



Quality characteristics of chicken meat marinated with antioxidant-rich fruit juices and powders

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Abstract

This study investigated the effects of functional marinades prepared from pomegranate, kiwi, and pineapple juices and powders on the technological, textural, and antioxidant properties of chicken breast meat. Marinades served as functional alternatives to standard marination liquids containing water, oil, and salt. Physicochemical parameters (pH, moisture, water activity, color), texture profile analysis (TPA), and thermal behavior (by DSC) were evaluated. Cooking loss, cooking yield, marinade absorption, and marinade retention were also determined. Antioxidant capacity was assessed via total phenolic content, CUPRAC, and DPPH assays. Significant differences ($p < 0.05$) were found among treatments for hardness, cohesiveness, gumminess, and resilience. Kiwi powder (KP) and pomegranate powder (PMP) yielded the highest hardness and resilience, indicating denser and more elastic protein matrices. Juice-based treatments resulted in softer textures due to dilution of enzymatic and phenolic activity. Marinades containing water increased protein denaturation temperatures, while acidic pomegranate and pineapple juices decreased L^* values. Fruit-based marinades increased antioxidant capacity, particularly in powder form. Overall, both fruit type and physical form influenced meat quality. Powders enhanced structural integrity and elasticity, whereas juices acted as tenderizing and antioxidant agents. These results highlight the potential of fruit-derived marinades as natural, clean-label alternatives for improving texture, color, and oxidative stability in poultry products.

Keywords Marination · Chicken meat · Pomegranate juice · Kiwi juice · Pineapple juice

Introduction

Consuming fatty meats has been linked to various health issues such as cardiovascular diseases, obesity, and certain cancers. However, as the fat content decreases, the flavor and satiety properties of meat tend to diminish [1]. Chicken is a low-calorie food rich in essential fatty acids and amino acids with high biological value, making it an important source of high-quality protein. Specifically, chicken breast is a good source of protein, iron, and niacin [2, 3].

According to the OECD-FAO Agricultural Outlook 2025–2034 report, global meat production reached approximately 365 million tons in 2024, with most of this growth driven by poultry meat. The U.S. Department of Agriculture’s “USDA, Livestock and Poultry: World Markets and Trade” report estimates that global poultry meat production will hit around 151.4 million tons in 2025. The same OECD-FAO report predicts that global poultry meat consumption will grow to 173 million tons by 2034 [4]. Data from IndexBox show that global poultry meat consumption was roughly 139 million tons in 2024 [5]. Additionally, a Rabobank analysis expects that global poultry meat demand will increase by about 2.5–3% in 2025 [6].

Compared to cattle, broiler chickens require less labor and have lower production costs. Due to their rapid growth rate, they are preferred as an accessible source of protein, especially in developing countries. Their ease of preparation also makes them appealing to consumers in high-income nations [7]. In high-income regions such as North America, Europe, and Central Asia, poultry is consumed

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as a lean and environmentally friendly protein source [8]. In their natural environment, chickens feed on protein-rich, easily accessible organisms such as worms, larvae, snails, termites, grasshoppers, silkworms, and caterpillars. This feeding behavior contributes to their classification as a sustainable food source [9]. Many factors influence the taste of chicken meat, such as feeding practices, breed, slaughtering methods, and cooking techniques. Flavor, which combines aroma and taste, enhances eating pleasure and directly influences consumer purchasing decisions [10]. Flavor can also be boosted through marinating, using various ingredients like fruits, vegetables, salt, vinegar, organic acids, and enzymes [11]. Marinating with these ingredients results in a tender, moist, and more sensory-pleasing product [12]. Marination not only adds flavor but also improves eating quality by impacting texture. Sodium bicarbonate (NaHCO₃), used alongside curing agents, increases chicken tenderness. This process can be sped up using ultrasonic curing instead of traditional methods [13]. It is also known that marinating chicken with lemon juice and ginger reduces fat and cholesterol levels while increasing moisture content [14]. Similar moisture enhancement was achieved with chicken marinated in aronia, grapes, and hawthorn [12]. Overall, marination improves the sensory qualities of chicken, catering to specific flavor preferences. Different marinade types, based on consumer tastes, offer a richer flavor profile and influence standard consumption habits [12, 14, 15].

Several studies have examined the use of kiwi and pomegranate juices in chicken meat marination [16–19]. However, limited information is available on the comparative effects of pineapple, kiwi, and pomegranate when applied in both juice and powder forms, particularly in relation to the textural and descriptive sensory profile properties of chicken meat. In addition, evaluating post-cooking quality characteristics after marination with fruit juices and powders represents a distinctive aspect of the present study. To contribute to the existing literature, this study evaluates physicochemical properties (pH, moisture content, and water activity), color parameters (L*, a*, b*, chroma, and hue), technological properties (marinade absorption, marinade retention, cooking loss, and cooking yield), and texture profile properties. The functional properties of the marinated chicken samples were also assessed through thermal behavior, including denaturation temperature, and antioxidant properties. Therefore, this study aimed to evaluate the effects of antioxidant-rich fruit-derived marinades prepared in juice and powder forms on the physicochemical, technological, textural, thermal, antioxidant, and sensory properties of cooked chicken breast meat.

Materials and methods

Marination

In the preliminary studies carried out, “100gr fillet cut chicken breast meat” was identified as the most appropriate cutting method and sample size for marination in terms of efficiency, cost savings, and suitability for the purpose.

Standard marination content may vary depending on the type of meat, the size of the piece, the age of the animal, and even the slaughtering methods. Therefore, preliminary trials have been conducted for marinating and cooking chicken breast. Standard marinades include “olive oil, salt, black pepper” and “olive oil, salt, black pepper, water” [20]. A deep lidded container (2 L) and 100 g chicken breast fillet were used to standardize the marination process. All marinades were prepared by mixing for 2 min, starting with pouring the liquids into the container first, then adding salt, black pepper, and other marinade ingredients separately, as shown in the examples in Table 1. To determine the best marination options, powder and liquid marination contents were evaluated using the hedonic scale in preliminary trials.

