyme activities, decrease in intra-muscular saturated fatty acids, and increase in monounsaturated fatty acids and polyunsaturated fatty acids in bust muscle (Yang et al., 2022).

There are external enzymes like phytase, protease, carbohydrase, polysaccharidase, and lipase that have been included in the feed of broiler for improving growth and gastrointestinal health as well as for better nutrient utilization. It has been established that the inclusion of marama bean meal (CMBM) pre-treat with fibrolytic multi-enzyme (FMENZ) enhances breast pH and hemoglobin levels in Jumbo Coturnix quail diets (Marareni et al., 2024). The broiler chickens fed 15% Spirulina with or without enzymes had significant ($p \leq 0.05$) increased yellowness, pigment concentration, and n-3 polyunsaturated fatty acids in both breast and thigh meats (Spínola et al., 2024). Moreover, the incorporation of protease into the feed lowered drip loss in breast meat similar to the effect of butchering (Lu et al., 2020). In broilers fed a low-metabolizable energy (low-ME) diet with a multienzyme blend, meat hardness was decreased, and breast muscle yellowness at 24 h postmortem was improved but there were no enhancements recorded on carcass performances or meat yields (Hussein et al., 2019).

Nutritional Strategies to Enhance Meat Quality of Red Meat

In the last few decades, scholars have shifted attention to attempting to alter the lipid profile of meat can be realized through genetic selection for specific, changing the diet of cattle, Probiotics, fatty acids, and or essential diet nutrients such as vitamins and some trace elements. Innovations in technology in feeding have enabled clients to feed their cattle with diets that contain fats with optimal PUFA, and ω-6/ω-3 fatty acids (Liput et al., 2021). At present, it is common practice to feed animals with canola and fish oils since they contain a high proportion of monounsaturated fatty acids, and more specifically, oleic acid is a vital factor of cell metabolism. Correa et al. (2022) replaced canola oil into the diet of Nellore cattle, the results showed that consuming canola oil enhanced the accumulation of unsaturated fat, ω-3 fatty acids, and CLA but also improved the ratio of ω-6/ω-3 and the quantity of saturated fatty acids of meat. This is because antioxidants such as selenium and vitamin E found in canola oil are known to enhance cholesterol-positive aspects and the HDL cholesterol fraction in the blood (Khalifa et al., 2021).

As an antioxidant, vitamin E supplement is essential, preventing cell membranes from being damaged by lipid peroxidation and preventing more formation of free radicals. A literature review has indicated that certain organic selenium supplements the mineral in *Latissimus dorsi* muscle of Nellore cattle while inorganic selenium generates thiobarbituric acid-reactive substance concentration (Silva et al., 2020). The results presented in this paper provide evidence of the usefulness of organic selenium in enhancing such properties of meat and its stability. Supplements containing such nutrients as trace minerals and vitamins are useful to beef cattle because they help the animals to grow to their maximum dietary potential for the producers' gain. Different techniques can be used to add trace minerals to animal feeds, however depending on the feed intake there was no way of ensuring that the animals get the required amount of the trace minerals (Harvey et al., 2021). Other techniques like the rumen boluses have a better release and distribution of trace elements between animals.

Rumen boluses form part of the feeding program to feed consistently, particularly during the finishing period, and intend to affect carcass characteristics (Lee et al., 2020). Adding antioxidants to animal feeding rations will enhance the improvement of new meat products, control lipid profile, and less use of antibiotics. Also, antioxidants work against oxidative stress, thus contributing to the animals' well-being and a decrease in immune diseases. Data from other earlier research indicated that feeding certain constituents can enhance the desirable features of meat color, nutritive quantity, and palatability after slaughtering. For instance, supplementation of 200 mg/kg of lycopene in the diets of finished pigs enhanced the color, nutritional values, and juiciness of the product (Wen et al., 2022). Also, the effectiveness of herbal extracts in formulated diets of 24 Holstein-Friesian bulls enhanced meat composition, technological properties, and sensory qualities (Modzelewska-Kapituła et al., 2018). Feeding dry grape pomace to Angus steers 150g/kg for 90 days improved the shelf life of beef under a retail display through increased antioxidant potential and decreased coliform count, lipids, and protein oxidation (Tayengwa et al., 2020).

