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Review

Evaluation of the Factors Contributing to Broiler Meat and Functional Quality a Systemic Review

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Abstract: In South Africa, the poultry sector is industry is essential because it promotes equitable, sustainable economic growth and employment creation. Chicken meat is often preferred for further processing, especially in regions where pork consumption is limited due to cultural or dietary reasons. Literature databases such as Web of Science and Scopus databases while the Google search engine from 1982-2024 were used. The PRISMA method was adopted, where 104 articles met the criteria for this review article after several exclusion criteria. Several factors can affect poultry meat quality properties causing significant differences in meat and functional quality. These include agro-ecological zone, sex, season, production system, age, strain, and diet. Commercially, the price of poultry meat depends on the overall product quality presented to the consumer. While meat processors focus on the technological meat quality properties, consumers are more invested in the nutritional and sensory quality. Literature indicates that female broilers (1.5 kg) are preferred for rotisserie chicken over heavy size (3.5 kg) male broilers, which are used for processed products. Literature also suggests that there can be sex variability in carcass yield and colour, with females exhibiting a higher yellowness index b* (3.55) compared to males (2.30). Comparable results were observed in female broiler chicken's yellowness index shows b* (3.57) compared to males b* (2.42). Male broiler chickens have been observed to present lower lipid content (6.8–9.1 g/100 g) than female broiler chickens (7.1–11.8 g/100g). In corroboration, others have cited that female chickens have lower moisture and fat content than males. Age is also important, as the haem pigments increase with aging, the meat colour becomes redder (a*) and less light (L*) in appearance. Production system, season and agro-ecological zone influence animal stress and can alter animal glycolytic potential and post-mortem pH. This review gives insight into the factors that contribute to a successful broiler enterprise.

Keywords: Broiler, Chickens, Carcass, Meat Quality

Introduction

Poultry production is essential to attaining the Sustainable Development Goals (SDGs) in South Africa because it promotes food security and equitable economic growth(Erdin and Ozkaya, 2020; Ramukhithi *et al.*, 2023). South Africa is a leading poultry producer in Africa (18.73%) followed by Egypt (13.39%), Morocco (8.21%), and Nigeria (2.38%) (Nkukwana, 2019). The South African local poultry industry is segmented into varied production systems to accommodate the different socio-economic groups. This is categorized into three productions namely, commercial scale with above 50 000 birds, subsistence scale equal (20 001–50 000 birds), and small-scale less than 20 000 birds (Ramukhithi *et al.*, 2023). Small-scale broiler chickens farming makes up to 25% of the poor farming communities (Mdletshe and Obi, 2023). The commercial broiler chicken producers trade their products through formally registered abattoirs, thereby dominating the larger market space (Queenan *et al*., 2022). Whereas small-scale broiler farmers thrive on the informal broiler markets. Currently, consumption of poultry products in South Africa supersedes the production rate creating the demand for imports into the country mainly from the European Union (EU) (46.3%), Brazil (46.1%), and United States (3.9%), SARS, 2022).This in turn has created the compulsion of increased tariffs and anti-dumping duties to address the large difference between the landed prices (R11/kg) of import chickens vs. the sale price (R50/kg) of domestically produced chickens (Ncobela, 2021).The cost of feed is one key driver for the vast difference in prices. Feed accounts for 70% of the industry's variable costs. Lead exporters such as Brazil and the United States are believed to produce at a lower cost than South Africa, owing to them having lower feed costs (Ncobela,2021).This, consequently, negatively affects local production's competitiveness and sustainability in comparison to imported products.

Poultry production provides a reliable source of high-quality protein and an excellent meat choice for further processing; especially in areas where pork is not consumed (Louw *et al*., 2013). Despite chicken meat having a similar cholesterol content (85g/100g) to that of red meat (84g/100g); its benefits supersede that from red meat for some nutrients. For instance, in comparison to other meat types, chicken contains more protein (27.60–31.02%) than beef (20.67–27.23%), lamb (22.16–28.0%) and pork (28.86%). In addition, chicken offers less fat (0.69–3.57%) compared to beef (0.81–7.63%), lamb (2.99–6.67%) and pork (4.62%), respectively (Kralik *et al*., 2018a; Yaranoglu *et al*., 2023). All these benefits make chicken a healthier lean product choice, especially for people suffering from heart and coronary diseases. In terms of meat pricing for 2015, broiler meat was the most affordable costing (R50/kg) way less than beef (R65/kg), pork (R72/kg) and mutton (R114/kg) (Ncobela, 2021). This trend in pricing difference persists with the increase in food pricing. Therefore, broiler meat stands out to be inexpensive consumed meat types.

For any poultry enterprise to thrive, a detailed insight of all the factors that affect the broiler meat as well as functional quality must be understood (Baéza *et al*., 2022). In essence, the profitability of any business enterprise is determined by the relationship between the value of the product produced and its resource costing. It is, therefore, important to understand what terms

define chicken meat quality to every end-user along the poultry meat value-chain. In brief, Meat quality is determined by its composition (muscle area, meat percentage, intramuscular fat, skin, and protein), functional quality (water holding capacity, pH, drip loss, and cooking loss), and eating quality (as judged by the consumer) (Sako *et al*., 2022). This eating quality is based on appearance, odour, texture, juiciness, tenderness, and flavour (Marchewka *et al*., 2023). Several factors can affect poultry meat quality, such as agro-ecological zone, sex, season, production system, age, strain, diet and genotypes (Sirri *et al*., 2011). Such factors can alter the overall nutritional content, ultimate pH, muscle colour, shear force, drip loss, yield intramuscular fat and eating quality. This review, therefore, aims to highlight insights on factors contributing to broiler meat quality and its functional properties.

Methods

This systematic review it aims was to highlight the current literature on factors contributing to broiler meat and functionality quality. The information in this review was gathered, assessed, and exploited from the Web of Science and Scopus databases while the Google search engine was used to obtain information on popular articles and retraction was made on articles published between 1982-2024. To reduce bias and guarantee accuracy in research inclusion, the study selection process for this review included a dual-reviewer screening approach at both the title and abstract stage and full-text review screening stage. The titles and abstracts of every record found using the comprehensive search strategy were first evaluated by two independent reviewers in accordance with the predetermined eligibility criteria specified in the study protocol.