Based on preliminary trials, the standard triple marination formulas were established. Therefore, the marination composition of Control 2 (C2) was set as 100 g olive oil, 10 g salt, and 10 g black pepper, while Control 3 (C3) included 100 g olive oil, 10 g salt, 10 g black pepper, and 100 g water. In other formulations, it was deemed appropriate to mix the liquid components in a 1:1 ratio, matching the total liquid amount in the marination.

Table 1 Marination ingredients and sample codes

| Codes | Marination contents | Content |
|-------|-----------------------------|---|
| C1 | Unmarinated | - |
| C2 | Standard marinade | 100 g olive oil, 10 g salt and 10 g black pepper |
| C3 | Standard marinade. water | 100 gr olive oil, 10 gr salt, 10 gr black pepper and 100 gr water |
| KJ | Kiwi juice marinade | Standard marinade+ 100 g kiwi juice |
| KP | Kiwi powder marinade | Standard marinade+ 20 g kiwi powder |
| PJ | Pineapple juice marinade | Standard marinade+ 100 g pineapple juice |
| PP | Pineapple powder marinade | Standard marinade+ 20 g pineapple powder |
| PMJ | Pomegranate juice marinade | Standard marinade+ 100 g pomegranate juice |
| PMP | Pomegranate powder marinade | Standard marinade+ 20 g pomegranate powder |

Furthermore, based on the results of the preliminary trials, the powdered marinade products that had the most distinctive aroma and the highest acceptability on the hedonic scale were found to be most effective at a level of 20 g.

The mise en place for powder marinade production was prepared using a green-colored board, chef's knife, peeler, 1/2 deep tub, 2/1 perforated tub, wax paper, kiwi, pineapple, pomegranate, lemon, and water. Peeled kiwi and pineapple were soaked in 1% lemon juice to prevent oxidation. They were cut into 3 cm thick pieces using the slicer "Öztiryakiler, Antalya/Türkiye" and placed on greaseproof paper with enough space between them to allow air flow, then positioned on a perforated 2/1 tray. For pomegranate powder, the pomegranate was first separated and crushed with a hand blender "Öztiryakiler, Antalya/Türkiye" to extract its juice. Without any additional straining, the pomegranate puree was placed on wax paper and dried in an industrial oven at 50 °C for 24 h. The dried samples were ground into powder with a coffee grinder.

The liquid marinades were prepared using the necessary mise en place: a 1/2 deep tub, fine-mesh strainer, disposable bonnet, hand blender, kiwi, pineapple, and pomegranate. Once the kiwi and pineapple were peeled, they were chopped into mir pua shapes, placed in a 1/2 deep bowl, and pureed with a hand blender. The puree was filtered through a bonnet in a fine-mesh strainer and transferred to another 1/2 basin, then stored at +4 °C. The peeled pomegranates were pureed for about 2 min with a hand blender, filtered similarly, and stored in an airtight container at +4 °C (Fig. 1).

Preliminary formulation selection

Before the main experiment, preliminary formulation trials were conducted to determine suitable fruit-based marinade formulations for chicken breast meat. Pineapple, kiwi, and pomegranate were selected based on their reported relevance to fruit-based meat marination and their potential effects on acidity, texture, color, antioxidant capacity, and sensory attributes of chicken breast meat [11, 12, 16, 19]. Both juice and powder forms were used to compare the effects of the physical form of the fruit-derived marinade.

The formulation ratios were determined by considering the structure of the standard marinade and the comparability of liquid- and powder-based treatments. For juice-based marinades, 100 g of fruit juice was added to the

standard marinade to provide a 1:1 ratio with olive oil and to maintain comparability with the water-containing standard marinade. For powder-based marinades, 20 g of fruit powder was added to the standard marinade. This amount was selected because it corresponded to the total amount of dry seasoning ingredients in the standard formulation, namely 10 g salt and 10 g black pepper. This approach allowed the juice- and powder-based treatments to be prepared according to a standardized formulation logic.

The preliminary formulations were first evaluated by the researchers in terms of homogeneous coating of the meat surface, absence of excessive surface residue, prevention of excessive softening, visible but acceptable color formation, post-cooking structural integrity, and suitability for sensory evaluation. After these preliminary checks, the formulations considered technologically applicable and sensorially suitable were selected for the main experiment. The selected formulations were then applied under the same marination conditions to ensure comparability among treatment groups.

Physico-chemical characterization

The moisture content (MC) of marinated chicken samples was determined based on the weight change after drying until a constant weight was reached at 105 °C. Trials were carried out in three parallels using approximately 3 g of sample and the results were obtained as an average using a vacuum oven (Elektromag M420P) [21].

MC is calculated using the following equation: W_1 is the initial weight of the tare and sample, W_2 is the final weight of the container's contents, and W_3 is the expressed weight of the sample and container (Eq. 1).

