Behavior of Quail Meat During Thermal Processing and Technological Implications: a Review

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Abstract

Quail meat (*Coturnix coturnix japonica*) is a valuable source of animal protein, with nutritional properties superior to other poultry species, including a high content of polyunsaturated fatty acids, essential amino acids, and micronutrients. Despite a steady increase in global quail production, the behavior of this species' meat during thermal processing remains poorly documented in the scientific literature, which motivates the present review. This paper synthesizes the available data on the physicochemical, structural, and sensory changes induced in quail meat by the main cooking methods (boiling, frying, roasting, grilling, and sous-vide), with emphasis on three key aspects: cooking losses and water-holding capacity, reported in the literature in the range of 10.0-34.2% depending on the method and temperature applied; texture modifications resulting from the denaturation of myofibrillar proteins (myosin and actin) and the solubilization of collagen; and the formation of volatile compounds through the Maillard reaction and lipid oxidation, with direct implications for the sensory profile of the final product. The literature analysis indicates that, at internal temperatures of 70-75°C, quail meat reaches optimal food safety parameters while maintaining moderate cooking losses and acceptable sensory texture. High-temperature, short-time methods (grilling, frying) promote the Maillard reaction and the generation of characteristic aroma compounds, whereas low-temperature, long-time methods (sous-vide) minimize cooking losses and improve tenderness. The paper highlights the need for dedicated experimental research on this species to optimize thermal processing parameters for both technological and gastronomic applications.

Keywords: cooking loss, Maillard reaction, quail meat, thermal processing, texture, volatile compounds

1. Introduction

Japanese quail (*Coturnix coturnix japonica*) has emerged as one of the fastest-growing segments in global poultry production. Although quail meat constitutes approximately 0.2% of total world poultry output, equating to an estimated 200,000-240,000 tons annually, the species accounts for roughly 11.8% of all domestic birds raised globally [1]. China dominates production with over 80% of global output, while the European Union produces more than 100 million quails annually, concentrated primarily in France, Italy, and Spain [2]. Brazil maintains a growing sector supported by government development programs [3]. The global quail meat and egg market was valued at approximately USD 0.5 billion in 2024, with projections reaching USD 1.2 billion by 2034 at a compound annual growth rate of 8.5% [4]. This expansion is driven by rising consumer awareness of the nutritional advantages of quail meat and growing demand for alternative poultry products in both developed and developing economies [4].

The Japanese quail offers significant advantages for commercial production: rapid growth to

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market weight of 150-210 g at 35-45 days of age, high carcass yield of 67-88% depending on strain, age, and sex, early sexual maturity, short generation interval, and modest space requirements compared to chickens and turkeys [5,6]. Meat represents a major source of high-quality dietary protein and essential micronutrients including iron, zinc, selenium, and B-group vitamins for a large proportion of the global population, with poultry products occupying an increasingly important role in meeting these nutritional needs [7,8]. These biological characteristics, combined with the species' adaptability to diverse climatic conditions, position quail farming as an accessible enterprise for smallholders and an efficient component of intensive production systems alike [9].

Quail meat is recognized as a nutrient-dense food source with a favourable nutritional profile. According to the USDA National Nutrient Database and corroborated by multiple research studies, raw quail meat (meat only) contains approximately 22.6% protein, 4.5% fat, 72.7% moisture, and 1.1% ash per 100 g [10]. The study [11] show similar values of 20.18% protein, 5.02% fat, 75.63% moisture, and 0.94% ash in Turkish quail meat. The research [12] confirmed that quail breast and leg meat range from 17-23% protein, 2-8% fat, 71-74% moisture, and 1.5-1.8% minerals, with the wide variation attributed to differences in anatomical cut, age, strain, and dietary regime.

The amino acid profile of quail meat is particularly notable. Essential amino acid content reaches 11.68 g/100 g protein in pectoral muscles and 10.16 g/100 g protein in thigh muscles, with high concentrations of lysine (1.91 g/100 g), leucine (1.87 g/100 g), and glutamic acid (2.82 g/100 g) [13]. The research focused on [14] calculated that the daily intake of just two quails provides 27-28 g of protein, including 11 g of essential amino acids, covering approximately 40% of the human dietary protein requirement.

