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Research Article

Effect of yoghurt, lemon juice and garlic-ginger paste marination on the quality of chicken meat during refrigerated storage

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Abstract

This study evaluated the effects of natural marinating agents on the quality, oxidative stability, microbial safety and sensory acceptability of broiler chicken breast meat during refrigerated storage at 4°C for 9 days. Fresh broiler breast meat samples were assigned to four treatments: T_0 (unmarinated control), T_1 (1% yoghurt), T_2 (1% lemon juice), and T_3 (1% garlic + 1% ginger paste). The experiment followed a 4 × 4 factorial arrangement under a completely randomized design with three replications per treatment-day combination. Samples were analyzed at 0, 3, 6 and 9 days for sensory attributes, proximate composition, pH, instrumental color, drip loss, cooking loss, shear force value, thiobarbituric acid reactive substances (TBARS), and total viable count (TVC). Marination and storage interval significantly affected all major quality traits. Storage increased pH, dry matter, ether extract, ash, drip loss, cooking loss, TBARS and TVC, while reducing crude protein, instrumental color stability and sensory scores. Lemon juice (T_2) showed the strongest pH-control effect, maintaining the lowest pH at day 9 (6.050) compared with the control (6.377). Garlic-ginger paste (T_3) provided the strongest overall preservation response, retaining the highest day-9 crude protein (21.457%), dry matter (27.030%), ether extract (2.319%), and sensory acceptability (3.280), while producing the lowest drip loss (3.408%), cooking loss (26.508%), shear force value (20.633 N), TBARS (0.209 mg MDA/kg), and TVC (6.087 log10 CFU/g). The control exceeded the microbiological acceptability threshold of 7.0 log10 CFU/g by day 9, whereas all marinated treatments remained below this level. Pearson correlation confirmed that quality deterioration was driven by the strong positive association of pH with TVC and cooking loss, and the negative association of oxidative and microbial deterioration with overall acceptability. Overall, garlic-ginger paste was the most effective formulation for maintaining chicken meat quality during refrigerated storage, while lemon juice was most effective for pH reduction. The higher additive load in T_3 should be considered when interpreting its superior formulation-level performance.

Introduction

Broiler chicken meat is an important source of high-quality animal protein and provides essential amino acids, minerals, vitamins and other nutrients required for human growth and health. Compared with many other animal-source foods, poultry meat is generally characterized by a relatively favorable protein-to-fat ratio and has become increasingly important in meeting the growing demand for affordable animal protein (Jahan et al., 2025; Khatun et al., 2022; Azad et al., 2021 and 2022; Wood et al., 2008). The rapid growth of the poultry sector has also made chicken meat an important component of food and nutrition security in many developing countries, including Bangladesh, where poultry production has expanded substantially in response to increasing consumer demand. The short production cycle, comparatively low production cost and wide consumer acceptance of broiler meat further contribute to its importance in the national food system. However, the same characteristics that make fresh chicken meat nutritionally valuable—particularly its high moisture content, high water activity, nutrient-rich composition and near-neutral pH—also make it highly susceptible to microbial deterioration and physicochemical changes during storage (Mondal et al., 2025; Hossan et al., 2024; Akter et al., 2022).

Refrigerated storage is one of the most commonly used approaches for maintaining the quality and safety of fresh chicken meat. Nevertheless, refrigeration does not completely prevent microbial growth or biochemical deterioration. Psychrotrophic and psychrotolerant microorganisms can multiply at chilling temperatures and progressively cause undesirable changes in meat, including off-odour development, slime formation, discoloration, protein degradation and loss of sensory acceptability. In addition to microbial spoilage, poultry meat is particularly susceptible to lipid oxidation because its phospholipid-rich cellular membranes contain considerable amounts of unsaturated fatty acids. Oxidation of these lipids produces primary oxidation products such as lipid hydroperoxides, which subsequently decompose into secondary compounds, including aldehydes such as malondialdehyde.