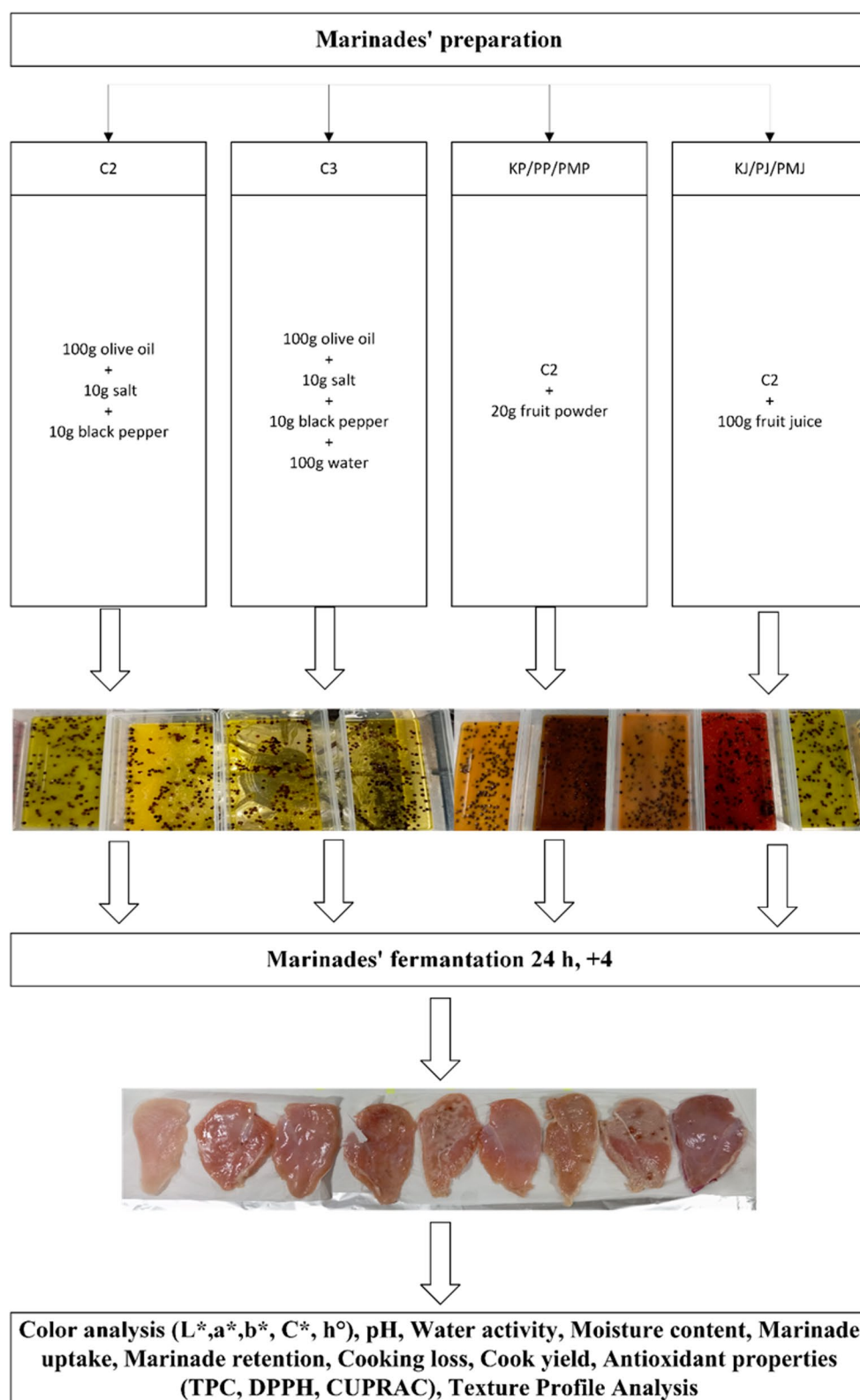
$$MC = (W_1 - W_2) / (W_2 - W_3) \times 300 \quad (1)$$

Water activity (a_w) of marinated chicken breast meats was measured using a water activity meter (FA-st/1 Model, GBX, France) between -25 °C and +30 °C, with a precision of 0.001. pH was measured using a pH meter (Thermo Orion) at 20 ± 1 °C.

Extraction procedure and antioxidant capacity aspects

Ultrasound-assisted extraction was used to prepare samples for analysis. 4 g of each sample were weighed into 50 mL centrifuge tubes. Then, 20 mL of 80% (w/v) methanol was added to each tube. The tubes were placed in an

Fig. 1 Flow charts of powder and liquid marinade preparation and marination process



ultrasonic bath at 40 °C and 40 kHz for 30 min. After this time, the samples were taken out and centrifuged at 4000 rpm for 10 min. Following centrifugation, the liquid phase was transferred to glass sample bottles and stored in the refrigerator.

The Folin-Ciocalteu method was used to quantify total phenolic compounds (TPC) in chicken meat samples, with some modifications, and the results were expressed as gallic acid equivalents (mg/g) [22]. The DPPH (2,2-diphenyl-1-picrylhydrazyl) and CUPRAC (Cu(II) ion reduction antioxidant capacity) methods were used to assess antioxidant capacity [23]. Cu(II) ion reduction antioxidant capacity (CUPRAC) was evaluated using the method described by Apak and Güçlü [24], with some modifications.

Color aspects

A handheld chroma meter (Konica Minolta INC.) was used to measure color characteristics, recorded as L* (darkness/lightness, 0–100), a* (–a=greenness, +a=redness), and b* (–b=blueness, +b=yellowness). Measurements were taken with a spectrophotometer calibrated using a white tile on a flat surface, ensuring the lens made maximum contact with the chicken meat. Measurements were made at three different points [25].

Technological aspects

Technological properties of the marinated chicken breast samples were evaluated by calculating marinade absorption (MA), cooking loss (CL), cooking yield (CY), and marinade retention (MR). Before marination, each chicken breast fillet was cut and standardized to an initial weight of 100 g. This initial weight was recorded as W₀. The samples were then placed in the marinade. After 3 h of marination, the samples were removed from the marinade, allowed to drain briefly to remove excess surface liquid, and weighed. This weight was recorded as W_{3h}. The samples were then kept under refrigerated conditions until the completion of the 24 h marination period and weighed again before cooking. This weight was recorded as W₂₄. The samples were then cooked under standardized conditions, and the final cooked weight was recorded as W_c.

