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Review

Influencing factors and quality traits of pigeon meat: A systematic review

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ABSTRACT

Pigeon meat is highly nutritious, offering medicinal benefits, and is often valued as a tonic due to its high protein and low-fat content. With advancements in breeding technology and evolving market demands, the quality and flavor characteristics of pigeon meat have become key areas of interest for researchers and consumers. In recent years, extensive research on pigeon meat quality traits, has been conducted both domestically and internationally, to enhance the production efficiency and product quality to meet market needs while also providing theoretical support and technical guidance for industry development. This review explores the recent advancements in under-standing the genetic and non-genetic factors that influence pigeon meat quality, focusing on candidate gene markers that guide breeding strategies to enhance meat quality. For instance, studies on genetic factors have identified several genes associated with pigeon meat quality. These include ATP binding cassette subfamily a member 8 (***Abca8b***), von willebrand factor (***VWF***), oxoglutarate dehydrogenase (***OGDH***), TGF beta induced factor homeobox 1 (***TGIF1***), dickkopf WNT signaling pathway inhibitor 3 (***DKK3***), glutamine-fructose-6-phosphate transaminase 1 (***Gfpt1***) and replication factor C subunit 5 (***RFC5***) which influence skeletal muscle development, and fatty acid binding protein 1 (***FABP1***), heart-type *FABP* (***H-FABP***), and diacylglycerol acyltransferase 2 (***DGAT2***) which impact intramuscular fat content. Furthermore, the comprehensive exploration of both genetic and non-genetic factors aims to provide a solid foundation and practical strategies for advancing the production and utilization of pigeon meat.

Introduction

Pigeons are found globally, and their meat is considered a delicacy in many cultures (Sales & Janssens, 2003). In traditional Chinese medicine, pigeon meat is highly regarded for its therapeutic properties, including the treatment of fatigue, diabetes, chronic diarrhea and menstrual disorders, as documented in one of the earliest monographs on diet therapy in this field. The therapeutic benefits of pigeon meat are closely linked to its exceptional nutritional profile, which features a higher protein content, lower fat levels, and elevated concentrations of polyunsaturated fatty acids and essential amino acids when compared to other types of meat (Chang et al., 2017; Pomianowski et al., 2009). Currently, China produces around 680 million squabs annually, accounting for over 80 % of global output (Jiang et al., 2019) positioning China as a leader in the global pigeon meat industry. With rising consumer demand, breeding stock increases annually, making pigeon meat the fourth most significant source of poultry products in China(Ji et al., 2022). To satisfy consumer expectations, the industry has shifted from merely increasing production volume to enhancing the nutritional quality and flavor of healthy pigeon meat (Yin et al., 2022).

Meat quality traits include physical and chemical quality parameters, and flavor components, which are influenced by factors such as breed, genetics, feeding environment, diet, and age. Although it is challenging to define meat quality precisely, it can be assessed through various indicators, including color, pH, water-holding capacity, drip loss, tenderness, intramuscular fat content, glycolytic potential, and flavor and sensory properties (Li et al., 2016). Physical quality parameters such as color and tenderness, directly impact consumer purchasing decisions. Chemical quality parameters, such as intramuscular fat content and muscle fiber structure, determine not only the meat's nutritional value but also its taste. Flavor, a crucial quality attribute of meat products greatly influences overall acceptability. It arises from soluble flavor compounds and volatile aroma compounds generated through the high-temperature chemical reactions of amino acids, fatty acids, inosinic acid, and other precursors within the meat. In poultry meat, volatile compounds such as aldehydes, ketones, alcohols, acids, esters, and

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sulfur-containing compounds form through lipid and water-soluble compound transformations, including the Maillard reaction, Strecker degradation, lipid oxidation, lipid-Maillard interactions, and thiamine degradation (Xu & Yin, 2024). During cooking, these reactions particularly the Maillard reaction, yield the distinctive aromas and flavors characteristic of pigeon meat (Liu et al., 2024). Cooking methods significantly impact the flavor of poultry meat, with variations in flavor composition and mouthfeel arising from different techniques, such as roasting, stewing, or boiling (Werenska, 2023).