These oxidative products can adversely affect flavor, aroma, color, nutritional value and overall consumer acceptability. Consequently, controlling both microbial proliferation and oxidative deterioration is essential for extending the refrigerated shelf life of fresh chicken meat. Increasing consumer interest in minimally processed and clean-label foods has stimulated considerable research into natural preservation technologies as alternatives or complements to conventional synthetic additives. Natural plant materials, fruit juices, fermented dairy products, herbs and spices contain organic acids, phenolic compounds, flavonoids, essential oils and other biologically active constituents that may provide antimicrobial and antioxidant effects (Islam et al., 2025; Masum et al., 2025; Mostafa et al, 2025; Biplob et al., 2024; Hasan et al., 2024; Das et al., 2022; Ali et al., 2022; Sadakuzzaman et al., 2021; Boby et al., 2021; Fernandez-Lopez et al., 2004). A recent comprehensive review concluded that natural marinades can improve sensory and technological characteristics of meat while contributing to microbial stability and delaying lipid and protein oxidation. The same review emphasized that the effectiveness of a marinade depends strongly on its composition, concentration, marination time, temperature and interactions between individual ingredients (Latoch et al., 2023). Thus, marination should not be considered solely as a flavor-enhancing technique; appropriately formulated marinades may also function as a non-thermal preservation strategy. Among natural marinades, yoghurt is particularly interesting because of its acidity, fermented microflora and milk-derived proteins and peptides. Lactic acid produced during yoghurt fermentation can reduce the pH of meat and create conditions that are less favorable for some spoilage microorganisms. In addition, yoghurt and yoghurt-derived products may contain bioactive compounds with antioxidant activity. Acid whey obtained from yoghurt production has recently been investigated as a natural meat marinade. Yoghurt acid-whey marination reduced meat pH and improved oxidative stability, with particularly notable effects observed in

chicken meat, although the response of tenderness and other quality attributes depended on meat type and marination conditions (Savvidou et al., 2023). Similarly, research on yoghurt-marinated chicken fillets has demonstrated the potential of yoghurt-derived preparations to retard lipid oxidation during refrigerated storage. These findings suggest that fermented dairy ingredients may simultaneously contribute to flavor development, acidification and preservation. Lemon juice represents another promising natural marinating ingredient because of its relatively high organic-acid content, particularly citric acid, together with vitamin C and other phytochemicals. Acidification can lower the surface pH of meat and may interfere with the growth of certain microorganisms, while antioxidant constituents may contribute to the inhibition of oxidative deterioration (Celic et al., 2025; Kumar et al., 2017). Recent experimental evidence has demonstrated that marination of poultry meat with lemon juice can reduce pH, improve tenderness and enhance microbiological stability. In particular, lemon-containing marinades have been associated with reductions in aerobic bacterial populations compared with unmarinated chicken meat (Wang et al., 2024; Smaoui et al., 2023).

Garlic and ginger are also widely used culinary ingredients with considerable potential for meat preservation. Garlic contains sulfur-containing compounds, particularly organosulfur constituents generated following tissue disruption, whereas ginger contains phenolic compounds such as gingerols and related bioactive substances. These compounds have been associated with antimicrobial and antioxidant activities. Garlic and ginger-derived compounds may inhibit microbial growth through interactions with cellular membranes and other microbial targets, while their antioxidant constituents may scavenge reactive species and retard oxidative reactions (Sidhu et al., 2023; Hossain et al., 2021; Sallam et al., 2004). Experimental studies have demonstrated the potential of garlic and ginger preparations to reduce microbial contamination in poultry, including Salmonella, and ginger-based preparations have also been investigated for their ability to extend the microbiological shelf life of chicken meat. The incorporation of herbs and spices into natural marinades has therefore attracted increasing attention as a means of combining desirable sensory characteristics with functional preservation effects. The preservation potential of natural marinades is particularly relevant to poultry meat because their effects may extend beyond microbial inhibition (Shohiduzjaman et al., 2024; Sadakuzzaman et al., 2024; Bithi et al., 2020; Disha et al., 2020). Marination can modify meat pH, water-holding capacity, color, tenderness, cooking characteristics and sensory properties (Mia et al., 2023). Organic acids may promote protein structural changes and improve tenderness, while fermented dairy ingredients may influence moisture retention and surface characteristics. Plant-derived antioxidants can reduce lipid oxidation and the development of undesirable oxidative flavors. However, these effects are not necessarily uniform among different marinade ingredients. Highly acidic marinades, for example, may produce excessive acidification, alter meat color or impart an overly acidic flavor when applied at inappropriate concentrations or for prolonged periods. Therefore, comparative assessment of different natural marinades under identical storage conditions is necessary to determine their relative effectiveness and possible limitations (Sarker et al., 2021).