The decision to include, remove, or mark records as "maybe" (where eligibility was unclear) was determined separately by each reviewer. The reviewers' disagreements were settled by discussion and consensus. Records that either reviewer indicated as "maybe" were moved on to the full-text review phase. All potentially relevant publications (those included or marked as "maybe") were screened for titles and abstracts before their full texts were acquired. The two reviewers carefully applied the eligibility criteria while going over the full texts. Once more, each reviewer made an individual decision about whether a study should be included or excluded, noting the grounds behind their decision. Discussion and agreement were used to settle discrepancies. The reasons for excluding articles were documented and reported in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow diagram for a structured review (Figure 1). The remaining articles were downloaded and exported to the Mendeley desktop application where duplicates were removed. The final set contained 104 relevant papers (29) from the Web of Science, (56) from Scopus, and (19) articles from Google.

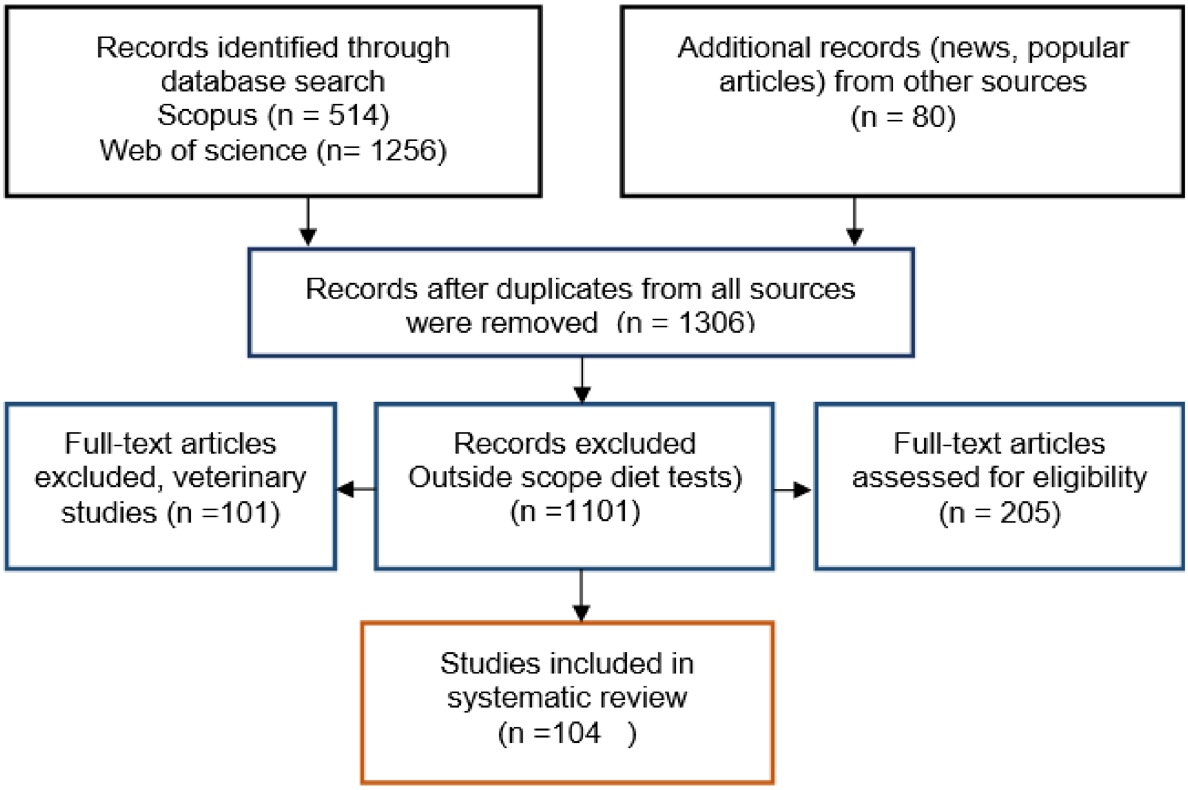

Fig. 1: The preferred reporting items for systematic reviews and Meta-analyses (PRISMA) flow diagram

Literature Search

All articles concerning Carcass composition and meat quality were gathered using an online database search

Exclusion and Inclusion Criteria

Study Design: Experimental studies and potentially observational studies if relevant.

Population: Broiler chickens (*Gallus gallus domesticus*).

Intervention: Factors affecting meat quality, including dietary factors (feed ingredients, nutrient levels, additives), management practices (housing, environment, vaccination), genetic factors (breeds/strains), and processing methods.

Outcomes: Meat quality parameters (composition, physicochemical properties, sensory attributes, nutritional value).

Language: Potentially limited to English or include other languages if translation is feasible.

Exclusion Criteria

Study Design: Review articles, case studies/reports, and studies with inadequate methodology.

Population: Other poultry species and non-broiler chickens.

Intervention: Irrelevant interventions and interventions not clearly defined.

Outcomes: Irrelevant outcomes and incomplete data.

Publication Type: Abstracts only and potentially books/book chapters.

This review gathered, analysed, and employed data from the Web of Science and Scopus databases while the Google search engine was used to obtain information on popular articles.

Extraction was made on articles published between 1982 and 2024. The search keywords from the title, abstract and subject descriptors contained "Broiler chicken meat quality". "AND" was used to obtain all possible alternative combinations of selected keywords to include "in South Africa", "at retail", "inspection", "defects", "in live markets", "for processors", "broiler muscle", "skin", "bone", "colour", "pH", "WHC", "drip loss", "cooking loss", "protein", "fat", "moisture", "ash", "dry matter", "strain effect", "age at slaughter", "rearing condition", "sex", "season", and "agro-ecological zone". Literature that focused on veterinary studies and dietary experiments on test feeds, experimental supplements and/or plant extracts, molecular work, and gene expression were removed except if they dealt with factors affecting meat quality and quality-related parameters and in all these databases".