Table 1: Effect of supplementation of different ingredients on meat quality of poultry, ruminants and fish

Ingredient	Effect on Meat Quality	Citations
Mulberry leaf powder (White Geese)	Improves breast muscle yield, decreases shear force, increases antioxidant background	(Wang et al., 2024).
Lysine (Poultry)	Enhances breast meat yield, reduces abdominal fat	(Oviedo-Rondón et al., 2021).
Methionine (Poultry)	Controls cooking loss, enhances pH of breast meat	(Wen et al., 2017)
Arginine (Poultry)	Modulates lipogenesis-related genes, enhances lean muscle	(Zampiga et al., 2019).
Omega-3 PUFAs (Poultry)	Improves immunological outcomes, broiler production results, and meat patterning	(Alagawany et al., 2019).
Glutamine (Poultry)	Improves daily gains, breast muscle yield, meat quality, antioxidant activity	(Kishawy et al., 2024).
Fish oil (Poultry)	Lowers fat deposition, omega-6 to omega-3 fatty acid ratio, increases drip loss	(Zampiga et al., 2019)
Rice bran oil and corticated marama bean meal (Poultry)	Enhances breast yield, immune organ chocolates, meat glutathione, reduces abdominal fat yield	(Selim et al., 2021).
Vitamin E (Heat-stressed broiler chickens)	Decreases heat stress, enhances antioxidant potentiality, reduces lipid peroxidation	(Pečjak et al., 2022).
Vitamin C (Heat-stressed broiler chickens)	No significant impact on meat quality under heat-stress conditions	(Zeferino et al., 2016).
Vitamin A (Broiler chickens)	Affects the occurrence and severity of wooden breast and meat yield	(Savaris et al., 2021)
Betaine (Slow-growing broiler chickens)	Increases meat redness and yellowness, reduces cooking and drip loss, improves muscular resilience and tenderness	(Yang et al., 2022).
Marama bean meal (CMBM) with fibrolytic multi-enzyme (FMENZ)(Jumbo Coturnix quail)	enhances breast pH and hemoglobin levels	(Marareni et al., 2024)
Canola oil (Cattle)	Enhances accumulation of unsaturated fat, ω-3 fatty acids, CLA, improves ω-6/ω-3 ratio	(Correa et al., 2022)
Spirulina with enzymes (broiler)	increased yellowness, pigment concentration, and n-3 polyunsaturated fatty acids in both breast and thigh meats	(Spínola et al., 2024)
protease	lowered drip loss in breast meat	(Lu et al., 2020).
Vitamin E (Cattle)	Prevents cell membrane damage, reduces free radical formation	(Khalifa et al., 2021).
Selenium (Cattle)	Enhances cholesterol-positive aspects and HDL cholesterol fraction	(Silva et al., 2020).
Lycopene (Finished pigs)	Enhances color, nutritional values, and juiciness	(Wen et al., 2022).
Dry grape pomace (Angus steers)	Improves shelf life, antioxidant potential, reduces coliform count, lipids, and protein oxidation	(Tayengwa et al., 2020).
Lacticaseibacillus casei and *Lactiplantibacillus plantarum* (lamb)	increasing the tenderness and taste of meat	(Liu et al., 2022)
Microalgal oils (Fish)	Enhance growth performance, feed intake, pigmentation, reduce pollutants, increase DHA content	(Zatti et al., 2023)
Vitamins A, C, D (Fish)	Improves immune function, maintains epithelial integrity and disease resistance	(Liu et al., 2022).
Vitamin E (Fish)	Reduces lipid peroxidation, retains flavor and color	(Ruff et al., 2003).
Zinc (Fish)	Enhances enzyme sites, nutrient absorption, and growth	(Kumar et al., 2020).
Magnesium oxide nanoparticles (Fish)	Restores redox homeostasis, contributes to muscle health	(Zhang et al., 2023).

Some of the benefits of probiotics when used on livestock include microbial profile, feed conversion, carcass characters, muscle fiber profile, meat quality health disease resistance, and immune system. Liu et al. (2022) reported that *Lacticaseibacillus casei* and *Lactiplantibacillus plantarum* aid in increasing the tenderness and taste of meat in lambs. Although supplementation with yeast (*Saccharomyces cerevisiae*) has yielded no influence on the carcass characteristic of lambs (Gadekar et al., 2015). Probiotics also influence muscle fiber characteristics that relate to carcass conformation and meat quality (Picard and Gagaoua, 2020). The inclusion of specific nutrients and compounds into cattle diets appears to mitigate oxidative changes in meat tissues that negatively impact meat quality. Table 1 shows the effect of supplementation of different ingredients on meat quality of poultry, ruminants and fish.