The lipid fraction of quail meat is characterized by a healthy fatty acid composition. The major fatty acids include oleic acid (41-42%), palmitic acid (24-26%), linoleic acid (13-14%), and stearic acid (7.3-7.5%) [15]. Japanese quail meat has a favourable polyunsaturated-to-saturated fatty acid ratio (P/S) of 1.08, substantially higher than that of Common quail (0.76), with an n-6/n-3 ratio of 9.54 and a thrombogenicity index of 0.60 [16]. Total PUFA content ranges from 13.8-14.3% of total fatty acids, which, while nutritionally beneficial, renders quail meat susceptible to lipid oxidation during thermal processing [15].

Quail meat is also an excellent source of minerals, with notably high levels of iron (4.51 mg/100 g), zinc (2.4-2.5 mg/100 g), phosphorus (275-282 mg/100 g), and copper (0.5 mg/100 g), and provides meaningful quantities of B-group vitamins, particularly niacin (8.2 mg/100 g), vitamin B6 (0.53 mg/100 g), thiamine (0.28 mg/100 g), and riboflavin (0.29 mg/100 g) [17].

Thermal processing of quail meat serves two fundamental purposes: ensuring microbiological safety and developing desirable sensory attributes. From a food safety perspective, quail carcasses harbour significant microbial loads [18]. This paper [18] indicate that fresh retail quail carcasses carried mesophilic counts of 5.25 ± 1.14 log CFU/g, with Listeria monocytogenes detected in 18.9% and Campylobacter jejune in 2.7% of samples. The USDA Food Safety and Inspection Service mandates a minimum internal temperature of 73.9°C (165°F) for all poultry, including quail, to ensure pathogen destruction [19]. Adequate thermal processing is therefore critical for consumer safety.

Beyond safety, cooking transforms the sensory and nutritional profile of quail meat through multiple biochemical mechanisms: protein denaturation alters texture and improves digestibility; the Maillard reaction generates characteristic flavour and colour compounds at surface temperatures exceeding 140°C; collagen solubilization at 53-63°C enhances tenderness; and lipid oxidation produces both desirable flavour volatiles and potentially undesirable off-flavours [20]. The relatively high myoglobin content of quail breast muscle (approximately 87% red/oxidative fibres versus 13% white/glycolytic fibres) distinguishes its behaviour during cooking from that of chicken breast, which is composed almost entirely of fast-twitch glycolytic fibres [21].

The principal thermal processing methods applicable to quail meat include conventional roasting, grilling, pan-frying, deep-frying, boiling, steaming, smoking, and the more recently developed sous-vide technique. Each method transfers heat through different mechanisms conduction, convection, radiation, or combinations thereof and produces distinct temperature-time

profiles at the meat surface and reviewed quail processing methods including tandoori (roasting), frying, and smoking [22]. This paper [20] investigated circulating non-fried roasting technology applied to quail. However, a systematic comparative study of different culinary cooking methods on quail meat quality remains absent from the peer-reviewed literature. This review aims to: summarize the available data on the physicochemical, structural, and sensory changes induced in quail meat by the main thermal processing methods (boiling, frying, roasting, grilling, and sous-vide); compare reported values for cooking loss, water-holding capacity, texture, color, lipid oxidation, and volatile compound formation; integrate quail-specific findings with relevant data from chicken and turkey, where direct evidence is lacking; and identify the main research gaps that should be addressed by dedicated experimental studies on this species.

2. Materials and methods

A systematic search of published literature was conducted using four major electronic databases: Scopus, Web of Science, PubMed/MEDLINE, and Google Scholar. The search covered the period from January 2005 to March 2026. The following keyword combinations were employed: "quail meat" AND ("cooking" OR "thermal processing" OR "heat treatment"); "Coturnix" AND ("cooking loss" OR "texture" OR "color" OR "color" OR "lipid oxidation" OR "TBARS" OR "volatile compounds" OR "Maillard"); "quail meat quality" AND ("roasting" OR "grilling" OR "frying" OR "boiling" OR "sous vide"); and "poultry meat" AND "thermal processing" AND ("cooking loss" OR "shear force" OR "TPA" OR "protein denaturation"). Additional searches were performed for specific parameters including "Warner- Bratzler shear force quail," "CIE L*a*b* quail meat," and "water-holding capacity quail.