It is essential to assess the quality traits of pigeons for enhancing the economic value of pigeons, advancing the pigeon breeding industry, supporting healthy diets, and facilitating scientific exploration. Understanding the mechanisms and regulatory pathways of these traits can provide a theoretical foundation and practical strategies for improving pigeon meat quality. This review therefore aims to summarize the influencing factors and evaluation indicators of pigeon meat quality, providing a useful reference for the development of high-quality pigeon genetic resources and the production of premium poultry meat.

Non-genetic factors affecting meat quality traits of pigeons

Pigeon meat is valued for its high protein content, low fat, tender texture, savory taste, and significant nutritional and medicinal benefits (Pomianowski et al., 2009). The primary non-genetic factors affecting pigeon meat quality include feed composition, stocking density, storage condition, and cooking methods. Effective regulation and management of these factors can substantially enhance meat quality.

Feed composition

Feed composition is a key determinant of pigeon meat quality, influencing factors such as nutrient level, micronutrient content, and use of food additives (Zhang et al., 2025, 2017). A well-balanced feed formula can improve the quality of pigeon meat, enhancing its delicacy, reducing nutrient loss and drip loss, boosting antioxidant capacity, and promoting healthy muscle development (Liu et al., 2023; Shao et al., 2023). As altricial birds, squabs cannot feed independently after hatching, making the nutrient content of breeder pigeon diets crucial for maximizing crop milk production and improving squab performance at slaughter. Studies have shown that the levels of metabolizable energy (**ME**) and crude protein (**CP**) in breeder diets significantly impact young pigeons' breast muscle mass. ME and CP levels of 12.8 MJ/kg and 18 %, respectively, have been shown to reduce the cross-sectional area of pectoral muscle fibers in squabs (Peng et al., 2023). An optimal energy to protein ratio improves squab meat quality resulting in enhanced slaughter performance. Methionine, an essential amino acid and the first limiting amino acid for poultry, also plays a critical role. Dietary supplementation with DL Methionine (**DL-Met**) and DL-methionyl-DL-methionine (**DL-Met-Met**) in breeder pigeons increases the a* color value of breast muscle, reduces drip loss and cooking loss, while enhancing antioxidant activity in the breast and thigh muscles (Jiang et al., 2019). Zinc, the second most abundant trace element, is crucial for growth performance, ranking above other elements such as copper, manganese, and iron (Bao et al., 2010). Dietary zinc supplementation at 120 mg/kg for breeder pigeons increases squabs' body weight and breast muscle yield. Lower zinc levels (30 mg/kg) can reduce the shear force in breast muscle, leading to a more tender, juicy meat texture (Shao et al., 2023). Inadequate micronutrient intake can negatively impact carcass traits, including eviscerated weight and breast muscle weight (Zhang et al., 2024). Dietary structure also impacts pigeon meat quality. Compared to complete-formula granulated feed (**CFG**), a whole grain plus granulated feed diet has been shown to enhance the b* color value of breast muscle potentially improving the odor and appearance of the meat by reducing lipid peroxidation (Zhang et al., 2022). Additionally, a mixed feeding approach combining corn and pelleted feed increases the redness and yellowness of breast meat and enhances muscular antioxidant capacity (Liu et al., 2023). A feeding strategy incorporating whole grains, such as corn, pea, and wheat, with pelleted feed, can increase both essential and non-essential amino acids in breast meat, positively influencing flavor and nutritional value (Liu et al., 2023). Moreover, natural feed additives can further improve pigeon productivity. For instance, supplementing breeder pigeons' diets with 200-400 mg/kg of tea polyphenols reduces the feed-to-meat ratio and enhances feed utilization by improving intestinal function (Chen et al., 2023). Although substantial research has been conducted on dietary factors impacting squab meat quality, further investigation is still required. Specifically, studies focusing on the effects of specific feed components, such as protein and lipids, and the optimal feed component ratios for enhancing meat quality and flavor require further investigation and refinement.