Marinade absorption was calculated to determine the net percentage weight gain of the samples after 24 h of marination using Eq. (2). Cooking loss was calculated from the difference between the weight before cooking and the weight after cooking

using Eq. (3). Cooking yield was calculated as the percentage of cooked meat weight relative to the weight before cooking using Eq. (4). Marinade retention was calculated to determine the proportion of marinade retained at 24 h relative to the weight gain measured after 3 h of marination using Eq. (5).

$$\text{Marinade absorption (\%)} = \left[\frac{W_{24} - W_0}{W_0} \right] \times 100 \quad (2)$$

$$\text{Cooking Loss (\%)} = \left[\frac{W_{24} - W_c}{W_{24}} \right] \times 100 \quad (3)$$

$$\text{Cooking yield (\%)} = \left(\frac{W_c}{W_{24}} \right) \times 100 \quad (4)$$

$$\text{Marinade retention (\%)} = \left[\frac{W_{24} - W_0}{W_{3h} - W_0} \right] \times 100 \quad (5)$$

Where W₀ represents the initial weight of the raw chicken breast sample before marination, W_{3h} represents the weight of the sample after 3 h of marination, W₂₄ represents the weight of the sample after 24 h of marination and before cooking, and W_c represents the weight of the cooked sample. All measurements were performed using the same weighing procedure for each treatment group to ensure comparability among samples.

Texture profile analysis (TPA)

Texture profile analysis (TPA) was conducted using a TA-XT Plus texture analyzer (Stable Micro System, UK) on chicken meat samples, with measurements taken at three different points [26]. The results are given as the average of these measurements. For the analysis, 10 × 10 mm marinated chicken pieces were compressed using a 36 mm diameter stainless steel cylindrical probe at a test speed of 3 mm/s.

Sensorial acceptability

Sensory evaluation was conducted with 10 semi-trained panelists aged between 28 and 41 years. Panelists were selected through a preliminary screening procedure in which basic taste solutions were presented to assess their ability to perceive and discriminate taste intensities. Only panelists who met the requirements for semi-trained sensory evaluation and had no reported oral or dental health problems were included in the panel.

The cooked chicken breast samples were served in portions of approximately 20 g for each panelist, which was considered sufficient for evaluating flavor and texture attributes. Samples were served at an appropriate tasting temperature under controlled sensory evaluation conditions to minimize external effects on sensory perception. Each sample was coded with a random three-digit number and presented to the panelists in a randomized order. Water and unsalted crackers were provided between samples as palate cleansers.

Descriptive profile analysis (DPA) and hedonic acceptability evaluation were carried out together using a 10-point scale. The descriptive profile form included attributes related to appearance, texture, taste, aroma, and general satisfaction. The full descriptive profile analysis form and attribute references are provided in Appendix Table 5.

Ethical approval

Ethical approval for this study was granted by the Scientific Research and Publication Ethics Committee for Science and Engineering at Antalya Bilim University (Decision No: 2025/10, dated June 2, 2025). The study titled “Physico-Chemical Quality Parameters and Sensory Characteristics of Chicken Meat by Marinating with Different Formulations Applied to Chicken Meat” was reviewed and determined to adhere to the institution’s research ethics guidelines. All sensory panelists were adult volunteers who were fully informed about the study procedures and provided their consent beforehand. No personally identifiable information was collected, participation was voluntary, and panelists could withdraw from the study at any time.

Thermal aspects

Thermal properties of marinated chicken meats using fruit juices, powders, and standard marination liquids consisting of salt and olive oil were measured with a Differential Scanning Calorimeter (DSC 7020, HITACHI High-Tech Corporation, Japan). A hermetically sealed aluminum pan containing approximately 10 mg of the sample was subjected to a programmed heating cycle from 25 °C to 110 °C at a rate of 10 °C·min⁻¹ under a continuous nitrogen flow [17].

Statistical analysis

All experimental measurements were performed in triplicate, except for sensory evaluation, which was conducted with 10 semi-trained panelists. The results were expressed

as mean±standard deviation. Statistical analyses were performed using IBM SPSS Statistics version 30.0. Differences among treatment groups were analyzed using one-way analysis of variance (ANOVA). When significant differences were detected, Tukey’s multiple comparison test was used to determine differences between groups. Statistical significance was accepted at $p < 0.05$. Different superscript letters in the same column indicate statistically significant differences among samples.

Results and discussion

When preparing marinated chicken breast meat, “Mise en place” is the first step in all processes. Its importance varies at different stages. For example, when making marinades, it not only helps preserve antioxidants, phenolic compounds, and other nutrients but also aims to limit microbial growth by keeping the chicken at room temperature. On the other hand, gathering all the necessary ingredients during the process reduces time, effort, and food waste, while also making the process safer.

Physico-chemical properties

Some physicochemical parameters, such as MC, pH, and aw values of marinated meats, are shown in Table 2. Marination with fruit powder and fruit juice reduced the pH of chicken breast meat samples compared to control samples ($p \leq 0.05$) (Table 2). When examining the pH levels of chicken breast samples after cooking, it is clear that they are close to acidic values. However, the control 1 sample exhibits a basic characteristic. Samples containing different marinades and olive oil display the acidity traits of the raw materials used in the marinade (olive oil, pineapple, kiwi, pomegranate). The pH values of the powder samples ranged from 6.10 to 6.61, indicating differences in the penetration depth of the powder-form marinades. In contrast, liquid marinades had pH values between 6.42 and 6.45, suggesting more uniform penetration. pH levels in chicken breast fillets from various marinade types and applications were reported by Zhuang and Bowker [27] at 5.86, Lytou et al. [28] between 5.1 and 5.9, Lytou et al. [29] between 4.1 and 5.8, Zhang et al. [30] between 6.24 and 6.58, Evrendilek [31] between 4.90 and 5.30, Singh and Sharma [32] between 5.92 and 6.21, and Çimen et al. [17] between 3.90 and 6.39. Studies on marinating and cooking processes of chicken breasts indicate that marinade type, technique, and duration directly influence the pH values of the samples. The pH values obtained in this study align with those in the literature, although differences exist depending on the marinades used, marination