The records found while writing this review included 1770 articles and one database. The quantitative assessment gave preference to research that were randomised experiments. The qualitative assessment was used to choose studies that met two criteria:

(1) Studies with specific objectives for research relevant to the current review
(2) Studies that provided adequate information about the context, sample selection, and data collection procedures. Moreover, 104 articles were considered for this review

Results and Discussion

Overview of South Africa's Poultry Industry

The poultry sector contributes adds to the economy through the ample job opportunities it promotes job creation in local areas, hence alleviating poverty. Broiler production systems range from subsistence farming to intensive innovative globally competitive enterprises that take up at least 70% of total farming space (Louw *et al*., 2017). Commercial birds are intensively raised straight-run, as mixed male and female chicks. The poultry industry is categorised by the broiler and egg production sectors (Ncobela, 2021). The broiler market is more susceptible to import competition since the meat products can be kept frozen for extended periods, while the more perishable eggs have a limited marketing shelf life (Ncobela, 2021). Poultry genetic material is externally sourced into South Africa since only large corporations can afford to run the breeding programmes. The Cobb 500 and Ross 308 represent the primary genetic stock followed by the Acres, Arbor, Hubbard and Hydro breeds (Kpomasse *et al*., 2021). Domestic poultry production in South Africa is strained by unfair trade practices, which are continuously monitored and revised to protect both the local industry players and consumers at large. Despite these challenges, poultry consumption continues to rise exponentially indicating the vast growth potential of this particular industry.

Factors Affecting Broiler Chicken Meat Quality

Several factors influence the value of broiler chicken meat and its functional quality. Feed supply forms a major prime factor for broiler farmers, as it determines growth during the different production phases. Feed stock costs can take up 70–75% of a producer's total production cost (Kpomasse *et al*., 2021). Disease outbreaks threaten the success of poultry producers, upsetting the marketing and commerce of the entire sector. The impact of these major factors influences important poultry marketing standards, namely slaughter weight, carcass yield, and appearance (visual flaws, skin pigmentation, nicks, inflammation, wounds, fractures, bruising, and abscesses) (De Smit *et al*., 2005). Meat quality can vary depending on season, agro-ecological zone, slaughter age, strain, farming management system, sex, diet and slaughtering conditions. These factors play part in profitability of the broiler meat industry in particular is explored into further detail.

Agro-Ecological Zone

To improve broiler chicken production, environmental and nutritional management must be monitored. Agro-ecological zones variations in agro-ecological zones can impact soil fertility, vegetation, water abundance, and climate, which in turn may influence environmental conditions for feed production and management practices (Mpofu *et al*., 2017). Temperature stress alters the physiological and metabolic pathways, adversely impacting animal welfare during the growth and post-slaughter phases (Gonzalez-Rivas *et al.,* 2020). Broiler chicks lack sweat glands, making them more sensitive to high temperatures than monogastric animals (Brugaletta *et al.,* 2022; Nambapana and Jayasena, 2024). Excessively, hot temperatures impair the animal's body heat degeneracy stressing the animal, while extremely cold weather rise muscular shivering can quickly deplete pre-mortem glycogen levels (Poveda-Arteaga *et al.,* 2023). Environmental condition stress can manipulate broiler muscle pH and colour values inducing poor quality meat with high pH and DFD (dark, firm, dry) conditions.

Adversely, birds exposed to high thermal heat are more prone to developing Pale Soft Exudative (PSE) meat quality disorders (Alam *et al*., 2024).This PSE broiler meat is unattractive to consumers, and, therefore, unmarketable. Very low temperature environments presented broilers with significantly undesirable lower L*, a*, and b* colour scores and higher pH (Zhang *et al*., 2019). Shakeri *et al*. (2018) reported that hot temperatures impair normal lipid metabolism, or lipolysis, by downregulating the enzymes responsible for lipid breakdown, leading in increased fat accumulation and lower muscle protein content. This claim is supported by Zhang *et al*. (2014), who reported that broiler chickens reared at lower temperatures (34-36°C) demonstrated a drop in muscle protein content, breast muscle mass (31,53%), and thigh muscle (11,17%) as compared to normal temperatures. Similarly, Geraert *et al*. (1996) reported that hot conditions impair the broiler activity while extreme cold temperatures can induce higher energy requirements and a sedentary lifestyle. These, in turn, influence the weight gain of the broilers at any given time. In a recent study, it was observed that hot temperatures disrupt water-holding capacity increasing drip loss, cooking loss, shear force, lowering the pH at the same time (Nawaz *et al*., 2021). Acute stress prior to slaughter has shown a significant increase in drip loss and cooking loss in meat (Bulkaini *et al*., 2022).

Sex

Multiple researches have agreed that carcass and meat quality characteristics are intricately associated with the broiler sex type, male chickens carry a higher carcass yield (871–4 384 g) than females (690–2 895 g). Male broiler chickens are believed to efficiently consume more feed compared to females. Broiler sex type is a vital prime factor when rearing chickens under conventional conditions (Baéza *et al*., 2022). Separating females and males broiler chicken in farming gives three various market segments of chickens light-size (1.5 kg) for rotisserie-produced products, medium-size (2.5 kg) for cut-up products, and heavy-size broilers (3,5 kg) for processed products. Male broiler chickens yield heavier bone mass than female broilers (Müsse *et al*., 2022). Young *et al*. (2001) reported female carcasses had significantly higher skin yield for the breast, thigh and drumstick portions compared to male broilers. The high skin yield in female broiler chickens could be attributed to hormones. Darker meat colour was reported in the meat of female broiler chickens than to the meat of male broiler chickens (Ristic and Damme, 2013).Contrary, some authors reported similar meat colour between female and male broiler chickens (Panpipat *et al*., 2022). Literature indicates that male carcass yields lower colour values because of less fat accumulation. In additional male chickens are more aggressive behaviour around female broiler chickens. Therefore, it can be concluded that rearing separated sexes during transportation and lairage before slaughter will results in uniform meat colour in both male and female chicken.