Stocking density

To reduce economic costs associated with increased space requirements in production systems, high-density conditions are commonly used in conventional poultry farming. However, excessively high stocking densities can negatively impact poultry production, health, and welfare. More importantly, they can affect carcass composition and meat quality (Weimer et al., 2022). Unlike other poultry, 28-day-old squabs reach nearly the same body size as adult pigeons. Additionally, pigeons are natural fliers, and regular exercise has been shown to enhance the antioxidant system and immune function in animals (Ruzicic et al., 2016). Previous studies have reported that housing breeder pigeons in cages or under high-density conditions induces stress responses, evidenced by increased relative organ weights, such as liver and abdominal fat, potentially altering lipid and ion metabolism (Xie et al., 2023). Furthermore, high-density conditions decrease the antioxidant capacity of the breast muscle and liver (Xie et al., 2023). These effects can lead to several adverse events. For instance, overcrowding in pigeons induces stress, which leads to the mobilization of muscle glycogen, resulting in a higher ultimate pH in post-mortem muscle. This, in turn, affects the oxygen penetration into the meat surface, leading to a larger layer of metmyoglobin and a smaller layer of oxymyoglobin in the muscle profile. The shift in the relative amounts of metmyoglobin and oxymyoglobin contributes to darker meat in high pH (low muscle glucose) conditions. Fats and proteins in the meat may also oxidize, forming unpleasant flavor compounds such as aldehydes and ketones, which degrade meat flavor. Oxidation can also cause protein cross-linking within muscle fibers, resulting in stiffness and decreased tenderness (Estevez, 2015; Estevez & Luna, 2017). Reduced liver antioxidant capacity may allow toxin accumulation, compromising meat safety (Beg et al., 2011). Abnormal fat metabolism can cause fat content in the meat to become excessively high or low, impacting both taste and nutritional value. Additionally, protein synthesis may be disrupted, affecting both protein content and quality (Yang et al., 2023). As a result, many producers believe that providing sufficient space for flight and exercise supports optimal reproductive performance, while limited cage space is detrimental to bird development during the breeding period. It is essential to balance feeding costs, stocking density, and overall benefits to maintain meat quality and animal welfare.

Storage condition of post-mortem pigeon meat

Pigeon meat contains higher levels of polyunsaturated fatty acids and essential amino acids when compared to other meats (such as chicken, pork, beef, and lamb) (Chang et al., 2017). However, these attributes also make pigeon meat more susceptible to deterioration in qualities such as color, texture and aroma over time. Various storage factors including temperature, humidity, oxygen concentration, light exposure, and storage duration can significantly impact the freshness and quality of pigeon meat. Inadequate preservation techniques can accelerate the oxidation of proteins and lipids reducing the meat's edibility and quality (Ren et al., 2022). Several preservation methods have been developed to inhibit oxidation, including electrostatic field (**EF**), electron beam irradiation (**EBI**), and modified atmosphere packaging (**MAP**) (Tong et al., 2024b). Low voltage electrostatic field (**LVEF**) is commonly applied to assist in freezing or thawing meat products, effectively shortening thawing times while protecting muscle microstructures (Qian et al., 2019). LVEF (1.20 kV/m) has been shown to help stabilize meat color, reduce water loss, and limit protein oxidation by inhibiting increases in carbonyl concentrations and decreasing sulfhydryl concentrations in pigeon meat (Tong et al., 2024b). Additionally, physical preservation methods impact volatile organic compounds and bacterial communities in pigeon breast meat. For instance, MAP and EBI treatments can extend the shelf life of pigeon breast meat to 10 and 15 days, respectively, by increasing the abundance of *Lactococcus spp.* and *Psychrobacter spp.*, which contributes to stabilizing the meat's aroma (Tong et al., 2024a). Ca^{2+} and myoglobin also play crucial roles in maintaining meat quality in pigeon post-slaughter. Under physiological conditions, Ca^{2+} is stored in the mitochondria and endoplasmic reticulum, but it is released after death. This release induces minor structural changes through nonspecific Ca^{2+} binding, slightly decreasing the thermal stability of pigeon myoglobin and ultimately impacting meat color and oxidative rancidity (Ragucci et al., 2021). To preserve the freshness and flavor of pigeon meat, it is advisable to store it at low temperatures with optimal humidity, minimal oxygen exposure, reduced light exposure, and limited storage time. Reducing stress before and after slaughter can also help improve meat quality. Furthermore, the accumulation of bacterial metabolites and volatile organic compounds (**VOCs**) can lead to meat spoilage. Tong et al. (Tong et al., 2024a) identified butanal as a prominent VOC and key contributor to aroma variations across different preservation methods, with compounds such as alpha-terpinolene, acetoin-M, gamma-butyrolactone, 1-hexanol-M, and 2,6-dimethyl-4-heptanone emerging as potential markers of spoilage in pigeon breast meat. These indicators provide a reference for monitoring the freshness of raw pigeon meat during transport and storage.