Table 2 Changes in physicochemical and technological properties of chicken breast meat subjected to various marination methods (Mean±SD)

| Codes | pH | a _w | MC | MA (%) | MR (%) | CL (%) | CY (%) |
|-------|-------------------------|-------------------------|--------------------------|------------------------|-------------------------|--------------------------|--------------------------|
| C1 | 7.76±0.01 ^a | 0.90±0.00 ^{ab} | 67.21±0.01 ^b | 0±0 ^b | 0±0 ^b | 12.08±0.86 ^b | 87.92±0.86 ^b |
| C2 | 6.71±0.01 ^{bc} | 0.85±0.00 ^b | 68.12±0.02 ^b | 1.27±0.06 ^a | 88.89±3.10 ^a | 9.25±0.20 ^a | 90.75±0.20 ^a |
| C3 | 6.90±0.01 ^b | 0.94±0.00 ^a | 74.21±0.01 ^a | 0.96±0.05 ^a | 89.67±5.29 ^a | 10.70±0.12 ^{ab} | 89.30±0.12 ^{ab} |
| PP | 6.27±00 ^d | 0.87±0.00 ^b | 64.41±0.01 ^{bc} | 1.14±0.13 ^a | 89.68±4.27 ^a | 11.11±0.39 ^{ab} | 88.89±0.39 ^{ab} |
| KP | 6.10±00 ^d | 0.89±0.00 ^{ab} | 56.33±0.04 ^c | 1.11±0.22 ^a | 87.30±3.92 ^a | 9.73±0.74 ^a | 90.27±0.74 ^a |
| PMP | 6.61±00 ^{bc} | 0.88±0.00 ^{ab} | 71.4±0.02 ^{ab} | 1.17±0.07 ^a | 89.93±4.34 ^a | 10.00±1.22 ^{ab} | 90.00±1.22 ^{ab} |
| PJ | 6.45±00 ^c | 0.86±0.00 ^b | 71.3±0.00 ^{ab} | 1.18±0.03 ^a | 89.05±3.55 ^a | 9.73±1.30 ^a | 90.27±1.30 ^a |
| KJ | 6.47±0.01 ^c | 0.96±0.00 ^a | 65.8±0.00 ^b | 1.20±0.21 ^a | 89.40±2.78 ^a | 11.26±0.92 ^{ab} | 88.74±0.92 ^{ab} |
| PMJ | 6.42±00 ^c | 0.88±0.00 ^{ab} | 54.6±0.00 ^c | 1.15±0.04 ^a | 91.03±0.43 ^a | 10.92±0.61 ^{ab} | 89.08±0.61 ^{ab} |
| p | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | <0.009 | <0.009 |

Values represent the mean±standard deviation. Different superscript letters within the same row are significantly different ($p < 0.05$)

C1. control 1 group unmarinated. C2. control 2 group standard marinated; C3. control 3 group. standard marinated with water; PP: Pineapple powder. KP: Kiwi powder. PMP: pomegranate powder. PJ pineapple juice, KJ kiwi juice, PMJ pomegranate juice, MA Marinade absorption, MR Marinade retention, CL Cooking loss, FY Final yield

methods, and duration. Notably, literature suggests that longer marination periods tend to increase pH values. Statistical analysis revealed a significant difference between the samples ($p < 0.001$).

Water activity values of cooked chicken breast samples range from 0.85 to 0.96 (Table 2). Among the control groups, the control 2 sample marinated only with oil had lower values than the control 3 sample marinated with a mixture of water and oil. This suggests that water in marinades positively influences water activity after cooking. In the other samples, this effect was only observed in kiwi marinades (powder-juice), while similar results appeared in the other marinade samples regardless of their form. Statistical analysis shows a significant difference between the samples ($p < 0.001$).

Moisture content of chicken breast samples ranges from 54.6 to 74.21 (Table 2). These values indicate the percentage of the sample’s weight that is water. This is especially evident in control 3, where oil and water are used in equal

amounts. Additionally, based on data from the panelists in the Descriptive Profile Analysis, this sample has the highest moisture content. Statistical analysis shows a significant difference between the samples ($p < 0.001$).

Color properties

Chicken breast samples were examined for color changes after cooking (Fig. 2.a, Fig. 2.b). The L* (Lightness) value of our unmarinated control 1 sample was 66.13. The values of our marinated samples ranged from 69.10 to 38.70. It was observed that 29.90 was comparable to the value reported in the literature for traditional open pan-fried chicken breast meat [33]. There appears to be an increase in the L* values of marinated chicken breast samples [34]. In contrast, the control 1 sample without marinade had higher L* values, likely because it was aged under the same conditions (heat, light, time, etc.) while the other samples underwent marination. Additionally, the stability

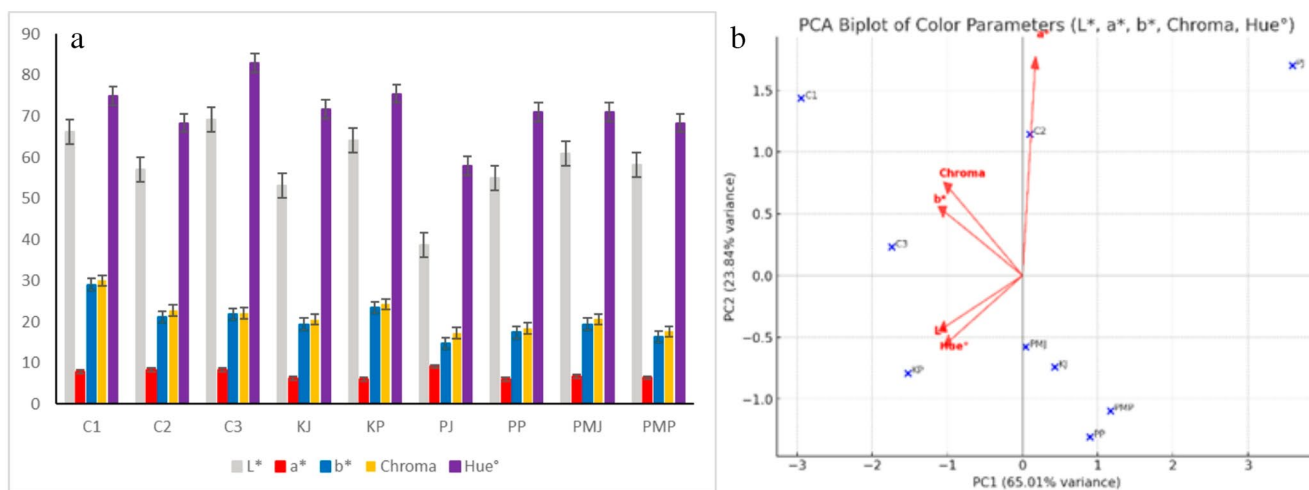


Fig. 2 a Color scores of the chicken breast meats treated with different marinades, b. Principle component analysis biplot of color parameters