Season

Seasonal variations can significantly affect broiler meat quality due to changes in environmental conditions (temperature, humidity and feed intake (Apalowo *et al*., 2024). Hot seasons can cause heat stress (PSE), reducing feed intake and growth rate (Vandana *et al*., 2021). Winter conditions can induce feed intake demand for thermoregulation, higher fat deposition, less protein (juicer, flavour meat) and slow metabolic adjustments (Zhou *et al*., 2021). Higher fat content mainly reduces the quality of broiler chickens meat (Habashy *et al.,* 2017). Disease susceptibility also fluctuates with seasonality (Quinteiro-Filho *et al*., 2012). Bogosavljevic-Boskovic *et al*., (2006) observed similar carcass yield of broiler chicken reared during the summer and spring seasons. Contrary to these findings, Bianchi *et al*., (2004) reported significant variations in muscle colour during different seasons. The high antemortem temperatures during the summer season were observed to influence the onset period of rigor mortis after meat quality (Çobanbaşi and Teke, 2022) . The broiler muscle during summer exhibited a higher L* (53.05) lightness index compared to autumn (52.79) and winter (51.31) and a lower yellowness index b* (3.25 vs. 3.34 and 3.93) for the same periods (Petracci *et al*., 2004). Similar result trends were observed by other authors, (Babji *et al*., 1982; Petracci and Cavani, 2012). In addition, the summer season accounts for significantly decreased pH, WHC, cooking loss, and better lightness (L*) values. Heat during summer months in small-holder broiler farming can be improved by implementing preventive measures and having a heat-stress response plan.

Age

Broiler haem pigments increase with aging, the meat colour becomes redder (a*) and less light (L*) in appearance (Mir *et al*., 2017; Wideman *et al*., 2016). A higher shear force in older animals associated with darker muscle colours, due to the more oxidative muscle fibres (Poveda-Arteaga *et al*., 2023).

Li *et al*. (2020) observed that older broiler chickens had heaver carcass yield and lesser L*, a*, b*, and pH values in muscle than younger broiler chickens. Young *et al*. (2001) indicated a direct relationship between broiler age and the meat cup-up. Literatures suggested that levels of myoglobin in muscle comparably rise with the greater natural animals age, thus exhibiting greater L* values (darker) of the meat of an older broiler chicken. A young broiler chickens resembles a low-level myoglobin muscle that positively influence in production of brighter fresh muscle. Mir *et al*. (2017) reported palatability traits decrease as carcass age increases. Li *et al*. (2020) reported variation among the different age groups of broiler chickens, the breast muscles on younger broiler chickens (days 60 and 90) had larger drip losses (3.93%) and (4.09%) when compared to the older broiler chickens reared in days 150 and 180. Furthermore, 180-day-old broilers had the greatest cooking loss values (23.28%), compared to those aged 60, 90, and 150 days of age. Furthermore, birds at 120, 150, and 180 days of age, had higher shear force values than those of 90-days ageing. These findings indicate that as broiler chickens get older the meat quality becomes less undesirable. Baéza *et al*. (2022) observed that chemical compositions and poly unsaturated fatty acids varies with animal age.

Genetic Strain

Cobb 500, Ross 308 and the Abor Acres are the most used strains in the poultry meat industry (Kpomasse *et al*., 2021).Commercial broiler chickens are characterized by white feathers, yellowish skin, and pinkish muscles. Cobb 500 has more composition, Ross 308 has higher breast yield, and Arbor Acres has good muscle development, especially in the breast (Figs. 2-3). As stated on by Hassan *et al*. (2021) commercial broiler meat varies with regards to functionality attributes specifically meat colour, pH and tenderness. Badar *et al*. (2021)reported that bird strain variations significantly influence cooking loss, drip loss, WHC, and colour. Sirri *et al*. (2011) observed slow-growing broiler genotypes (Abor Acres breed) had a higher leg yield, lower pH values, and poorer water holding capacity than the Ross 308 broiler chickens. These findings implicate that Ross 308 produces better functionality properties compared to Abor Acres. Therefore, it is advisable to broiler chicken's producers to farm with the fast-growing breeds given the better product quality specs.

(A) (B) (C)

Fig. 2: Different male broiler strain A: Cobb 500, B: Ross 308 and C: Arbor Acres

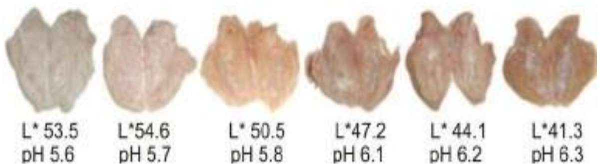

Fig. 3: Effect of pH of breast meat colour. Adopted from Oda *et al*. (2003)

Production System

Production and management systems significantly affect the broiler carcass yield as well as pre-post slaughter pH and meat colour. Literature suggests that consistent management plays an important role in sensory attributes specifically juiciness, tenderness, and flavour. However, a study by Souza *et al*. (2011) has observed variances in meat functionality quality between poultry meat reared from intensive and extensive production systems are mainly genetic in nature, while production environment is less important. Wang *et al*. (2009) found that the broiler chickens reared in free-range production systems yielded higher breast and thigh when birds were given outdoor access and kept at a lower stocking density. Minimum stocking density results in desirable cooking and drip loss, while the broiler chickens reared extensively increase WHC and reduce cooking loss (Marchewka *et al*., 2023). Literature suggests that leaner meat are related with lower stocking densities. This attribution might have been associated with intramuscular fat, that was lower for broiler chickens raised at a reduced stocking density. Confined broiler chickens with the use of growth promoter, *ad* libitum, and access to high feed energy accumulate higher fat content (Marchewka *et al*., 2023). Previous study has evaluated the combined impact of both bird genotype and type of production system on broiler meat quality (Cömert *et al*., 2016). This finding suggests that exposing broiler chickens to pasture was associated with a decline in fat concentration in breast, thigh and drumstick meat and a rise in protein content.