Studies were included if they (a) reported original quantitative data on physicochemical, textural, color, or biochemical properties of quail meat, or (b) provided comparable data from chicken or turkey meat under defined cooking conditions that could be reasonably extrapolated to quail. Review articles were included when they synthesized information relevant to mechanisms of thermal transformation in poultry meat. Studies were excluded if they focused exclusively on quail egg products, lacked quantifiable outcome measures, or were published in non-peer-reviewed outlets without verifiable methodology. Earlier landmark studies (pre-2005) were included when they provided foundational mechanistic data not superseded by more recent publications.

The initial search identified approximately 420 records across all databases. After removing duplicates and screening titles and abstracts, 87 full-text articles were assessed for eligibility. A total of 38 articles met the inclusion criteria and were incorporated into this review, comprising 22 original research articles on quail meat, 12 comparative poultry/meat studies providing data from chicken and turkey, and 4 review articles addressing mechanisms of heat-induced changes in meat proteins, lipids, and volatiles.

3. Results and discussion

Cooking loss (CL) represents the percentage of weight lost during thermal processing due to moisture evaporation, fat melting, and drip expulsion, and is a critical determinant of both economic yield and eating quality [23]. In Japanese quail breast meat, CL values under standardized water-bath cooking (70-74°C internal temperature) range from 19.2% to 24.0% across most studies, though the full reported range spans 13.7-34.2% [24]. The present research [24] documented a mean CL of 24.02% (range 13.74-34.23%) in 1,093 pedigreed Japanese quails slaughtered at 35 days of age, with moderate heritability for this trait. This analysis [13] reported that white-plumaged quails exhibited the lowest CL at 19.21% in pectoral muscle and significantly higher WHC (22.17%) compared to golden, grey, and brown strains. According to [25] CL of 19.9-21.5% in white Japanese quails at 42 days, while [26] confirmed that white strains consistently exhibited the highest WHC and lowest drip loss and CL among different color variants.

This study indicated [27] that CL of only 10-12% (mean 11.68% under thermal comfort conditions) using vacuum-sealed samples cooked in water bath at 74°C for 40 minutes. These substantially lower values likely reflect species differences in muscle fiber composition and pH characteristics between European and Japanese quail.

Water-holding capacity in quail meat is closely linked to ultimate pH (pHu). Japanese quail pHu typically ranges from 5.30 to 6.58 [14,26,27], which is higher than that of chicken (typically 5.7-5.9 for normal breast meat). This elevated pH, further from the isoelectric point of myosin (pH=5.4), promotes greater electrostatic repulsion between myofilaments, thereby increasing the space available for water retention [28]. The study [14] reported WHC values of 21.68-22.39% for breast and 25.08-26.91% for thigh muscles, findings confirmed [29]. The higher WHC of thigh muscles reflects their greater oxidative fiber content and higher intramuscular fat [30].

For comparison, chicken breast cooked conventionally to 71°C internal temperature exhibits CL of approximately 26.5%, while sous-vide cooking at 60°C for 1 hour reduces this dramatically to 6.58% [31]. The study [32] demonstrated that chicken breast fillet CL ranges from 18.8% (stewing) to 26.8% (broiling), while turkey breast shows wider variation from 12.0% (pan-frying) to 30.3% (broiling). These authors confirmed that methods employing higher heating rates and shorter durations such as pan-frying and grilling consistently produce lower CL than slow moist-heat methods.

The mechanism underlying cooking loss involves sequential protein denaturation events. The data [33] established that meat undergoes transverse shrinkage at 40-60°C (myosin denaturation phase), followed by longitudinal shrinkage at 60-90°C (collagen and actin denaturation). Water is expelled from the myofibrillar lattice as proteins denature and aggregate, with the most dramatic moisture loss occurring between 60-80°C when both collagen shrinkage and actin denaturation progress simultaneously [34,30].

Table 1. Cooking losses (%) and water-holding capacity of quail meat under different conditions

Reference	Species/Strain	Cooking Method	Temperature	Time	Cooking Loss (%)	WHC (%)	Notes
[26]	Japanese quail, 35 d	Water bath	~74°C internal	Standard	24.02 (mean); range 13.74-34.23	-	n=1,093; heritability moderate
[13]	Japanese quail (white), 6 wk.	Water bath	74°C	Standard	19.21 (pectoral)	22.17	Lowest CL among 4 color strains
[27]	Japanese quail (white), 42 d	Water bath	~74°C internal	Standard	19.9-21.5	-	Genetic evaluation study
[29]	European quail, 37 d	Water bath (vacuum bag)	74°C	40 min	10-11.68	-	Species-specific low CL
[14]	Japanese quail	Standardized	-	-	-	21.68-22.39 (breast); 25.08-26.91 (thigh)	Pharaoh and Manchurian Golden
[34]	Chicken breast	Pan-frying/stewing/broiling	Various	Various	18.79-26.83	-	Comparison: lowest CL with frying
[34]	Turkey breast	Pan-frying/broiling	Various	Various	11.98-30.30	-	Wide range by method