Cooking methods

Culinary traditions across cultures have led to diverse methods of preparing pigeon dishes. For example, roasted pigeon is widely popular, particularly in Asian countries, for its rich and distinctive aroma (Liu et al., 2024). Similarly, braised squabs are a renowned Cantonese delicacy, famous for their crispy exterior and tender interior (Zhao et al., 2022). While the number of muscle fibers is determined at birth in both mammals and birds (Rehfeldt et al., 1999), different cooking techniques can significantly impact the physicochemical properties of meat. Compared with raw and fried meat, braised squab exhibits significantly higher crude protein content, pH value, muscle fiber diameter, hardness, elasticity, and chewiness (Zhao et al., 2022). These changes are largely due to the effects of cooking temperature, time, and seasoning on the transformation of various flavor compounds. Studies have shown that lipid oxidation contributes to the formation of several aromatic compounds (Benet et al., 2016; Frank et al., 2017). Both marinating and frying influence the flavor profile of pigeon meat with an increase in volatile compounds primarily resulting from the Maillard reaction during the heat-processing stages of marinating and frying. The main volatile aroma components in braised pigeon include benzaldehyde, phenylacetaldehyde, and octanaldehyde (Qian et al., 2020). A study examining the formation of aroma compounds and lipids during circulating non-fried roasting of pigeon identified 18 key aroma compounds, including 5-methyl-2, 3-diethylpyrazinechemometric. Additionally, nine lipid biomarkers, including PA (P-20:0/22:4 (7Z,10Z,13Z,16Z)) and LPC (16:0-SN1) were identified, which could characterize roasted pigeon within 50 min of cooking (Liu et al., 2024). Other cooking methods, such as marinating and high-pressure braising, may also produce distinct flavor compounds and warrant further investigation to understand their impact on the flavor profile of pigeon meat.

Genetic factors affecting meat quality traits of pigeons

Pigeon meat quality is influenced by various genetic factors, including breed, sex, age, and specific genes associated with meat quality. Considering these factors in breeding programs is essential to produce pigeons with superior meat quality.

Breed

Breed is a crucial factor that impacts pigeon meat quality. Variations in genetic characteristics, muscle types, and protein and fat content among different pigeon breeds directly influence meat quality. Historically, carrier pigeons were primarily used for message delivery, while meat pigeons have been bred for over 40 years. The American King Pigeon, the world's first improved meat pigeon breed, significantly contributed to the rapid expansion of pigeon breeding (Ashraful, 2021). Compared to carrier pigeons which are adapted for flight, King pigeons bred for meat have breast muscles with lower water content but higher protein, fat, and collagen levels. Their leg muscles also have less water and protein but more fat, while their breast muscles exhibit greater electrical conductivity, lightness, yellowness, chroma, and hue (Kokoszynski et al., 2020).