Nutritional Strategies to Enhance Fish Meat Quality

Fish and seafood are important sources of dietary omega-3 LC-PUFA, EPA, and DHA, known for their health-promoting effects in developed countries. To meet the increasing market demand for healthy, nutritionally sound seafood, omega-3 enhancement in aquaculture feeds has become mandatory (Tocher et al., 2019).

Fish oil, which used to be the main source of EPA and DHA in aquaculture diets, remains the main factor that defines the concentration of these fatty acids in fish muscle (Santigosa et al., 2021). However, replacing fish oil with vegetable oils, which contain higher amounts of n – 6 PUFA but not n – 3 LC – PUFA, lowered the content of omega-3 in farmed fish (Tocher et al., 2019). Although fish oil enriches both fish growth and consumer nutritional value (Tacon et al., 2020), sustainable fish feed ingredients such as omega-3 PUFAs from microalgae and genetically modified plant oils are emerging (Bartek et al., 2021).

The advantages of microalgal oils compared to fish oil include lower vulnerability of corresponding sources; more predictable and better-controlled production; and no content of toxins, which are inherent in marine products like *Schizochytrium sp.* oils (Miller et al., 2007). The research shows that supplementing fish oil with algal oil leads to the enhancement of growth performance, feed intake, and pigmentation in actively growing Atlantic salmon while decreasing pollutants and increasing DHA content which is beneficial for the health of human consumers (Zatti et al., 2023). Because it becomes difficult to artificially make LC-PUFA, microalgae are heavily sold based on their lipid content, thereby having species variability (Ferreira et al., 2019).

Some of the important PUFA microalgae involving *Schizochytrium* and *Crypthecodinium* for DHA and *Nannochloropsis* and *Isochrysis* for EPA and others (Nagappan & Kumar Verma, 2018; Lu et al., 2021) In the same way, plant-based proteins in aquafeeds have had some effects as indicated by the following. According to studies with tilapia *(Oreochromis niloticus)* and crucian carp *(Carassius carassius),* soy and rapeseed meal enhances antioxidant potential, muscle attributes, and flavor as well as growth rates (Peng et al., 2022; Yang et al., 2024).

Besides, vitamins are important sources of nutrients needed to sustain the health of fish. Vitamins A, C, and D improve immune function and maintain epithelial integrity and disease resistance in fish species including Atlantic salmon and rainbow trout (Liu et al., 2022). In any case, vitamin E also reduces the rate of lipid peroxidation in fish fillets, thus retaining flavor and color (Ruff et al., 2003). Lithium is required for proper bowel movement while zinc and magnesium are necessary for muscular health. They have further described that zinc enhances enzyme sites and nutrient absorption, and increases growth in various species which is also evident by using striped catfish (Kumar et al., 2020). The intake of magnesium, especially in the form of magnesium oxide nanoparticles, restores redox homeostasis and contributes to the muscles of fish such as blunt snout bream (Zhang et al., 2023).

Conclusion

Nutritional regime improvement for meat quality is an emerging area of study, concerning issues of meat production systems that are correlated with consumer preference on consumption of healthier and sustainable animal muscle foods. Several factors are considered here which indicate that by manipulating dietary components like energy, protein, amino acids, and lipids and including the bioactive compounds, vitamins, and minerals meat quality improvement is easy in poultry, ruminants, and fish. Besides improving the sensory characteristics of meat, these interventions also promote better health status and standard of animals to achieve the objectives of production possibility frontier and quality. Technological solutions are microalgal oils and vegetable proteins as more sustainable alternatives to the traditional inputs for livestock and aquaculture enterprises. Also, the incorporation of antioxidants, enzymes, and vitamin trace minerals has shown possibilities in maintaining meat quality, increasing shelf life, and increasing nutritional values. Prospects in this field are based on precision nutrition and innovative feed formulations for better diets according to animal requirements and market value. To create new and viable solutions, the academia and international counterparts must carry out research and collaborate with industrial partners to ensure that they adopt innovations in line with global trends in health, innovative environmental consciousness, and customer preferences.

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