[1]CL = cooking loss
[2]WHC = water-holding capacity

3.1 Texture and mechanical properties during thermal processing

Texture is a primary quality attribute of cooked quail meat, governed by the interplay of myofibrillar protein denaturation, collagen transformation, and moisture content changes during heating. Warner-Bratzler shear force (WBSF) and texture profile analysis (TPA) provides the principal instrumental measures of these properties [34,35].

The present research [24] reported a mean WBSF of 7.75 kg for Japanese quail breast meat

cooked via water bath, a notably firm value that reflects the high proportion of oxidative muscle fibers in quail pectoralis. WBSF correlated negatively with pHu (r = -0.62), confirming that lower pH produces tougher meat through greater protein denaturation and reduced WHC. This paper [5] demonstrated that slaughter age profoundly affects texture: spent quails (52 weeks) exhibited significantly higher hardness, chewiness, and gumminess but lower springiness compared to young quails (6 weeks), with significant age × sex interaction effects (P = 0.017 for WBSF). These changes parallel the increased collagen cross-linking and decreased muscle fiber hydration that accompany aging.

For TPA parameters, the study [36] reported the following values for 5-month-old breeding quail pectoral muscle cooked to 70.2°C: hardness 14.67 N, cohesiveness 0.29, springiness 0.97 cm, gumminess 4.54 N, and chewiness 10.06 N×cm. These values position quail meat within a similar textural range to chicken breast, for which [37] reported TPA hardness of 17.3 N after conventional oven cooking and 9.40 N after sous-vide at 60°C/1h. WBSF values for chicken breast range from 21.7 to 36.98 N depending on cooking method and initial frozen/thawed state [38].

The mechanistic basis of texture changes during cooking centers on three sequential protein denaturation events, as established by [20] and [39]:

Myosin denaturation (40-60°C): Onset of structural changes; myosin heavy chain disappears on SDS-PAGE above 53°C. Initial toughening occurs as transverse shrinkage compresses muscle fibers [40,20].

Collagen denaturation (53-63°C): Helical collagen undergoes thermohydrolysis, converting to gelatin. This transition can increase tenderness as connective tissue weakens [41]. This paper [38] observed that soluble collagen more than doubled from 50 to 70°C in chicken breast.

Actin denaturation (66-80°C): The most thermally stable major myofibrillar protein. Actin denaturation triggers dramatic longitudinal shrinkage, moisture expulsion, and substantial toughening [42]. The research [43] demonstrated that elastic modulus increased dramatically only when actin denaturation initiated, confirming actin as the primary driver of cooking-induced toughness.

For poultry meat, which contains procollagen (immature collagen) that swells easily in aqueous environments, prolonged heating is not required for collagen transformation. Adequate tenderness and juiciness are maintained if internal temperature does not exceed approximately 65°C [44], a principle that underpins the success of sous-vide cooking in poultry applications.

Table 2. Texture parameters of quail meat under different thermal treatments

Reference	Species/Age	Cooking Method	Temp. (°C)	WBSF (N or kg)	Hardness (N)	Springiness (cm)	Cohesiveness	Notes
[26]	Japanese quail, 35 d	Water bath	~74 internal	7.75 kg	-	-	-	n=1,093; mean of pedigreed population
[38]	Japanese quail, 5 mo.	Water bath	70.2	-	14.67	0.97	0.29	Gumminess 4.54 N; chewiness 10.06 N×cm
[5]	Japanese quail, 6 wk.	Water bath	70.2	Lower than spent (P<0.05)	Lower than spent	Higher than spent	NS (P=0.305)	Age significantly affects most TPA traits
[5]	Japanese quail, 52 wk.	Water bath	70.2	Higher than young (P<0.05)	Higher than young	Lower than young	NS	Spent quail tougher across all shear measures
[34]	Chicken breast	Multiple methods	Various	6.80–17.08 N	-	-	-	Lowest with high-temp short-time methods
[39]	Chicken breast	Conventional oven vs sous-vide 60°C	71 vs 60	29.1 vs 21.7 N	17.3 vs 9.40	-	-	Sous-vide significantly reduced toughness

[1]WBSF = Warner-Brazer Shear Force

[2]NS = Not Significant

3.2 Color parameters and their modification by heat

Color is the first quality attribute assessed by consumers and provides visual cues for perceived freshness, species identity, and doneness. Raw quail breast meat exhibits a distinctive color profile driven by its high myoglobin concentration in predominantly oxidative muscle fibers [45].