Research indicates that the meat quality of certain local Chinese pigeon breeds surpasses that of the White King pigeon. For instance, the breast muscle of Taihu, Shiqi, Tarim, and Boot pigeons displays a darker color, superior water retention, higher protein and inosine levels, a higher proportion of essential amino acids, and a lower saturated fatty acid content (including lauric, palmitic, eicosanoic, and behenic acids) than that of White King pigeons. Taihu pigeons, in particular, have the highest protein content, monounsaturated fatty acids, and eicosapentaenoic acid levels (Chang et al., 2023). Inosinic acid, a nucleotide derivative of hypoxanthine, is another key factor influencing meat quality. It impacts water-holding capacity, physical properties, and sensory attributes, making it integral to the flavor profile of meat. Globally, inosinic acid is widely recognized as a reliable indicator of meat freshness (Wang et al., 2021). Shiqi squabs exhibit higher intramuscular fat (**IMF**) and a lower shear force than White King squabs with a favorable fatty acid profile showing higher ratios of polyunsaturated to saturated fatty acids and a greater sum of omega-6 fatty acids. Candidate genes, such as *FABP3* (fatty acid binding protein 3) and *CAPN2* (calpain-2) are promising targets for selecting squabs with increased IMF, tenderness, and a more desirable fatty acid composition (Ye et al., 2018). Each pigeon breed also possesses distinct genetic characteristics and physiological structures, which influence meat flavor. Studies using Gas chromatography-mass spectrometry (**GC–MS**) and Gas chromatography-ion mobility spectrometry (**GC-IMS**) have shown that the variety and concentration of volatile flavor compounds are richer in Liangtian King pigeon soup than in soups made from the American ground king, Dabao, and Shiqi pigeons (Jiang et al., 2022). Zhang et al. (Chang et al., 2023) found that meat from Chinese local pigeon breeds, including Taihu, Shiqi, Tarim, and Boot pigeons, possess a higher inosine content than that of White King pigeons, enhancing flavor and consumer appeal. Additionally, Li et al. (Li et al., 2023) found that Shiqi pigeons have a higher myofiber density and a greater number of myofibers with diameters in the range of 50-100 μm when compared to the European meat pigeon Mimas strain at embryonic day 6 and day 1 post-birth. RNA-seq analysis and RT-qPCR identified myogenic differentiation (***MYOD***), myogenic factor 6 (***MYF6***), prostaglandin-endoperoxide synthase 1 (***PTGS1***), myogenic factor 5 (***MYF5***), myosin heavy chain 1 (***MYH1***), myostatin (***MSTN***), and peroxisome proliferators-activated receptors (***PPARG***) as candidate genes crucial for embryonic muscle development (Li et al., 2023).

Table 1
Genes associated with meat quality attributes in pigeons.

Gene Symbol	Function	Study Model or Breeds	Technology Used for Identification	Refs
DES	Promotes muscle structure and cell integrity	Shiqi pigeon,	RNA-seq	(Li et al., 2023)
MYOD	Converts non-muscle cells into skeletal muscle cells	European meat pigeon	RT-qPCR	
MYF6	Establishes ligand/receptor interactions between muscle stem cells and their associated muscle fibers	Mimas strain		
PTGS1	Higher muscle fiber density			
MYF5	Directs progenitor cells to establish skeletal muscle lineages			
MYH1	Associated with skeletal muscle contraction			
MSTN	A negative regulator of skeletal muscle growth and development Inhibits myoblast proliferation			
PPARG8	Performs muscle repair and promotes muscle stem cell function			
LPL, FABP4, CAPN2, FABP3	Used for targeted selection of young pigeons with higher intramuscular fat content, tender meat, and a more favorable fatty acid composition	Shiqi meat-type pigeon, white king meat-type pigeon	qRT-PCR	(Ye et al., 2018)
PPARγ, FAS, LPL	More remarkable ability to generate fat	*Columba livia*	qRT-PCR	(Dai et al., 2024)
UBE2B	One of the E2 ubiquitin-coupled enzymes that is essential for muscle protein homeostasis under catabolic conditions	White-King pigeon	RNA-seq	(Luo et al., 2022)
Pax7	Controls the expansion and differentiation of satellite cells during muscle formation			
AGTR2	Related to muscle fiber composition, exercise state, and aerobic exercise performance			
HDAC1	Regulates the transcriptional activity of MyoD and affects myogenic program			
Sox8	Negatively regulate skeletal muscle differentiation and inhibit myogenesis			
TCONS_00066712, TCONS_00026594, TCONS_00001557, TCONS_00001553, TCONS_00003307	Skeletal muscle development is regulated by the cell cycle pathway	White-King pigeon	High-throughput sequencing technology	(Zhang et al., 2021)
Abca8b, TCONS−00004461, VWF, OGDH, TGIF1, DKK3, Gfpt1, RFC5	Essential mRNA regulating skeletal muscle growth and development in pigeon	Tari pigeon	RNA−seq, qRT - PCR	(Ding et al., 2021)
KIF1C	Reshapes the extracellular matrix and influences the differentiation of muscle cells			
MYPN	Promotes skeletal muscle growth by activating the serum response factor (SRF) pathway in muscle			
DKK3	Renal tubulointerstitial fibrosis is induced by its action on the typical Wnt/β-catenin signaling pathway			
tropomyosin beta chain, myosin regulatory light chain 2, and myosin binding protein C	Potentially implicated in breast muscle development	Yuzhong pigeons and European meat pigeons	Iso-seq and RNA-seq	(Yang et al., 2024)
DGAT2	AA genotype had the highest value of carcass traits, and BB genotype had better meat quality	*Columba livia*	Association analysis of SNPs by DNA direct sequencing	(Mao et al., 2018b)
ADSL	For the C13065G SNP located in exon11, the IMP content of breast muscle in the AA and AB genotypes was higher than in the BB genotype	*Columba livia*	Association analysis of SNPs by DNA direct sequencing	(Mao et al., 2018a)
MyoD1	The mutations A2967G and G3044A were significantly associated with meat quality traits in pigeon	*Columba livia*	Association analysis of SNPs by DNA direct sequencing	(Dong et al., 2019)
H-FABP	SNP g.3313A>G, the AA genotypes showed high inosinic acid concentrations, intramuscular fat content, and the relative mRNA expression level	*Columba livia*	Association analysis of SNPs by DNA direct sequencing	(Mao et al., 2021)
FABP1	The SNP of G161C and SNP C1376T were associated with inosine acid and intramuscular fat content, respectively	*Columba livia*	Association analysis of SNPs by DNA direct sequencing	(Mao et al., 2020)
ACAA1(S357N), ACAA2(T234I), and ACACB (H1418N)	Screen squabs with the best intramuscular fat content and fatty acid spectrum in the breast muscles	Shiqi pigeon, White King pigeon	Association analysis of SNPs by DNA direct sequencing	(Yuan et al., 2023)
MYH7, FITM2, IRS2B, CD1D, CAMK1D, COL4A6, SCUB1, FABP3, MCM3, CYP3A28, CLPS, ACOX2, GFPT2, CCNB2, CX3C, ACAP3	Involved in muscle growth and lipid metabolism	*Columba livia*	RNA-Seq, qPCR	(Yin et al., 2022)