The widespread culinary use of yoghurt, lemon juice and garlic–ginger paste in South Asian chicken preparations, comparatively limited information is available on their relative effectiveness when used individually as natural marinades and subsequently evaluated throughout refrigerated storage. In particular, there is a need for systematic comparison of these commonly available ingredients with respect to sensory characteristics, proximate composition, physicochemical properties, lipid oxidation and microbial quality of broiler chicken meat under controlled chilling conditions. Such information is especially relevant in Bangladesh, where these ingredients are inexpensive, readily available and culturally familiar and where simple, natural approaches for maintaining the quality of fresh poultry meat could have practical value for households, food businesses and small-scale meat processors.

Therefore, the present study was designed to evaluate the effects of yoghurt, lemon juice and garlic–ginger paste marination on the quality and shelf stability of broiler chicken breast meat during refrigerated storage at 4°C for up to 9 days. The study specifically assessed changes in sensory attributes, proximate composition, physicochemical characteristics, lipid oxidation and microbial quality during storage. Comparative evaluation of these three commonly used natural marinades is expected to provide useful information regarding their potential as accessible, consumer-friendly and natural approaches for maintaining the quality of refrigerated chicken meat and extending its acceptable storage period.

Materials and Methods

Experimental Site, Sample Collection and Design

The experiment was conducted at the Meat Science Laboratory, Department of Animal Science, Bangladesh Agricultural University, Mymensingh, Bangladesh. Fresh broiler chicken breast meat (pectoralis major) was collected from the Kamal-Ronjit Market, Bangladesh Agricultural University campus, within a short period after Halal slaughter and transported to the laboratory under chilled conditions. The experiment was arranged in a 4 × 4 factorial design under a completely randomized design, including four treatments and four refrigerated storage intervals (0, 3, 6 and 9 days), with three replications per treatment-storage combination.

Treatments And Marinade Preparation

The treatment groups were T_0 = unmarinated control, T_1 = yoghurt marinade, T_2 = lemon juice marinade, and T_3 = garlic + ginger paste marinade. Commercial plain yoghurt was used at 1% (w/w), freshly squeezed lemon juice was used at 1% (w/w), and garlic-ginger paste was prepared from equal proportions of fresh garlic and ginger, applied as 1% garlic + 1% ginger (w/w). All marinades were prepared freshly before application, thoroughly mixed with standardized chicken meat pieces, packed in sterile polyethylene bags and stored at 4 ± 1°C until the assigned storage interval.

Sensory Evaluation

Sensory attributes were evaluated by a trained panel using a 5-point hedonic scale, where 5 indicated excellent quality and 1 indicated poor quality. Flavor, color and overall acceptability were evaluated at each storage interval. Panel members were trained according to standard meat sensory evaluation procedures (AMSA, 1995).

Proximate, Physicochemical, Biochemical and Microbial Analyses

Dry matter, crude protein, ether extract and ash contents were determined following AOAC (2000) methods. Meat pH was measured using a calibrated penetration pH meter. Instrumental color values were measured in the CIE L*, a* and b* system using a calibrated colorimeter. Drip loss and cooking loss were determined gravimetrically following standard meat quality procedures (Honikel, 1998). Shear force value was measured using a Warner-Bratzler-type shear apparatus and expressed in Newtons (N). Lipid oxidation was determined by the TBARS method and expressed as mg MDA/kg meat (Schmedes and Holmer, 1989). Total viable count was determined using standard aerobic plate count procedures and expressed as log10 CFU/g (ISO, 1991).

Statistical Analysis

Data were analyzed using two-factor analysis of variance to determine the effects of treatment, storage interval and their interaction. Mean separation was performed using Tukey's HSD test. Pearson correlation analysis was used to examine associations among major quality traits. Differences were considered statistically significant at $p < 0.05$, and highly significant trends were interpreted where applicable.