Diet

The diet of broiler chickens has a considerable influence on meat quality (Mir *et al*., 2017). Diet compositions may changeably influence a fresh muscle colour due to the type of feed ingredient fed to the chickens, which are strongly associated with fat deposition and meat protein content. A low-fat and carbohydrate-rich diets insignificantly influence sensory characteristics, interestingly, producing a low-fat carcass linked to tender and leaner meat (Vargas-Ramella *et al*., 2022). The high nutrient source specifically, protein unsaturated fatty acids, vitamins, macro and micronutrients, cholesterol, and other biologically active compounds results in high nutritional quality of poultry meat (Sokołowicz *et al*., 2016). A balanced commercial diet with a quality provided to chicken's increases growth rates which in turn consistently shorten the time to achieve commercial slaughter weight, therefore, increasing L* values in meat. Brink *et al*. (2022) observed that diet with low CP levels in the grower phase (20.5% high), 18.7% medium, and 17.5% low) and in the finisher phase (19.5% high, 18.0% medium, and 16.6% low) increased thawing loss. Consistently, (Chodová *et al*., 2021) demonstrated that normal CP diets (21, 6% in the starter phase, 19.7% in the grower phase and 18,0% in the finisher phase feed) increased drip loss in the breast meat. Rosa *et al*. (2007) reported that high-energy feeds (2 950 vs. 3 200 vs. 3 450 kcal/kg in the feed) linked to better fat levels in broiler chickens. Lipiński *et al*. (2019) reported that feeds with low energy ranging between 23.9 to 59.75 kcal/kg in the control feed, is associated with higher fat content and increased water holding capacity, drip loss, pH, lightness (L*), and reduced redness (a*) in the breast muscles.

Carcass Evaluation

Muscle Content of Broiler Chickens

Muscles are made up of fibres that comprise muscle cells, connective tissue, and fat. Moreover, muscle tissue is the dominating tissue in meat, and each of attributes and level of proportion are responsible for the leanness quality (Listrat *et al*., 2016) . Muscles are crucial sources of essential nutrients and are widely valued for their typical flavours (Barbut, 2005). Consumers prefer high yield portions reflecting fresh meat quality (Godfray *et al*., 2018). Lean meat can be described as a meat with low fat and high protein content. It is commonly reported that muscle pieces are related to price (Ismail and Joo, 2017).

Broiler muscles have become the most preferred choice for consumers, due to fast ready-to-cook products (Zuidhof *et al*., 2014). Muscles are preferred for further processing for frying and braaiing purposes. A rapid change in market demand for whole birds decreased as a result of the demand for portions increased in the meat industry.

Bone Content Mass of Broiler Chickens

Commercially, the bone of chicken meat is a deterrent of the management system of farmers, while meat processors regard the bone as having high-value efficiency. It is known that bone abnormalities are associated with leg weakness, lameness, and metabolic disorders (Julian, 2005). It has been reported that bone composition is made of 70% minerals (calcium and protein), 20% organic (mainly collagen), 10% water. (Paz *et al*., 2006). Broiler chicken bones are used as alternative medication of osteoporosis in humans due to high calcium content and in the processing industry it is used as processed meat product binders (Barbut, 2005).

Skin Content of Broiler Chickens

Chicken skin is one of the by-products that is considered as residue and is underutilized while accounting 4% of live weight chicken (Suurs *et al*., 2022). Chicken skin has high nutritional density, shelf life, unique texture and flavour. Furthermore, chicken skin serves as a significant role in the production of co-products such as polonies, sausages, bacon, Vienna's, burgers, patties, and nuggets (Lima *et al*., 2020). Broiler chicken skin improves the organoleptic properties of meat by increasing juiciness and flavour components (Ciobanu *et al*., 2019). Literature suggests that white meat of chicken has the highest amount of unsaturated fatty acids (65–68%), in comparison to other sources of animal fat, (Peña-Saldarriaga *et al*., 2020). Similarly to the study of Nizar *et al*. (2013) who explored comparison of the fatty acid composition based on animal origin. The authors observed that chicken fat has a high unsaturated fatty acid (65%) than sheep (37%) and beef (33%) and a lower proportion of stearic acid (10%) when compared to bovine fat (31%), sheep (32%) or lamb (14%).

Poultry Meat Functionality Properties

Functional Meat Quality Attributes

Meat quality is defined by its compositional quality (meat percentage, intramuscular fat, marbling, lean-to-fat ratio, protein, and muscle area), functional quality (water holding capacity, pH, drip loss, colour, and cooking loss), and eating quality (appearance, juiciness, tenderness, and flavour) (Sako *et al*., 2022). Each criterion depends on a variety of factors, including the age of the chicken at slaughter, sex of the chicken, rearing condition, strain type, season, and agro-ecological zone. Animal nutrition and genetics both play substantial roles in flavour, protein, and fat accretion and contribute to the features of tissues and the metabolism of meat quality (Webb, 2015).

Meat pH

Meat pH is the amount of acidity or alkalinity in meat. Broiler meat pH ranges between 5.50 to 6.30 (Ristic and Damme, 2013). Normal meat pH level (5.8) correlates with fresh, tender, juicy meat while a high pH value can lead to rapid meat spoilage, discolouration, and even a sour taste (Droval *et al*., 2012). Chicken breasts within 24 hours post-mortem with L* value ≥ 53 and pH ≤ 5.8 are classified as PSE, with intermediate values of $44 <$ L* value< 53, and $5.8 <$ pH > 6.2 as normal meat colour. PSE meat has the highest L* values, the lowest pH and WHC levels, and the maximum cooking loss. DFD meat, on the other hand, has an ultimate pH value of 6.2, which is characterised by decreased shelf life and unpleasant smells. A high meat pH (6.3) is associated with a reduction in meat quality resulting to Dark, Firm and Dry (DFD), unappealing meat, and consumer distrust (Glamoclija *et al*., 2015).