Sex

Sex-related differences exist in several meat quality indicators in pigeons. Variations in muscle growth rate, fat content, and muscle fiber characteristics between male and female pigeons can influence the tenderness, juiciness, and taste of the meat. In white king squabs, female breast muscles exhibit greater tenderness when compared to males, with lower shear force. This may be attributed higher intramuscular fat deposition, smaller myofiber diameter, lower hydroxyproline content, and elevated monounsaturated fatty acid levels in female squabs (Dai et al., 2024). Conversely, male white king squabs tend to have breast muscles with higher nutritional value, containing greater proportions of n-6 and n-3 polyunsaturated fatty acids, as well as higher levels inosine 5′-monophosphate and essential, free, and sweet-tasting amino acids (Dai et al., 2024). Similarly, in adult Columbia green pigeons, sex differences affect meat quality, with male meat showing higher crude fat content and female meat possessing a higher nitrogen-free extract. Male pigeon meat also scores higher in organoleptic properties, such as color, flavor, tenderness, juiciness, and texture, when compared to female pigeon meat (Apata et al., 2015).

Age

The growth and development of different muscle tissues in pigeons (*Columba livia*) exhibit distinct patterns. For instance, breast meat yield steadily increases from days 1 to 28, while leg meat yield peaks around day 14. As pigeons age, the physiological functions of various organs, serum profiles, and nutrient transport mechanisms in the small intestine also undergo dynamic changes (Gao et al., 2016). These factors can indirectly influence the nutritional composition and quality of pigeon meat. Each age stage brings unique characteristics to pigeon meat, making age-related variations an important consideration when evaluating meat quality and composition. Previous research has shown that pigeon age significantly impacts carcass composition, physicochemical properties, meat texture and microstructure (Wlodarczyk et al., 2024). For example, among Liangtian king pigeons of different ages (18 days, 28 days, and 4 years), the soup from 28-day-old pigeons contained higher levels of volatile flavor compounds (Jiang et al., 2022).

Candidate genes

The candidate genes discussed here play significant roles in shaping the overall quality and sensory attributes of pigeon meat (Table 1).