Results And Discussion

Table 1: Effect of different marinating agents on sensory attributes (Mean ± SD) of chicken breast meat during refrigerated storage at 4°C

Parameters	DI	Treatment				Mean	Level of sig.		
		T_0	T_1	T_2	T_3		T	DI	T×DI
Flavor score	0	4.607±0.052a	4.680±0.023a	4.690±0.021a	4.820±0.023a	4.699±0.089			
	3	4.213±0.055b	4.267±0.030b	4.310±0.017b	4.517±0.023b	4.327±0.133			
	6	3.413±0.052c	3.623±0.049c	3.640±0.040c	4.207±0.020c	3.721±0.340	*	*	*
	9	2.517±0.058d	3.043±0.044d	3.083±0.054d	3.617±0.113d	3.065±0.449			
	Mean	3.688±0.925	3.903±0.720	3.931±0.713	4.290±0.514	3.953±0.692			
Color score	0	4.627±0.026a	4.530±0.012a	4.417±0.015a	4.810±0.012a	4.596±0.166			
	3	4.127±0.035b	4.097±0.030b	4.083±0.027b	4.403±0.012b	4.178±0.151			
	6	3.310±0.012c	3.407±0.015c	3.287±0.012c	4.090±0.031c	3.523±0.381	*	*	*
	9	2.360±0.032d	2.950±0.036d	2.847±0.038d	3.347±0.098d	2.876±0.406			
	Mean	3.606±0.992	3.746±0.704	3.659±0.719	4.162±0.618	3.793±0.726			
Overall acceptability	0	4.613±0.028a	4.660±0.021a	4.640±0.053a	4.790±0.026a	4.676±0.079			
	3	4.183±0.050b	4.307±0.020b	4.287±0.046b	4.507±0.015b	4.321±0.135			
	6	3.380±0.052c	3.540±0.042c	3.640±0.066c	4.097±0.073c	3.664±0.308	*	*	*
	9	2.347±0.091d	2.963±0.044d	3.070±0.045d	3.280±0.059d	2.915±0.401			
	Mean	3.631±0.997	3.868±0.763	3.909±0.696	4.168±0.657	3.894±0.733			

T_0 = control; T_1 = yoghurt marinade; T_2 = lemon juice marinade; T_3 = garlic + ginger paste marinade; DI = storage day interval. Means bearing different superscripts within the same row or column differ significantly. * Indicates significant difference at $p < 0.05$; ** indicates $p < 0.01$.

Sensory Attributes of Marinated Chicken Meat

The effects of marinating agents and storage intervals on sensory attributes are presented in Table 1. Treatment, storage interval and their interaction significantly affected flavor, color and overall acceptability. In all treatment groups, sensory scores declined progressively as storage advanced, indicating gradual deterioration in fresh eating quality. However, marinated samples retained higher sensory scores than the control throughout storage.

At day 9, the control showed the lowest flavor (2.517), color (2.360) and overall acceptability (2.347), falling below the practical acceptability threshold of 3.0. In contrast, T_3 maintained the highest flavor (3.617), color (3.347) and overall acceptability (3.280) at day 9. Yoghurt and lemon juice also improved sensory retention compared with the control, but their day-9 scores were lower than those of T_3. The superior sensory stability of garlic-ginger paste may be attributed to the combined flavor-enhancing, antioxidant and antimicrobial effects of garlic organosulfur compounds and ginger phenolic constituents (Burt, 2004; Nanasombat and Wimuttigosol, 2011; Sidhu et al., 2023).

Table 2: Effect of different marinating agents on proximate composition (Mean ± SD) of chicken breast meat during refrigerated storage at 4°C