Published CIE L*a*b* values for raw Japanese quail breast meat show considerable variation depending on strain, age, and measurement conditions. This paper [24] reported L* = 43.09, a* = 19.24, b* = 7.74 (pHu = 5.94) in 35-day-old pedigreed quails, representing relatively dark, intensely red meat. The experiment [13] found that white-strain quails at 6 weeks exhibited L* = 46.40, a* = 9.20, b* = 12.46 (pHu = 6.28), with significantly different color parameters across plumage color strains. The present research [46] documented higher lightness in both young quails (L* = 58.93, a* = 12.86, b* = 20.86; pH = 6.53) and spent quails (L* = 61.54, a* = 6.84, b* = 19.81; pH = 6.62), with young birds showing significantly higher redness than spent birds. The study [25] reported notably different values of L* = 53.88, a* = 5.52, b* = -1.69 at 42 days, illustrating the extent of methodological and genetic variation in color measurements.

The present research [47] estimated heritability's for color traits in Japanese quail at L* = 0.23, a* = 0.45, b* = 0.22, with a phenotypic correlation between pHu and L* of -0.26, confirming the well-established inverse relationship between pH and lightness. The moderate-to-high heritability of redness (0.45) suggests significant genetic control over myoglobin concentration in quail meat.

During thermal processing, color changes proceed through several temperature-dependent mechanisms. Myoglobin denaturation begins at approximately 60°C, causing the transition from red/pink oxymyoglobin to grey-brown denatured globin hemochrome the characteristic color change associated with meat "doneness" [48]. At surface temperatures exceeding 140°C, the Maillard reaction produces melanoidin pigments responsible for surface browning, decreasing L* and increasing b* values [49]. Caramelization reactions commence above 165°C, while pyrolysis and charring occur above 200°C. Boiling (100°C) produces pale, greyish-white meat with minimal surface browning because internal temperature is insufficient for Maillard chemistry. In contrast, roasting (175-230°C), grilling (200-350°C surface), and frying (150-200°C) generate pronounced surface browning through rapid Maillard reaction and, at higher temperatures, caramelization [50].

No published study has yet systematically documented CIE L*a*b* values for quail meat across different cooking methods, representing a notable research gap. Based on poultry meat science principles, cooked quail breast would be expected to show increased L* (paler interior) and decreased a* (loss of redness) after internal temperatures exceed 70°C, with surface values varying dramatically by cooking method and duration.

Table 3. Color parameters (CIE L*, a*, b*) of raw quail breast meat from published studies

Reference	Age/Type	L*	a*	b*	pH	Notes
[26]	35 d, pedigreed	43.09	19.24	7.74	5.94	n=1,093; darkest/reddest values
[13]	6 wk., white strain	46.40	9.20	12.46	6.28	Lightest among 4 color strains
[48]	8 wk., young	58.93	12.86	20.86	6.53	Higher lightness methodology
[48]	8 mo., spent	61.54	6.84	19.81	6.62	Lowest redness; oldest birds
[27]	42 d, white	53.88	5.52	-1.69	-	Negative b* (unusual)
[29]	37 d, European quail	52.2-54.5	8.9-9.8	12.9-13.8	5.49-5.65	Affected by thermal environment. low pH
[51]	Japanese quail	54.9	9.70	2.59	5.92	Early results; L* high
[49]	Japanese quail, 35 d	43.09	19.24	7.74	5.94	Pedigree reference values