Candidate genes involved in skeletal muscle traits

Skeletal muscle plays a crucial role in determining meat quality, particularly in terms of tenderness, taste, and nutritional value. Well-developed skeletal muscle suggests higher levels of pigeon activity, which enhances muscle fiber delicacy and elasticity, resulting in more tender meat. The fine structure of pigeon muscle fibers contributes to its tenderness, making it easy to chew and digest. Additionally, skeletal muscle is a primary protein source in pigeons; therefore, its development level may significantly influence the nutritional value of pigeon meat. Luo *et al.* (Luo et al., 2022) discovered that certain long non-coding RNAs (**lncRNAs**) and messenger RNAs (**mRNAs**) are vital for muscle growth. Specifically, differentially expressed lncRNAs—such as lncRNA-LOC102093252, lncRNA-G12653, lncRNA-LOC110357465, lncRNA-G14790, and lncRNA-LOC110360188—potentially target genes like ubiquitin conjugating enzyme E2B (***UBE2B***), paired box 7 (***Pax7***), angiotensin II receptor type 2 (***AGTR2***), histone deacetylase 1 (***HDAC1***), and sex determining region Y-box transcription factor 8 (***Sox8***), which may contribute to muscle development in White-King pigeons. Additionally, lncRNA TCONS_00026594 is suggested to regulate the Facioscapulohumeral muscular dystrophy region gene 1 (***FRG1***) and the SRC pro-to-oncogene, non-receptor tyrosine kinase (**SRC**) by sponging cli-miR-1a-3p, thereby influencing skeletal muscle development in White-King pigeons (Zhang et al., 2021). Other candidate genes identified for regulating skeletal muscle growth and development in pigeons include ATP binding cassette subfamily a member 8 (***Abca8b***), *TCONS−00004461*, von willebrand factor (***VWF***), oxoglutarate dehydrogenase (***OGDH***), TGF beta induced factor homeobox 1 (***TGIF1***), dickkopf WNT signaling pathway inhibitor 3 (***DKK3***), glutamine-fructose-6-phosphate transaminase 1 (***Gfpt1***) and replication factor C subunit 5 (***RFC5***) (Ding et al., 2021). Furthermore, Yang et al. reported that the breast muscle ratio of Yuzhong pigeons was 25.24 ± 4.00 %, indicating a higher proportion when compared to European meat pigeons, which averaged 22.83 ± 2.63 % (Yang et al., 2024). By analyzing Iso-seq and RNA-seq data from domestic Yuzhong pigeons and European meat pigeons, they identified several genes potentially involved in breast muscle development, including tropomyosin beta chain, myosin regulatory light chain 2, and myosin binding protein C (Yang et al., 2024). These findings enhance our understanding of the molecular mechanisms driving skeletal muscle growth in pigeons, offering valuable insights for the pigeon breeding industry.

Candidate genes affecting fat traits

IMF is a combination of lipids deposited in muscle tissue through extracellular uptake and *de novo* fatty acid synthesis, and it is widely recognized as a key factor in enhancing poultry meat quality, contributing to flavor and juiciness. Currently, it is commonly accepted among researchers that higher IMF content improves the flavor of poultry meat (Cui et al., 2024). Various factors influence IMF content, including nutrition, environment, feeding methods, and genetic factors. Fatty acid-binding proteins (***FABP***), a family of intracellular proteins, play an essential role in lipid metabolism and intracellular lipid transport. *FABP1*, in particular, has been identified as a potential candidate gene for marker-assisted breeding to produce high-quality meat pigeons. Studies examining single nucleotide polymorphisms (**SNPs**) and their associations with the meat quality traits of the *FABP1* gene in pigeons have shown that the BB genotype for SNPs G161C and C1376T correlates with higher IMF levels and increased *FABP1* mRNA expression in breast muscle; In the SNP G161C, the BB genotype displayed significantly higher (2.41 vs 2.24 and 2.08, $P < 0.01$) intramuscular fat than genotype AA and AB; In the SNP C1376T, the BB and AB genotypes showed significantly higher (2.31 and 2.35 vs 2.04, $P < 0.01$) intramuscular fat than the AA genotype. (Mao et al., 2020). Additionally, analysis of the SNP g.3313A>G in heart-type *FABP* (*H-FABP*) revealed that pigeons with the AA genotype exhibited the highest IMF content and the greatest relative *H-FABP* mRNA expression level when compared to those with AB and BB genotypes, suggesting that *H-FABP* may also serve as a candidate gene for high-quality meat production in pigeons (Mao et al., 2021). Diacylglycerol acyltransferase 2 (***DGAT2***), an enzyme catalyzing the final step in triglyceride synthesis, shows the highest expression levels in subcutaneous fat during the early growth phase (0–4 weeks) compared to other tissues. Correlation analysis has demonstrated a significant association between *DGAT2* mRNA expression in pigeons and IMF content in breast muscle (Mao et al., 2022). Moreover, in the G22484C SNP in *DGTA2*, the breast muscle weight in AA genotypes was higher than that of the AB and BB genotypes by 12 and 9.8 g, respectively; In the G18398T SNP in *DGTA2*, pigeons with AA and AB genotype showed higher abdominal fat weight and abdominal fat rate than those with BB genotype (Mao et al., 2018b). Myogenic differentiation 1 (***MyoD1***), a member of the *MyoD* family involved in myogenesis, is integral to defining muscle fiber characteristics. Mutations A2967G and G3044A in the *MyoD1* gene have been significantly associated with meat quality traits in pigeons (*Columba livia*). For example, AA and AB genotype pigeons had higher inosinic acid concentrations in the breast muscle (0.15 mg/g), and increased IMF content by 0.21 % and 0.26 %, respectively (Dong et al., 2019).