Parameters	DI	Treatment				Mean	Level of sig.		
		T_0	T_1	T_2	T_3		T	DI	T×DI
Dry matter (%)	0	25.145±0.176a	25.554±0.181a	25.263±0.202a	26.059±0.114a	25.505±0.407			
	3	25.614±0.262a	25.930±0.237a	25.435±0.332a	26.247±0.151a	25.806±0.358			
	6	26.046±0.218b	26.219±0.174ab	26.095±0.209ab	26.132±0.456ab	26.123±0.073	*	*	*
	9	26.355±0.250b	26.607±0.233b	26.247±0.185b	27.030±0.204b	26.560±0.348			
	Mean	25.790±0.527	26.078±0.446	25.760±0.484	26.367±0.449	25.999±0.497			
Crude protein (%)	0	22.028±0.063a	22.742±0.102a	22.710±0.200a	22.809±0.156a	22.572±0.365			
	3	21.739±0.167b	22.148±0.192b	22.423±0.283ab	22.529±0.315ab	22.210±0.353			
	6	21.292±0.104b	21.967±0.261b	21.964±0.130b	21.953±0.275b	21.794±0.335	*	*	*
	9	20.646±0.252c	21.201±0.547b	20.996±0.497bc	21.457±0.283b	21.075±0.343			
	Mean	21.426±0.602	22.014±0.635	22.023±0.751	22.187±0.603	21.913±0.654			
Ether extract (%)	0	1.703±0.018a	1.832±0.018a	1.833±0.020a	1.776±0.038a	1.786±0.061			
	3	1.821±0.046a	1.919±0.028a	1.932±0.018ab	1.985±0.007ab	1.914±0.068			
	6	1.876±0.014ab	1.975±0.008ab	2.040±0.024b	2.024±0.021b	1.979±0.074	*	*	*
	9	1.940±0.041b	2.010±0.010b	2.212±0.019c	2.319±0.059c	2.120±0.176			
	Mean	1.835±0.101	1.934±0.078	2.004±0.162	2.026±0.224	1.950±0.156			
Ash (%)	0	0.953±0.045a	1.011±0.016a	1.002±0.009a	1.004±0.045a	0.992±0.027			
	3	1.014±0.005a	1.034±0.018a	1.023±0.009a	1.070±0.027a	1.035±0.025			
	6	1.020±0.008ab	1.075±0.016ab	1.108±0.012ab	1.100±0.033ab	1.076±0.040	*	*	*
	9	1.159±0.029b	1.149±0.009b	1.135±0.015b	1.243±0.035b	1.171±0.049			
	Mean	1.036±0.087	1.067±0.061	1.067±0.064	1.104±0.101	1.069±0.076			

T_0 = control; T_1 = yoghurt marinade; T_2 = lemon juice marinade; T_3 = garlic + ginger paste marinade; DI = storage day interval. Means bearing different superscripts within the same row or column differ significantly. * Indicates significant difference at $p < 0.05$; ** indicates $p < 0.01$.

Proximate Composition

The proximate composition of marinated chicken breast meat is summarized in Table 2. Dry matter increased progressively with storage, rising most prominently in T_3 at day 9 (27.030%). This increase reflects moisture loss and concentration of total solids during refrigerated storage. Crude protein declined in all treatments with increasing storage time, indicating progressive proteolytic and storage-related degradation. However, T_3 retained the highest day-9 crude protein (21.457%) compared with T_0 (20.646%), T_1 (21.201%) and T_2 (20.996%).

Ether extract and ash increased gradually over storage. The highest day-9 ether extract (2.319%) and ash (1.243%) were observed in T_3, suggesting a concentration effect from water loss along with possible contribution of the garlic-ginger formulation. Although storage-related changes in proximate composition are partly concentration-driven, better protein retention in marinated groups indicates that natural marinades may slow biochemical deterioration of chicken meat during chilled storage.

Table 3: Effect of different marinating agents on physicochemical and instrumental color properties (Mean ± SD) of chicken breast meat during refrigerated storage at 4°C