A low meat pH (5.3) is associated with PSE-like conditions. Sammari *et al*. (2023) reported that the pH for normal, pale soft, exudative (PSE), and dark firm dry meat were 5.87, 5.61, and 6.18 respectively. Petracci *et al*., (2004) also reported similar pH findings for normal (5.89), pale soft and exudative (PSE: 5.77), and dark firm dry (DFD: 6.04). Barbut (2005) reported pH values of normal (6.02), PSE (5.72), and DFD (6.27). Szmańko *et al*. (2021) reported that for normal, PSE, and dark firm dry was 6.00, 5.50, and 6.60, respectively. Qiao *et al*. (2002) observed lower lightness (L*) values for dark, firm, and dry (DFD) 45.68, normal 51.32, and higher (L*) pale, soft exudative (PSE) 55.9.

Once pH declines below 6.0, proteins begin to denature, causing meat discolouration in appearance and a lower water holding capacity to give PSE meat (Manalo and Gabriel, 2020).When chickens are stressed, the pH within the muscle reduces L* values, Water Holding Capacity (WHC), Drip Loss (DL), Cooking Loss (CL), and pH influence (Karunanayaka *et al*., 2016). The decline pH is linked to microbial spoilage, discolouration, and dullness (Abdullah *et al*., 2025). Pale, Soft Exudative (PSE) meat is distinguished by its light colour, soft texture, low water-holding capacity, and pale appearance, reduced protein, and softer texture (Morel *et al*., 2023). Previous studies indicate that 37% of breast muscles observed in particular processing plants presented qualities of PSE meat.

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Research conducted previously documented that Chickens exposed to stress prior to slaughter yield PSE meat, which causes the metabolism to accelerate, dropping the pH, and affecting the breast muscle tenderness (Barbut *et al*., 2008).

According to Duclos *et al*. (2007) a breast muscle with PSE would appear to have a soggy texture, but excessive exudation causes it to be tougher than a breast muscle not affected by PSE. This disorder influences consumer acceptance.

Based on the literature, several solutions are proposed to alleviate the PSE problem, such as reducing stress in housing before slaughter, alternative transport, unloading methods, rest periods after transport, or less stressful methods of stunning chickens (Barbut *et al*., 2008). This disorder can also be prevented by avoiding pre-slaughter stressors at all costs.

Meat Colour

Meat colour depends on the pigment content in the muscle's (Choi *et al*., 2023). Customers' perceptions of product quality are based on appearance and their purchase decisions (Karunanayaka *et al*., 2016; Ranasinghe *et al*., 2024). Uniformity and consistency of meat colour traits assist in choosing meat products at the purchasing level as well as assessing the final meat quality product at the consumption level (Ranasinghe *et al*., 2024). Fresh raw thigh and leg meat is dark reddish in hue, while fresh raw breast meat is pale pink. The meat industry faces difficulties because of meat defects include bone discolouration, poor bleeding, and bruising.

Quality properties of normal, pale soft and exudative, and dark firm dry broiler breast meat are illustrated in Table 1. Previous studies have reported the variation in normal meat, DFD, and PSE disorder; 44.88 and 50.16 L*normal, 57.70 and 50.16 PSE, and 44.80 and 43.03 DFD, (Petracci *et al*., 2004; Barbut, 2015). Furthermore, (Zhang and Barbut, 2005) observed PSE (56.81), normal (59.00), and DFD (53.84). The differences in meat colour might be due to the different methods of evaluating the meat colour employed in the study. As commercial broiler chickens grow older the more the meat gets tougher compared with the younger broiler chickens a* (2.14) is redder, yellow b* (4.75) than old chickens a* (1.59) and b* (4.35) (Vargas-Ramella *et al*., 2022).The broiler muscles increase with age, and the meat converts to more red and darker (Baéza *et al*., 2022). Previous studies documented that transporting live broiler chickens to an abattoir is a stressful and exhausting experience for the chickens, exposing them to psychological and physical stimuli (Ncho *et al*., 2024). This includes temperature and humidity changes, handling, and aggressive behaviour. This, in turn, causes a stress response in animals, resulting in a n meat discolouration.

Table 1: Quality properties of normal, pale soft and exudative, and dark firm dry broiler breast meat

Parameter	Normal	PSE	DFD	References
Colour (L*)	44.88	57.70	44.80	Barbut *et al*. (2005)
	53.51	57.53	48.29	Petracci *et al*. (2004)
	50.16	57.50	43.03	Zhang and Barbut (2005)
Mean (±SD)	44.89±0.01	58.06±0.84	47.22±5.79	
pH_u	6.02	5.72	6.27	Barbut *et al*. (2005)
	5.89	5.77	6.04	Petracci *et al*. (2004)
	5.87	5.61	6.18	Samari *et al*. (2023)
	6.00	5.50	6.60	Szmańko *et al*. (2021).
Mean (±SD)	5.95 ±0.07	5.65 ±0.12	6.27 ±0.23	
WHC (%)	58.81	78.65	24.41	Zhang and Barbut (2005)
	43.77	51.73	38.50	Lee *et al*. (2022)
	63.58	58.60	66.28	Szmańko *et al*. (2021)
Mean (±SD)	55.38 ±10.34	62.99±13.98	43.06 ±21.30	
CL (%)	25.77	20.96	21.32	Zhang and Barbu (2005)
	20.09	23.91	-	Lee *et al*. (2022)
	23.30	25.30	21.90	Sheard *et al*. (2012)
Mean (±SD)	23.05±2.85	23.39±2.21	21.61±0.21	
DL (%)	0.72	1.24±0.02	-	Lee *et al*. (2022)
	2.44	3.24	1.55	Kralik *et al*. (2014a)
	2.11	3.24	1.55	Kralik *et al*. (2014b)
Mean (±SD)	1.76±0.91	2.25±1.15	1.55±0	