during cooking allowed us to obtain similar results across samples. The L^* value of raw chicken breast fillet meat stored in the refrigerator for 4 h was 53.1 and increased to 58.3 after 48 h [27]. Kartepe et al. [34] reported that in their rhubarb juice-based chicken breast marinade studies, higher L^* values correlated with lower pH. In our study, pineapple juice with low pH had the lowest L^* value (38.38.70) among the juice-based marinades, but the other samples did not show an increase proportionate to pH. However, the marinated chicken with kiwi powder, which had the lowest pH among the powdered samples, also had the lowest L^* value (53.53.20). Singh and Sharma [32] conducted a study on ultra-fast air-cooled broilers and marinated chicken breast fillets, obtaining L^* values between 50.70 and 52.58. Çimen et al. [17] reported L^* values ranging from 53.47 to 65.52 in ultrasound-assisted marination of spent chicken breast meat. Akdemir Evrendilek [31] found L^* values between 50.33 and 61.23 in a study involving marinization and high hydrostatic pressure treatment of minced chicken breast, which are similar to our results. This increase in L^* values appeared to correspond with higher pH in powdered marinades. Statistical analysis indicated significant differences among all samples ($p < 0.001$).

It was observed that the a^* value, which indicates redness and greenness among color values, was 7.87 in control 1 samples. This value increased in the control 2 group marinated with oil to 8.40, while it decreased in the control 3 group marinated with water and oil to 2.77. In other marinated samples, there was an increase in redness according to the color of the marinade. For example, the sample with the lowest value, 6.03, was the yellow marinade pineapple, while the sample with the highest value, 6.47–9.20, was the pomegranate sample. The main point to note here is that liquid marinades reflect the color values better than powder marinades for samples of this color. When examining this process among samples that can produce red and green colors, as mentioned in the study of Kartepe et al. [34], low pH caused us to obtain low a^* values. Singh and Sharma [32] conducted a study on ultra-fast air-cooled broilers and marinated chicken breast fillets and obtained a^* values between 3.45 and 3.53. Çimen et al. [17] reported a^* values between 0.33 and 2.70 in the ultrasound-assisted marinating process of spent chicken breast meat. Yusop et al. [35] found a^* values between 11.82 and 14.74 in their study on the effect of processing method and waiting time on the physical and sensory qualities of cooked marinated chicken breast fillets. The a^* values presented in the literature and this study show both differences and similarities.

This is mainly due to the redness and greenness indicated by the a^* value, which varies because the colors of the marinades used in the studies differ from each other. This situation directly influences the results. As a result of statistical analysis, there is a significant difference between the samples ($p < 0.001$).

Among the color parameters, the b^* value indicates the level of yellowness-blueness. All sample color values are positive, showing that all samples lean toward yellow tones. Control groups had the highest b^* values, ranging from 21.20 to 29.10. The sample with the highest b^* value of 29.10 was control 1. Among samples with different marinades, the one with pineapple juice had the highest value at 23.47. Zhuang and Bowker's [27] study on the effect of marinization on b^* values reported ranges between 9.5 and 13.0. Yusop et al. [35] found b^* values between 18.46 and 23.90 when examining how processing methods and waiting times affect the physical and sensory qualities of cooked marinated chicken breast fillets. Chicken breast studies show that most b^* values vary whether raw or cooked, mainly because of different marinades used during preparation. Statistical analysis reveals a significant difference between the samples ($p < 0.001$).

C^* (Chroma) values indicate the brightness intensity of the samples. These values range from 17.37 to 30.10. It is clear that all samples fall within the bright color category. The highest value, 30.10, is observed in the Control 1 sample. When comparing powder and juice marinades, we find that juice marinades tend to have higher C^* values. However, when analyzed separately, there is no difference in kiwi (powder-juice) and pomegranate (powder-juice) marinades. The main difference is seen in pineapples (powder-juice). Statistical analysis shows a significant difference among the samples ($p < 0.001$).

h° values indicate color tones. All marinated and cooked chicken breast samples exhibited color tones ranging from red (0°) to green (90°). The sample values ranged from 58.00 to 82.97, which are notably closer to green hues. The lowest value was observed in samples with pomegranate (anthocyanin) marinade (powder-juice), indicating a positive result for the sample using pomegranate marinade, as it should exhibit the highest redness value. The control 1 sample approaches the redness value of control 2, which contains basic spice and oil, while the control 3 sample, including basic spice, oil, and water, approaches the greenness value. Statistical analysis reveals a significant difference among the samples ($p < 0.001$).

Technological properties

Changes in the technological properties of chicken meat after marination were monitored using marinade absorption (MA), marinade retention (MR), cooking loss (CL), and cooking yield (CY) levels (Table 2). When examining MA values, it is observed that marinade uptake remained low across all marinated samples. This primarily depends on the marinating method and the pH characteristics of the marinades. Low pH marinades denature meat proteins and hinder the penetration of marinades as the waiting time increases [35, 36].