Parameters	DI	Treatment				Mean	Level of sig.		
		T_0	T_1	T_2	T_3		T	DI	T×DI
pH	0	5.820±0.012a	5.700±0.006b	5.550±0.006c	5.780±0.006a	5.713±0.119			
	3	5.930±0.006a	5.850±0.012b	5.640±0.006c	5.900±0.012a	5.830±0.131			
	6	6.250±0.012a	6.023±0.009b	5.850±0.012c	6.110±0.012b	6.058±0.167	*	*	*
	9	6.377±0.015a	6.150±0.012b	6.050±0.012c	6.250±0.012b	6.207±0.140			
	Mean	6.094±0.262	5.931±0.197	5.772±0.224	6.010±0.210	5.952±0.235			
L* value	0	54.283±0.661a	56.867±0.906a	57.889±0.344a	55.360±1.263a	56.100±1.596			
	3	51.987±1.039ab	54.397±0.537a	55.410±1.218a	52.485±1.235a	53.570±1.608			
	6	51.257±1.186b	52.197±0.999ab	53.230±1.199ab	50.372±1.196b	51.764±1.229	*	*	*
	9	49.440±1.133c	49.103±0.900b	49.383±0.502b	49.500±1.186b	49.356±0.176			
	Mean	51.742±2.004	53.141±3.299	53.978±3.606	51.929±2.608	52.697±2.799			
a* value	0	4.730±1.128a	4.297±0.570a	3.707±0.196a	3.953±0.200a	4.172±0.444			
	3	3.600±0.384a	3.530±0.390a	3.373±0.489a	3.387±0.408a	3.473±0.111			
	6	3.433±0.174a	3.130±0.287ab	2.627±0.228b	2.927±0.064ab	3.029±0.339	*	*	*
	9	2.507±0.300b	2.233±0.453b	2.037±0.237c	2.567±0.330b	2.336±0.247			
	Mean	3.567±0.912	3.297±0.859	2.936±0.750	3.208±0.599	3.252±0.743			
b* value	0	6.570±0.811a	7.083±0.552a	7.427±0.346a	7.540±1.082a	7.155±0.436			
	3	6.107±0.559a	6.493±0.347a	6.803±0.485a	6.480±0.294a	6.471±0.285			
	6	5.303±0.566b	5.430±0.347ab	6.460±0.329a	6.043±0.237a	5.809±0.541	*	*	*
	9	4.937±0.402b	5.067±0.130b	5.363±0.390ab	5.670±0.895a	5.259±0.327			
	Mean	5.729±0.744	6.018±0.933	6.513±0.865	6.433±0.809	6.173±0.820			
Drip loss (%)	0	1.421±0.109a	1.403±0.087a	1.638±0.046a	0.949±0.045b	1.353±0.290			
	3	1.942±0.115a	1.626±0.112b	1.845±0.052ab	1.218±0.116b	1.658±0.322			
	6	3.186±0.092a	2.800±0.083b	3.190±0.141a	2.388±0.146c	2.891±0.382	*	*	*
	9	4.481±0.087a	3.795±0.094b	4.011±0.074b	3.408±0.133c	3.924±0.447			
	Mean	2.757±1.367	2.406±1.110	2.671±1.128	1.991±1.133	2.456±1.107			
Cooking loss (%)	0	22.682±0.146b	20.526±0.310c	23.536±0.318a	18.132±0.124d	21.219±2.417			
	3	24.355±0.236b	23.118±0.104b	25.400±0.274a	21.588±0.488c	23.615±1.642			
	6	27.918±0.117b	25.413±0.209c	28.118±0.176a	23.260±0.128d	26.177±2.302	**	*	*
	9	32.353±0.234b	28.121±0.118c	32.864±0.218a	26.508±0.275d	29.962±3.134			
	Mean	26.827±4.282	24.294±3.239	27.479±4.053	22.372±3.487	25.243±3.991			
	0	28.300±1.128a	26.300±1.185ab	27.773±1.259a	24.300±1.127b	26.668±1.791			

	3	30.200±0.608a	23.467±1.129b	22.900±0.850b	21.733±0.926b	24.575±3.819			
Shear force value (N)	6	34.133±1.550a	21.300±1.185b	21.633±0.921b	26.433±5.136b	25.875±5.984	***	*	*
	9	31.033±3.345a	21.567±0.371b	23.200±0.520b	20.633±0.837b	24.108±4.737			
	Mean	30.916±2.430	23.159±2.306	23.877±2.685	23.275±2.606	25.307±4.039			

T_0 = control; T_1 = yoghurt marinade; T_2 = lemon juice marinade; T_3 = garlic + ginger paste marinade; DI = storage day interval. Means bearing different superscripts within the same row or column differ significantly. * Indicates significant difference at $p < 0.05$; ** indicates $p < 0.01$.

Physicochemical Properties and Color Stability

The physicochemical and instrumental color traits are presented in Table 3. Meat pH increased with storage time in all groups, indicating microbial and biochemical deterioration. Lemon juice (T_2) consistently maintained the lowest pH, increasing from 5.550 at day 0 to only 6.050 at day 9, whereas the control increased from 5.820 to 6.377. The pH-control effect of lemon juice is associated with citric acid and other organic acids, which suppress pH-elevating microbial and enzymatic changes (Mia et al., 2024; Augustynska-Prejsnar et al., 2021; Unal et al., 2022).