Water Holding Capacity

Water holding capacity is the ability of meat to preserve its internal moisture throughout fabrication, processing, and storage, as well as the ability of meat to maintain water even when external forces (such as gravity, heat, pressure, and centrifugation) are applied to it (Barbut, 2024), and is a significant economic indicator that affects income as carcasses are sold by the kilogramme (Sako *et al*., 2022). Water holding capacity contributes to the sensations of juiciness and tenderness. Sako *et al*., 2022, further indicated that stress and *antemortem* glycogen depletion in muscle resulted in meat with higher pH values. The water holding capacity of breast chicken meat is a significant quality attribute that affects the final yield of the cooked product value and eating quality. Ndakeva (2018) stated water holding capacity in animal meat muscle ranges between 0, 34% and 0, 47%. Several researchers (Lee *et al*., 2022; Szmańko *et al*., 2021; Barbut, 2005), reported water holding capacity normal meat (43,77–63.58%), DFD (24.41–66.28%), and PSE (51.73–78.65%). Age, genetic strain, and sex differences among the broiler chickens may be responsible for variations in the data. Normal meat had WHC (58.81%), PSE WHC (78.68%), and DFD WHC (24.41%) (Zhang and Barbut, 2005). Water holding capacity in the pectoral muscles of chickens ranged from 0.24 to 0.79%. Ranasinghe *et al*. (2024) documented that the WHC of broiler chickens' breasts was 48.28% meat and thigh muscle (32.92%). The summer season demonstrated a lower percentage of DFD (7.77%), normal (61.11%) incident and a higher percentage of PSE (31.12%) when compared to those reared in winter (DFD: 55.55%, normal: 44.44%, and PSE: 0.00%), spring (DFD: 16.67%,normal:71and PSE: 12,12%) and autumn (DFD: 34.44%, normal: 63.33 %, and PSE: 2.23%) (Çobanbaşi and Teke, 2022.). It could be the case that extreme heat and high relative humidity influence stress response, thereby promoting higher carcass temperature and lower pH, denaturing protein content, and reducing the WHC.

Meat Drip Loss

Drip loss is described as when muscle is converted to meat after slaughter, it loses some of its components, such as proteins, water, myofibers, and iron, along with its natural flavour and texture (Nawaz *et al*., 2021). Furthermore, Sako *et al.* (2022) reported that the quantity of water lost from a carcass during the first 24 to 48 hours after postmortem is known as drip loss. Drip loss is described myofiber leakage and the loss of proteins, water, and iron as muscle converts into meat. The ideal range for drip loss is between 0.72 to 2.52% (Adzitey and Huda, 2010). Li *et al.* (2015) reported that drip loss ranges from 1.46 to 3.78%. Woelfel *et al*., (2002) observed the normal breast chicken drip loss value is 3.32%, while for PSE meat drip loss is 4.38%. Kralik *et al*. (2018b) reported that drip loss for normal, pale soft, exudative, and dark firm dry was 2.11%, 3.24%, and 1.55% respectively. Lee *et al*. (2022) observed (lower values) of drip loss for normal, pale soft, exudative, and dark firm dry to be 1.00, 1.65, and 0.69%, respectively.

Meat Texture and Cooking Loss

Cooking loss (CL) refers to the measured percentage of weight lost from a product after cooking (Ranasinghe *et al*., 2024). Cooking loss is a vital quality parameter to the meat industry since it influences the worth and value of a product (Ježek *et al*., 2019; Vujadinović *et al*., 2014). Customers expect minor cooking loss when cooking meat because marketing prices are based on weight. Meat tenderness also remains one of the most essential physical attributes of meat-eating consumption levels after meat cooking. (Kadim *et al*., 2004) reported CL differed among animals, ranging from 21.3 to 25.2%. Schf~snfeldt *et al.* (1993) reported that the ideal CL ranges between 15.54 to 18.61%. Zhang and Barbut (2005) stated that cooking loss of meat ranges from 20.96% for PSE meat, 25.77% for normal meat, and 21.32% for DFD meat.

Zhang and Barbut (2005), reported the cooking loss of broiler chickens normal at 25.77%, pale soft and exudative at 20.96%, and dark firm dry at 21.32%. Sheard *et al*. (2012) stated a cooking loss of broiler chickens' meat containing 23.3% normal, 25.3% pale soft and exudative, and 21.9% dark firm dry. The difference could be possible due to the feed type strains significantly influence meat yield after cooking (Dales, 2014). A study review by Ranasinghe *et al*. (2024) found variation between the broiler chickens (23.63%) and Thai native chickens (20.14%). The corroborating finding was reported in broilers (27.33%) and indigenous chicken (20.20%) in both thigh and breast muscles. Pale Soft, Exudative (PSE), and Dark Firm Dry (DFD) meats are the key quality defects challenging the meat industry. As a result, it reduces end-user acceptability, shelf life, and yield of meat.

Carcass Composition

Nutritional Quality

Broiler chicken is high in protein and lower fat , iron, thiamine, as well as riboflavin content than red meat (Kralik *et al*., 2018a). Commercial broiler chickens have a distinct flavour, chewy texture, tougher texture, and high nutrient content, including proteins, phospholipids, and essential fatty acids (Devatkal *et al*., 2018).Lipids can influence meat flavour, juiciness, tenderness, and caloric content.

Proximate quality, fat, protein, and ash play an economical role to poultry meat on account of connection with production efficiency (Woo-Ming *et al*., 2018). Sensory properties are determined by proximate quality traits. Žlender *et al*. (1995) reported that the protein content in the leg muscles ranged between 15.8 and 17.9%. Previous study has recently revealed that protein and fat muscle play a vital role in meat quality parameters and contribute significantly to nutritional characteristics. (Michael *et al*., 2016) reported that protein plays significantly roles as regulators in metabolic pathways, which are crucial for maintenance, growth, reproduction, and immunity. Moisture content is a vital physiochemical attribute in meat as it affects its palatability. Furthermore, to yield good quality fresh, average levels of fat, content must be assured. This will contribute to high consumer acceptability (Sako *et al*., 2022).