The amount of marinade absorbed during the marination process directly influences the water-holding capacity of the meat. Greater absorption allows acidic components and dietary fibers from fruits or vegetables to interact more effectively with muscle tissue. This interaction causes structural changes in the muscle fibers, leading to an expansion of the protein network and, ultimately, better water retention. Conversely, acidic components lower the pH of the meat, increasing electrostatic repulsion among myofibrillar proteins, which results in a more relaxed protein structure and space capable of holding water. Additionally, dietary fibers naturally present in fruits and vegetables strongly bind water and form polymeric structures, creating a more complex network within the meat matrix. As a result, increased marinade uptake enhances water-holding capacity through both chemical mechanisms (pH changes, ionic interactions) and physical mechanisms (fiber swelling, water binding) [37].

Freezing, thawing, and sub-sampling affect the marination process of chicken breast meat. In a study, the marination values for fresh whole chicken breasts marinated for 15, 30, and 45 min ranged between 5.34 and 10.14 [35]. A separate study on how processing methods and holding times influence the physical and sensory qualities of cooked marinated chicken breast fillets shows that the marinade uptake value from the dipping method is 1.34. It was explained that the marinating method and duration are key factors. The explanation also noted that, especially as time increases, penetration decreases, and the immersion method results in the least penetration. Based on these findings, we can conclude that using the immersion method and longer marination times lower marinade uptake values.

Marinade retention values were generally consistent with the marinade uptake pattern observed in the present study and with values reported in the literature. The MR values of the marinated samples were close to each other, ranging approximately between 87.30% and 91.03%. Although C1 was coded as 0 because no marinade was applied, the MR values among the marinated treatments were generally similar. Bowker and Zhuang [36] have reported that freezing-thawing and sub-sampling affect the marination performance of chicken breast

meat, with the study showing that the values obtained from the whole chicken breast range between 85.7 and 86.7.

Cooking loss values ranged from 9.25% to 12.08%, with C1 showing the highest value and C2 showing the lowest value. A statistically significant difference was observed among the samples for cooking loss. This is mainly because of efforts to keep the process consistent. These efforts included preparing the marinade under the same conditions, marinating uniformly, and cooking in a controlled manner as similar as possible. Barbanti and Pasquini [38], in their study on the “Influence of cooking conditions on cooking loss and tenderness of raw and marinated chicken breast meat,” stated that the highest cooking loss occurred at 150 degrees for 4 min, the lowest at 130 degrees, and the median at 170 degrees. Compared with those values, the cooking loss values obtained in the present study were relatively low. This is because samples cooked at 200 degrees for 4 min quickly seal and do not release their internal liquids.

The cooking yield of the chicken breast samples ranged from 87.92% to 90.75%. The similarity of these values is important for the study’s stability, as the cooking loss values support this. Additionally, similar results have been reported in chicken breast studies in the literature [32, 36].

Antioxidant properties

Bioactive compounds, especially phenolics in fruits and vegetables, are essential for antioxidant activity [39]. Variations in total phenol content among control samples, affected by olive oil and spice levels, are statistically significant ($p < 0.05$) (Table 3). Overall, marinating with fruit juice and powder significantly boosted the total

Table 3 Effects of kiwi, pineapple, and pomegranate juices and powders on the antioxidant properties evaluated as TPC, CUPRAC and DPPH values of chicken breast samples (Different superscript letters within the same row are significantly different ($p < 0.05$) by Tukey test)

| Sample | TPC | CUPRAC | DPPH |
|--------|------------------------------|----------------------------|-----------------------------|
| C1 | 199.20 ± 22.00 ^c | 2.227 ± 0.256 ^a | 6.853 ± 0.005 ^c |
| C2 | 300.87 ± 12.31 ^b | 2.997 ± 0.175 ^b | 7.838 ± 0.044 ^b |
| C3 | 301.90 ± 19.00 ^b | 2.917 ± 0.162 ^b | 7.814 ± 0.014 ^b |
| KJ | 449.50 ± 47.40 ^a | 3.416 ± 0.055 ^b | 7.991 ± 0.082 ^{ab} |
| KP | 401.97 ± 6.58 ^a | 2.702 ± 0.013 ^b | 8.024 ± 0.038 ^{ab} |
| PJ | 479.98 ± 4.52 ^a | 3.353 ± 0.095 ^b | 8.060 ± 0.102 ^a |
| PP | 394.40 ± 23.70 ^a | 3.527 ± 0.297 ^b | 7.885 ± 0.023 ^{ab} |
| PMJ | 282.10 ± 31.40 ^{bc} | 3.161 ± 0.056 ^b | 7.844 ± 0.060 ^b |
| PMP | 396.00 ± 59.10 ^a | 3.030 ± 0.581 ^b | 7.990 ± 0.034 ^{ab} |

C1. control 1 group unmarinated. C2. control 2 group standard marinated; C3. control 3 group. standard marinated with water; PP: Pineapple powder. KP: Kiwi powder. PMP: pomegranate powder. PJ pineapple juice, KJ kiwi juice, PMJ pomegranate juice, MA Marinade absorption, MR Marinade retention, CL Cooking loss, FY Final yield

phenol content in all samples ($p < 0.05$). The chicken breast marinated with pineapple juice (PJ) exhibited the highest TPC value. Samples marinated with kiwi juice (KJ) and pomegranate powder (PMP) followed. It has been reported that TBARS values, which indicate oxidation in meat products, are reduced by marinating with vegetable and fruit products containing polyphenols [40, 41].

CUPRAC and DPPH values of all samples did not show any correlation with TPC values (Table 3). Although the marination process increased CUPRAC values in all samples ($p < 0.05$), the effects of fruit juice and fruit powder marinades were not significant. DPPH values of marinated chicken breast samples showed a significant difference from the control groups ($p < 0.05$). Similar results have been reported in marination studies with different fruit juices [42].