Instrumental color changed significantly during storage. Lightness (L*) declined from initial values above 54 to approximately 49 by day 9, indicating reduced surface brightness. Redness (a*) and yellowness (b*) also decreased during storage, reflecting pigment and surface quality changes. Although lemon juice showed relatively higher initial lightness, garlic-ginger paste maintained the highest day-9 L* value (49.500), indicating better late-storage visual stability. These color changes are consistent with known interactions among pH, lipid oxidation and pigment stability in poultry meat (Faustman et al., 2010; Celic et al., 2025).

Drip loss, cooking loss and shear force value were significantly influenced by treatment and storage interval. Drip loss increased sharply in the control, reaching 4.481% at day 9, whereas T_3 recorded the lowest value (3.408%). Cooking loss was also lowest in T_3 at day 9 (26.508%) and highest in T_2 (32.864%). The lower water loss in T3 suggests improved water retention and reduced structural deterioration. Shear force value declined in all marinated treatments compared with the control, with T_3 showing the lowest day-9 value (20.633 N), indicating superior tenderization. This improvement may be linked to ginger proteolytic activity and the combined softening effects of garlic and ginger bioactive compounds (Kumar et al., 2017; Sidhu et al., 2023).

Table 4: Effect of different marinating agents on lipid oxidation and microbial load (Mean ± SD) of chicken breast meat during refrigerated storage at 4°C

Parameters	DI	Treatment				Mean	Level of sig.		
		T_0	T_1	T_2	T_3		T	DI	T×DI
TBARS (mg MDA/kg)	0	0.186±0.002a	0.162±0.004b	0.151±0.003b	0.147±0.002b	0.162±0.018			
	3	0.196±0.004a	0.168±0.003b	0.162±0.003b	0.156±0.003b	0.171±0.018			
	6	0.209±0.005a	0.197±0.002ab	0.195±0.004ab	0.181±0.001b	0.196±0.011	*	*	*
	9	0.246±0.005a	0.225±0.004b	0.216±0.002b	0.209±0.003b	0.224±0.016			
	Mean	0.209±0.026	0.188±0.029	0.181±0.030	0.173±0.028	0.188±0.029			
TVC (log10 CFU/g)	0	4.747±0.049a	4.473±0.174ab	4.520±0.106ab	4.320±0.081b	4.515±0.177			
	3	5.883±0.082a	4.967±0.087b	4.887±0.075b	4.863±0.087b	5.150±0.491			
	6	6.470±0.121a	5.330±0.032b	5.320±0.074b	5.283±0.163b	5.601±0.580	*	*	*
	9	7.353±0.180a*	6.103±.067b	6.117±0.087b	6.087±0.046b	6.415±0.625			
	Mean	6.113±1.093	5.218±0.686	5.211±0.687	5.138±0.745	5.420±0.843			

T_0 = control; T_1 = yoghurt marinade; T_2 = lemon juice marinade; T_3 = garlic + ginger paste marinade; DI = storage day interval. Means bearing different superscripts within the same row or column differ significantly. * Indicates significant difference at $p < 0.05$; ** indicates $p < 0.01$.

Biochemical and Microbial Quality

The effects of marinating agents on TBARS and TVC are presented in Table 4. TBARS values increased progressively during storage, confirming gradual lipid oxidation in refrigerated chicken meat. The control reached 0.246 mg MDA/kg at day 9, whereas T_3 showed the lowest value (0.209 mg MDA/kg). The lower TBARS in T_3 indicates stronger oxidative stability, likely due to antioxidant compounds in garlic and ginger, including organosulfur compounds, gingerols and shogaols (Nanasombat and Wimuttigosol, 2011; Sidhu et al., 2023).

TVC also increased continuously throughout storage. The control reached 7.353 log10 CFU/g at day 9, exceeding the commonly used microbiological acceptability threshold of 7.0 log10 CFU/g for fresh meat. In contrast, all marinated treatments remained below this limit, with T_3 showing the lowest day-9 TVC (6.087 log10 CFU/g), followed by T_1 (6.103 log10 CFU/g) and T_2 (6.117 log10 CFU/g). The microbial suppression observed in marinated groups agrees with the antimicrobial roles of organic acids, lactic acid bacteria, garlic sulfur compounds and ginger phytochemicals (Codex Alimentarius Commission, 2009; Augustynska-Prejsnar et al., 2024; Rahman et al., 2023).