Future perspectives

Recent advancements in pigeon meat quality research have significantly supported the sustainable development of the pigeon industry and responded to growing consumer demand for healthful products. These advancements point to a promising future in technological innovation, breed improvement, nutrition management, and other critical areas. Genetic breeding innovations, for example, are set to enhance and refine pigeon breeds. With the rapid development of biotechnologies such as gene editing and genomics, researchers can further analyze the molecular mechanisms underlying meat quality traits and breed new varieties with improved meat characteristics. For example, double digest restriction site-associated DNA (**ddRAD**) sequencing is another valuable technology that reduces genome complexity and enables the rapid identification of thousands of SNPs, producing high-density genotyping datasets. Previous research using ddRAD sequencing identified SNPs in the genomes of Shiqi squabs and White King squabs, pinpointing functional genes influencing fat-related meat traits in breeders (Yuan et al., 2023). Genomic analyses have also uncovered selection regions within commercial meat pigeons (Euro-pigeons) when compared to traditional Chinese ornamental pigeons (Silver King pigeons) (Hou et al., 2021). Additionally, transcriptome sequencing and differential expression analyses have clarified the molecular basis of phenotypic differences in pectoral muscle between commercial meat pigeons and traditional ornamental pigeons, with multiomics revealing several genes related to cell differentiation, muscle development, and skeletal muscle function. Such insights aid in understanding genomic imprinting in various pigeon breeds resulting from artificial selection. Moreover, identifying differentially expressed functional genes between high and low IMF squabs provides DNA markers that can predict IMF storage potential in squabs (Ye et al., 2016). In the future, pigeon meat quality research will likely continue to advance across multiple fronts, including genetic breeding, feeding management, nutritional regulation, health-focused breeding, and strategies for disease prevention and control. This progress will drive the transformation and sustainable growth of the pigeon industry, enabling it to meet evolving consumer demands while maintaining high standards of quality and sustainability.

Conclusions

This article presents a comprehensive overview of the advancements in understanding the factors influencing pigeon meat quality. These include the non-genetic factors such as feed composition, stocking density, storage condition, and cooking methods, as well as genetic factors like breed, age, and sex. Additionally, the discussion highlights numerous genes associated with key pigeon meat quality traits, including *Abca8b, VWF, OGDH, TGIF1, DKK3, Gfpt1*, and *RFC5* which are involved in skeletal muscle development, and *FABP1, H-FABP*, and *DGAT2* which influence intramuscular fat content. These findings highlight the importance of gaining a comprehensive and in-depth understanding of the mechanisms underlying these factors, and studying their interactions is critical for providing a scientific foundation for the optimization and advancement of the meat pigeon industry. This progress is essential to meet the global demand for high-quality protein and while addressing the challenges posed by rising costs and the need for superior meat quality. Modern animal husbandry continues to evolve, offering innovative solutions to meet these demands and support the implementation of the "One Health" concept in food-producing animals (Farschtschi et al., 2022).

Author contributions

Xinwei Xiong: Conceptualization, Funding acquisition, Project administration, Resources, Writing - review & editing. **Yuehang Lan and Qin He:** Writing - original draft, Writing - review & editing. **Bahareldin Ali Abdalla Gibril, Jiguo Xu**, and **Hanle Shang:** Writing - review & editing. All authors read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no conflicts of interest.

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