3.3 Maillard reaction products and volatile compound formation

The volatile profile of cooked quail meat results from three interconnected reaction systems: lipid oxidation (producing aldehydes, alcohols, and ketones), the Maillard reaction (generating pyrazines, furans, and Strecker aldehydes), and thermal degradation of sulphury-containing amino acids and thiamine (producing sulphury compounds) [52]. This analysis [**Error! Bookmark not defined.**] provided the most comprehensive quail-specific data, identifying 62 volatile compounds in quail meat roasted using circulating non-fried roast technology at

approximately 230°C for up to 40 minutes. These compounds comprised 14 aldehydes (the dominant class, consistent with lipid oxidation as the primary reaction pathway), 12 nitrogen-containing compounds (mainly pyrazines from Maillard chemistry), 10 alcohols, 8 ketones, 8 acids, 3 esters, 3 furans, 2 sulphury-containing compounds, and 1 phenol [53]. The number of detectable volatiles increased progressively from 31 at 0 minutes to 51 at 40 minutes of roasting. Nineteen key odorants with odor activity values (OAV) greater than 1 were identified at 40 minutes, with concentrations of most odorants reaching maximum levels within the first 30 minutes [**Error! Bookmark not defined.**,54]. Lipidomic analysis revealed that phospholipids (PC, PE) and triglycerides were significantly correlated with volatile formation, with decreasing phospholipid concentrations paralleling increasing volatile compound production [55].

The experiment [56] conducted the only published direct comparison of roasted quail volatiles with those of other land fowl. Across roasted quail, pheasant, partridge, and chicken, a total of 83 different aroma compounds were detected. Quail yielded [57] compounds, with 2 compounds unique to quail (species-specific) and 38 compounds common to all four species, establishing a shared land fowl aroma basis. Notably, no single "character impact" compound responsible for species-specific roast aroma was identified for any species, suggesting that the distinctive flavors of each bird arise from quantitative differences in shared compounds rather than unique molecular markers [56].

Regarding Maillard-derived heterocyclic amines (HCAs) potentially carcinogenic compounds formed during high-temperature cooking no quail-specific data exist. Chicken studies provide the closest comparable data [57]. The current investigation [58] reported that pan-fried chicken breast contained PhIP up to 38 ng/g, while boiled chicken showed only trace levels of harmane and norharman. Barbecued chicken at extreme surface temperatures (339-365°C) can generate PhIP concentrations of 270-480 ng/g [58]. HCA formation is strongly temperature-dependent: The study [59] shows progressive increases in MeIQx (up to 23.7 ng/g), DiMeIQx (up to 2.7 ng/g), and PhIP (up to 12.7 ng/g) as frying temperatures increased from 150°C to 225°C. PhIP forms more readily in chicken than in beef, pork, or fish, a pattern likely applicable to quail given similar precursor concentrations in poultry muscle.

3.4 Lipid oxidation during thermal processing

Lipid oxidation represents both a flavors-development pathway (at low to moderate levels) and a quality deterioration mechanism (at elevated levels) in thermally processed quail meat. The relatively high PUFA content of quail meat (13.8-14.3% of total fatty acids), while nutritionally desirable, renders it inherently susceptible to oxidative degradation during heating [60].

TBARS values for fresh raw quail meat have been documented at 0.40-0.48 mg MDA/kg by [61] and at 0.44 mg MDA/kg (pectoral) and 0.93 mg MDA/kg (thigh) by [13]. Thigh muscles show higher baseline oxidation due to greater lipid content. These values fall well below the Egyptian Standards threshold of 0.9 mg MDA/kg for acceptable chilled poultry and the general rancidity detection threshold of 1.5 mg MDA/kg [62]. This analysis [63] demonstrated that dietary supplementation with Pleurotus ostreatus mushroom (10-20 g/kg diet) reduced TBARS by 33.5% at day 15 of storage, confirming the susceptibility of quail meat lipids to oxidation and the potential for dietary antioxidant interventions.

Although no study has specifically measured TBARS in quail meat cooked by different methods, data from other meat species provide a robust predictive framework. The current investigation [64] demonstrated in foal meat that microwaving and roasting produced the highest TBARS values, while grilling and frying produced the lowest among cooked samples (all significantly higher than raw, $P < 0.001$). Total volatile compounds dominated by aldehydes from lipid oxidation were highest in roasted samples (409.1 AU×10^6/g dry matter for aldehydes) and lowest in grilled samples (217.2 AU×10^6/g). For cooked chicken breast patties, TBARS values of 1.93 ± 0.02 mg MDA/kg at day 1 post-cooking have been reported, approximately four-fold higher than raw quail baseline values, illustrating the magnitude of cooking-induced oxidation [65].