Correlation Among Quality Traits

Pearson correlation analysis further supported the integrated deterioration pattern of marinated chicken meat during refrigerated storage (Figure 1). pH was strongly and positively correlated with TVC ($r = 0.974$) and cooking loss ($r = 0.960$), indicating that microbial growth and water loss increased together with storage-related pH elevation. TBARS was positively correlated with TVC ($r = 0.817$) and negatively associated with overall acceptability ($r = -0.882$), demonstrating that lipid oxidation and microbial proliferation jointly reduced sensory quality. Overall acceptability was strongly and negatively correlated with pH ($r = -0.968$), TVC ($r = -0.962$) and cooking loss ($r = -0.939$), confirming that sensory deterioration was closely linked to physicochemical and microbial quality loss.

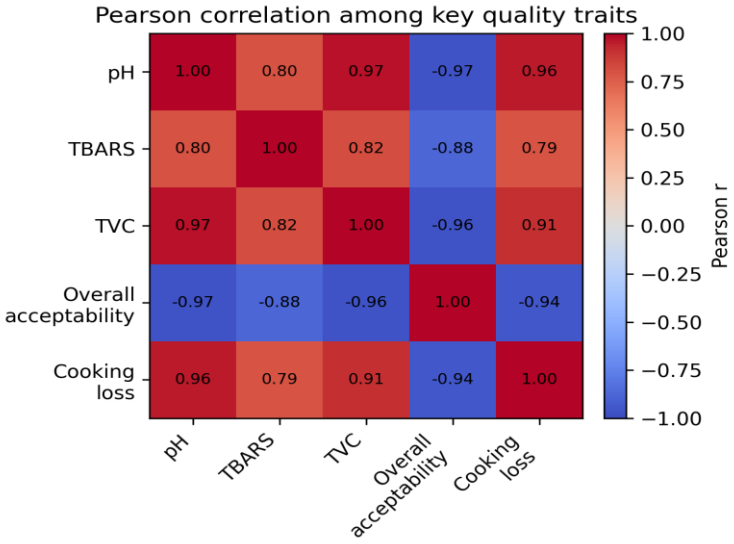

Figure 1: Pearson correlation heatmap among key quality traits of marinated chicken breast meat during refrigerated storage.

Conclusion

This study demonstrated that natural marinating agents significantly influenced the quality, oxidative stability, microbial safety and sensory acceptability of broiler chicken breast meat during 9 days of refrigerated storage at 4°C. Storage time progressively reduced sensory quality, color stability and crude protein, while increasing pH, dry matter, water loss, lipid oxidation and microbial load. Among the tested formulations, lemon juice provided the strongest pH-control effect, whereas garlic-ginger paste produced the most favorable overall preservation profile. At day 9, the T_3 maintained the highest sensory acceptability, crude protein, dry matter and ether extract, while minimizing drip loss, cooking loss, shear force value, TBARS and TVC. The control exceeded the microbiological threshold by day 9, while all marinated treatments remained within acceptable limits. Therefore, garlic-ginger paste can be considered a promising clean-label formulation for improving refrigerated chicken meat quality under the tested conditions. However, because T_3 contained a higher total additive load than yoghurt or lemon juice treatments, its superiority should be interpreted as formulation-level effectiveness rather than equal-dose superiority.

Future Perspectives

1. Future studies should evaluate different inclusion levels of yoghurt, lemon juice and garlic-ginger paste to compare treatments on an equal total additive basis.

2. Further work should include sensory panels with larger consumer groups, pathogen-specific microbial analysis and volatile flavor profiling to confirm commercial acceptability.

3. Packaging systems such as vacuum packaging, modified-atmosphere packaging and active packaging should be compared with marination to develop integrated shelf-life extension strategies.

Ethical Approval

The animals were slaughtered following Halal procedure and standard hygienic practices.

Conflict Of Interest

The authors declare no conflict of interest.

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