Table 2 illustrates proximate properties of normal, pale soft, exudative, and dark firm dry broiler breast meat. As state by Qiao *et al*. (2002) the moisture quality of broiler chicken meat is typical to PSE 74.85%, the normal (74.45%), and DFD meat proximate (74.54 %). Ash quality of meat classified as 1.24% for PSE meat, 1.31% for normal meat, and 1.35% for DFD meat. Fat quality for PSE, normal, and DFD was 1.29, 1.25, and 1.24%, respectively, while protein quality was 23.27, 22.96 and 22.58%, respectively (Qiao *et al*., 2002). According to the values of proximate meat quality (moisture, ash and protein), King *et al*. (1998), the chicken meat was certified as normal, with measurements of moisture: 76, 05%, ash: 1.31%, and protein: 22.96%, and PSE meat with measured values moisture: 76.40%, ash: 1.24%, and protein: 22, 44%. Li *et al*. (2015) reported that PSE meat of moisture (75.29%), had lower ash (0.01%), fat (0, 01), and higher protein (22.45 %), while normal meat was of moisture: 75.12%, ash: 0, 98, fat: 0, 11 % and protein: 25.96 %. Carvalho *et al*. (2017) reported that PSE meat had fat 2.93% and protein of 27.47%. The authors denied the meat to be of normal quality if exhibiting fat 2.93% and protein 25.96 % content.

Several factors have been reported to influence the broiler chicken's proximate quality. These include genetic makeup, muscle type, sex, age, diet, management, season, and agro-ecological zone (da Silva *et al*., 2017). Higher moisture content (75.24%). lower ash (1.36%), and normal protein content (22.92%) was recorded in the summer season, and lower moisture (74.19%), higher ash (1.45%) and higher protein (23.22%) (Bianchi *et al*., 2007). The sedentary lifestyle due to cold temperatures lowers the fat and increases the protein content of poultry meat (Fanatico *et al*., 2009). Broiler carcass fat and protein content have been shown to increase with age (Al-Abdullatif and Azzam, 2023). Conversely, Wang *et al*., (2019) argue that an increase in carcass fat deposition increases with age, but protein content decreases in the same period. The older chickens, the more the body weight, protein content, and daily amino acids increase.

Future Considerations

Research on meat and functionality quality in broiler chickens has revealed some significant gaps and opportunities for further investigation. One major development is devising pre- and post-slaughter management measures tailored to broiler chickens, which could optimize broiler production outcomes, through understanding factors that contribute to meat quality and a successful broiler enterprise. Future studies should also delve into the effects of strain, age, production system, and diets on the fatty acid profile of broiler chickens. This study highlights that to attain desirable meat quality attributes, the above-mentioned factors must be controlled prior to rearing your chicks. Novel delivery, such as study review in indigenous chickens, may improve and strengthen knowledge of factors contributing to meat and functionality quality, leading to better understanding on how well sex, diet, age, production and strain affect carcass composition and meat quality.

Table 2: Proximate properties of normal, pale soft, exudative, and dark firm dry broiler breast meat

Parameter	Normal	PSE	DFD	References
Moisture (%)	74.45	74.85	74.54	Qiao *et al*. (2002)
	76.40	76.05	-	King. (1998)
	75.12	75.29	-	Li *et al*. (2015)
Mean (±SD)	75.32±0.99	75.40±0.60	74.54±0	
Ash (%)	1.31	1.24	1.35	Qiao *et al*. (2002)
	1.31	1.24	1.35	King (1998)
	0.98	0.01	-	Li *et al*. (2015)
Mean (±SD)	1.20±0.19	0.83±0.71	1.35±0	
Fat (%)	1.25	1.20	1.24	Qiao *et al*. (2002)
	-	-	-	King. (1998)
	0.11	0.01	-	Li *et al*. (2015)
	2.93	2.98	-	Carvalho *et al*. (2017)
Mean (±SD)	1.43±1.42	1.43±1.49	1.24	
Protein (%)	22.96	22.58	23.27	Qiao *et al*. (2002)
	22.96	22.44	23.27	King *et al*. (1998)
	22.87	22.45	-	Li *et al*. (2015)
	25.96	27.47	-	Carvalho *et al*. (2017)
Mean	22.93±0.05	22.72±0.048	22.93±0.49	

Strengths and Limitations

This systematic review's strength is the meticulous approach used to find and assess relevant studies. The literature was found using several of reliable databases, including Web of Science and Scopus databases as well as the Google search engine, which enhances the possibility of obtaining variety wide range of relevant studies. Additionally, this systematic review adhered to predetermined inclusion and exclusion criteria, focussing on high-quality research such as Randomised Controlled Trials (RCTs), controlled trials, and observational studies, which increased the dependability of the findings. The study focused primarily on the impact of factors that influence broiler meat and functional quality, providing a specific and comprehensive analysis of these key areas. Additionally, limiting the selection to studies published from 1982-2025 ensures that the findings are based on recent advancements in meat and functional quality research. Given these strengths, there are a few limitations to consider. Firstly, while many databases were searched, other relevant databases or grey literature sources were not considered, perhaps resulting in the absence of certain relevant studies. Secondly, solely publications written in English were evaluated, possibly eliminating relevant research published in other language. Thirdly, studies including assortments of veterinary studies and dietary experiments on test feeds, experimental supplements and/or plant extracts, molecular work, and gene expression were excluded, which may limit the generalizability to real-world poultry production scenarios where such combinations are commonly used. Lastly, inherent biases in the included research, specifically genetic variants and study conditions, could have affected results, despite endeavours to reduce these biases by rigorous inclusion criteria.

Conclusion

This review aims to highlight the current literature on factors contributing to broiler meat and functionality quality. The literature relating to the influence of rearing condition and season on muscle, bone and skin content of small-scale broiler chickens in both rural and urban communities is very limited. Based on the findings thus, it may be concluded that upgrading of carcass and meat quality depends on various factors, such as sex, age, rearing condition, strain, diets, season, and agro-ecological zones. PSE broiler breast meat has lower pH compared to normal breast meat, but higher DFD, resulting in paleness, low WHC, and drip loss, while higher L* and cooking loss occurred. Improper handling of any of these factors will result in poor carcass and meat quality. Therefore, these factors are essential in making the production of broiler meat even more affordable and beneficial for human health. Furthermore, this study highlights that to attain desirable meat quality attributes, the above-mentioned factors must be controlled prior to rearing cycle of chicks.

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Authors Contributions

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All authors have read and agreed to the published version of the manuscript.

Ethics

The corresponding author confirms that all the authors read and approved this study and no ethical matters involved.

Conflict of Interest Declarations

There is no conflict of interest to declare.

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