The α-tocopherol content of quail meat provides natural antioxidant protection, with Japanese quail breast containing 1.49 μg/g fresh meat, though wild common quail exhibits higher levels at 2.40 μg/g [66]. The P/S ratio of 1.08 in Japanese quail, combined with linoleic acid as the predominant PUFA, creates a lipid substrate

highly reactive with atmospheric oxygen at elevated cooking temperatures, particularly above 150°C where radical-mediated chain reactions accelerate [67].

3.5 Protein structural changes and digestibility

Heat-induced protein modifications in quail meat follow the established cascade of denaturation, aggregation, and cross-linking that governs all muscle foods. As outlined by [20], sarcoplasmic proteins aggregate between 40-60°C, myofibrillar proteins undergo progressive unfolding from 30-50°C with gelation at 45-50°C, and the most heat-resistant protein, actin, denatures at 66-80°C. These transitions have been confirmed by DSC analysis of chicken breast muscle, which shows three endothermic peaks at approximately 53°C, 70°C, and 79°C [68,69].

SDS-PAGE analysis of heated chicken breast muscle the closest available model for quail demonstrates that myosin heavy chain band intensity disappears after internal temperature reaches 53°C, while the actin band disappears above 68°C [70]. These structural changes underpin the progressive loss of protein solubility during cooking. The data [38] reveals that soluble protein decreased by approximately 90% from 23°C to 80°C in chicken breast, while soluble collagen more than doubled from 50°C to 70°C as collagen underwent thermohydrolysis.

The cooking method significantly influences the extent and type of protein modification. Deep-frying and roasting produce relatively higher protein oxidation than boiling, with stir-frying and deep-frying promoting greater conversion of α-helix secondary structure to β-sheet conformation [71]. This structural reorganization has functional consequences: deep-fried and stir-fried chicken showed significantly lower in vitro gastrointestinal digestibility compared to boiled and microwaved preparations ($P < 0.05$) [71]. Deep-frying increased Schiff base formation, a marker of advanced protein oxidation by more than 10-fold compared to raw meat [72]. The study [73] provided a comprehensive review of cooking-induced protein modifications, documenting carbonylation, aromatic residue modification, and Maillard type adduct formation as the principal molecular level changes.

For quail meat specifically, [16] demonstrated that Japanese quail breast contains lower total collagen than chicken, which combined with the predominance of immature procollagen in poultry muscle suggests that quail requires less intensive thermal treatment for collagen solubilization and tenderness development than red meat species.

3.6 Nutritional changes induced by cooking

Thermal processing modifies the nutritional composition of quail meat through moisture loss (concentrating nutrients on a wet-weight basis), fat rendering, vitamin degradation, and mineral leaching. The apparent protein content of cooked quail meat increases on a wet-weight basis because moisture loss (cooking loss 10-34%) concentrates the remaining protein fraction [74]. This concentration effect is a mathematical artefact rather than a true increase in absolute protein; total amino acid mass is largely preserved during cooking, with retention rates of 83-100% reported across different poultry cuts and cooking methods [75].

Fat content changes are method-dependent. Dry-heat methods (roasting, grilling) promote fat rendering and loss, potentially reducing total fat content on a dry-weight basis. Conversely, frying in oil can increase total fat content through oil absorption. The proximate composition of raw versus cooked chicken shows highly significant differences ($P < 0.01$) in moisture, protein, fat, and gross energy content, while total ash content remains relatively stable [76,77].

Mineral retention during cooking follows a predictable pattern: minerals are not destroyed by heat but can be lost through leaching into cooking water or drip. This study [48] established that boiling causes the greatest mineral loss among common cooking methods; while steaming and dry-heat methods retain substantially more minerals. Average mineral retention across cooking methods is approximately 60-70%. Calcium levels may paradoxically increase during bone-in cooking through leaching from the skeleton, while potassium and magnesium show the greatest susceptibility to leaching losses. For quail meat, with its notably high iron content (4.51 mg/100 g versus approximately 0.7-1.0 mg/100 g in chicken breast), mineral retention during cooking is of particular nutritional significance [78,79,16].

Vitamin losses during cooking are primarily governed by thermal stability, water solubility, and cooking duration. Thiamine (B_1) is the most heat-sensitive B vitamin, with losses of 38-87% reported during poultry roasting. Riboflavin shows better thermal stability with negligible cooking losses, while niacin is relatively heat-stable [80]. The research [81] reported that raw Japanese quail meat contains B_6 at 0.52-0.68 mg/100 g, niacin at 6.0-10.3 mg/100 g, thiamin at 0.10-0.17 mg/100 g, and riboflavin at 0.16-0.50 mg/100 g, values that would be expected to decrease by 15-45% during typical cooking depending on method and duration. The relatively high vitamin B_6 content of quail meat (0.53 mg/100 g; 38% of daily value) makes vitamin retention during cooking an important consideration for nutritional labelling and dietary planning [82,83].

4. Conclusions

The thermal processing of quail meat is well characterized at the mechanistic level but remains under-investigated at the level of practical application

The biochemistry that governs heat-induced transformations in *Coturnix coturnix japonica* muscle follow the same physical principles described for chicken, turkey, beef, and pork; however, the species displays a specific combination of properties that distinguishes it from other poultry and justifies dedicated investigation rather than extrapolation from related species.

Three findings emerge from the literature synthesized in this review. First, the thermal denaturation cascade myosin (40-60°C), collagen (53-63°C), and actin (66-80°C) occurs within narrow, predictable temperature windows that can be controlled during processing. The "tenderness window" between approximately 60°C and 65°C, where collagen has begun its transition to gelatin while actin denaturation has not yet driven catastrophic moisture loss, defines the thermodynamic basis for the success of sous-vide and other low-temperature techniques in poultry applications. For quail, this window is particularly attractive given the predominance of immature procollagen and the relatively low total collagen content of the pectoralis major. Second, quail meat combines a high ultimate pH (5.9-6.6), comparable to or higher than that of chicken thigh, which favors water-holding capacity, with a high PUFA content (P/S ratio 1.08), which increases susceptibility to lipid oxidation. The selection of the cooking method therefore implies a trade-off between texture and oxidative stability, which has not yet been quantified in the quail-specific literature. Third, the volatile profile of roasted quail meat (62 compounds identified, 19 with OAV > 1) is dominated quantitatively by lipid-derived aldehydes, while pyrazines and Strecker aldehydes from the Maillard reaction contribute to qualitative differentiation; no single character-impact compound has been identified, indicating that the aromatic profile of quail derives from quantitative differences in shared compounds rather than from species-specific molecular markers.

The most striking observation, however, is methodological rather than chemical. After more than three decades of intermittent investigation, no peer-reviewed study has yet executed a controlled, factorial comparison of culinary cooking methods (roasting, grilling, pan-frying, deep-frying, boiling, sous-vide, microwave) on quail meat using standardized endpoint temperatures and integrated outcome measures. Every cooking-loss value tabulated in the present review derives from laboratory water-bath methodology; every protein denaturation temperature is borrowed from chicken or red-meat DSC studies; every TBARS dataset reflects raw or stored not differentially cooked quail meat; and every heterocyclic amine concentration cited as relevant to quail is, in fact, a chicken value. This is not a minor lacuna. It represents a structural absence at the foundation of quail meat science.

This gap is also an opportunity. Quail's biological characteristics short generation interval, modest space requirements, rapid growth to market weight make it an exceptionally tractable experimental subject for the kind of factorial cooking-method × temperature × time studies that have already been performed on chicken and turkey. A single well-designed factorial trial, integrating instrumental color, Warner-Bratzler shear force, TPA, TBARS, carbonyl and Schiff-base markers, volatile profiling by GC–MS, in vitro digestibility, and sensory analysis, would generate more foundational quail-specific data than has accumulated in the literature over the past two decades. The commercial relevance of such work extends beyond the quail sector itself: as alternative and small-scale poultry species gain

market share within the broader trend toward dietary diversification, quail offers a model system for understanding how the principles of poultry meat science scale across species with different muscle fiber composition, lipid profiles, and connective-tissue characteristics.

In synthesis, quail meat behaves during thermal processing as a high-pH, high-PUFA, oxidative-fiber-rich poultry matrix who's textural, chromatic, aromatic, and oxidative changes follow the general principles of meat science but differ quantitatively from those of chicken and turkey. The mechanistic framework for understanding these divergences is well established. What is needed is a body of cooking-method-specific experimental data that allows processors and nutritionists to apply this framework in practice. For a species that already accounts for more than one in nine domestic birds raised globally, and whose market is projected to more than double by 2034, this gap should be addressed by dedicated experimental studies.

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