Texture profile aspects

Textural parameters of meat samples varied significantly across control and treatment groups, reflecting the distinct effects of fruit-derived marination media and their physical states (powder vs. juice) (Table 4). The hardness of samples increased markedly ($p = 0.002$) in marinated groups compared with the unmarinated control (C1), with the highest value recorded in the *kiwi powder* (KP; 5995.25 ± 137.57 N). This pronounced increase indicates effective proteolytic and cross-linking interactions during marination, which may have contributed to the tightening of the myofibrillar matrix. Kiwi and pineapple are known to contain actin and myosin degrading enzymes such as *actinidin* and *bromelain*, which initially soften the tissue but can also promote reorganization and compaction upon heating, depending on concentration and exposure time. The *pomegranate powder* (PMP) group also demonstrated relatively high hardness, possibly related to phenolic-protein crosslinking effects reported for punicalagin-containing systems. Conversely, juice-treated samples generally exhibited lower hardness values (PJ, KJ, PMJ), indicating that dilution of enzymatic or phenolic activity in liquid marinades limited structural reintegration following proteolysis.

No significant difference was found in adhesiveness among all treatments ($p = 0.077$). The homogeneous range of values (-0.86 to -5.16 N) suggests that surface tackiness was not strongly influenced by fruit type or processing form. This consistency may be due to similar post-cooking moisture release rates across treatments.

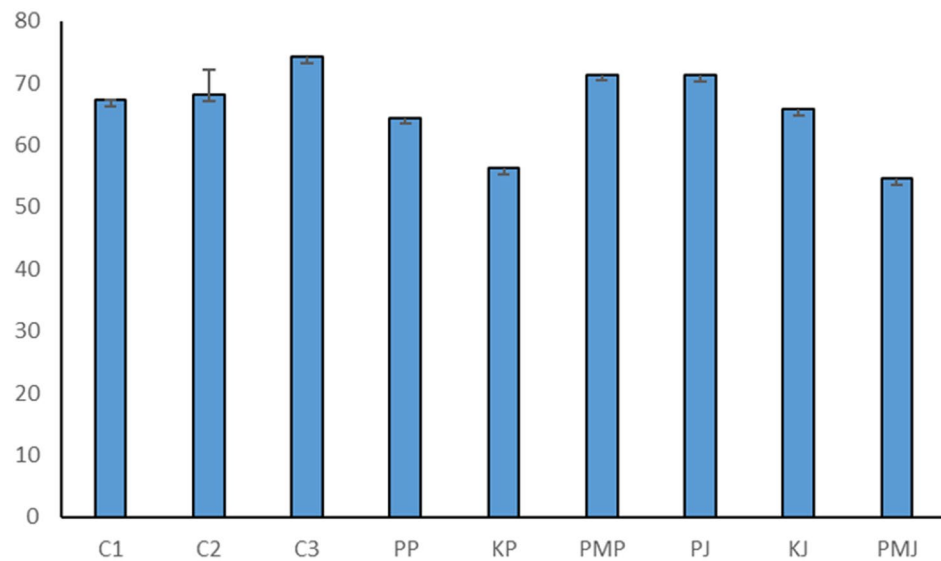
The springiness parameter showed no statistical variation ($p = 0.35$), remaining between 0.84 and 0.96 mm. This stability implies that the elastic recovery of samples

Table 4 Textural properties of different juice and powder marinated chicken breast meats

| | Control | | | Powder | | | Juice | | | P |
|--------------------|-----------------------------|--------------------------------|------------------------------|-----------------------------|-------------------------------|-------------------------------|------------------------------|-------------------------------|------------------------------|--------|
| | 1 | 2 | 3 | PP | KP | PMP | PJ | KJ | PMJ | |
| Hardness (N) | 1615.20±539.50 ^c | 4577.48±1210.67 ^{abc} | 3241.32±468.53 ^{bc} | 3618.71±275.18 ^a | 5995.25±137.57 ^{abc} | 2961.37±823.74 ^{bc} | 2921.2±217.55 ^c | 1779.9±250.08 ^{bc} | 3111.88±924.32 ^{bc} | 0.002 |
| Adhesiveness | -0.86±0.39 ^a | -4.96±2.47 ^a | -2.66±0.31 ^a | -1.95±0.09 ^a | -3.17±2.37 ^a | -2.51±0.54 ^a | -1.51±0.95 ^a | -5.16±0.07 ^a | -3.19±0.75 ^a | 0.077 |
| Springiness (mm) | 0.92±0.03 ^a | 0.96±0.06 ^a | 0.91±0.04 ^a | 0.85±0.02 ^a | 0.87±0.06 ^a | 0.89±0.04 ^a | 0.84±0.10 ^a | 0.93±0.04 ^a | 0.96±0.05 ^a | 0.35 |
| Cohesiveness | 0.73±0.01 ^c | 0.85±0.02 ^{bc} | 0.89±0.04 ^a | 0.79±0.00 ^{ab} | 0.87±0.00 ^{ab} | 0.81±0.00 ^{cd} | 0.75±0.01 ^{bc} | 0.85±0.01 ^{de} | 0.84±0.02 ^{abc} | <0.001 |
| Gumminess (N) | 1215.63±434.73 ^a | 3872.78±1137.09 ^a | 3689.61±554.4 ^a | 2511.43±271.83 ^a | 4101.61±1430.87 ^a | 3563.08±988.1 ^a | 2177.64±144.74 ^a | 1515.1±203.36 ^a | 2547.29±639.11 ^a | 0.033 |
| Chewiness (N × mm) | 1080.92±412.98 ^b | 3730.83±1314.3 ^{ab} | 3426.69±230.16 ^{ab} | 2035.98±151.19 ^a | 4508.14±389.33 ^{ab} | 3333.66±1002.03 ^{ab} | 1839.51±331.70 ^{ab} | 2801.71±1725.12 ^{ab} | 2422.6±481.54 ^{ab} | 0.053 |
| Resilience | 0.42±0.01 ^c | 0.55±0.04 ^{ab} | 0.55±0.03 ^{ba} | 0.51±0.06 ^a | 0.65±0.01 ^{bc} | 0.50±0.00 ^{bc} | 0.42±0.00 ^{bc} | 0.52±0.01 ^c | 0.48±0.04 ^{bc} | <0.001 |

Mean±s.d. Error: The values marked with different letters in the same column are statistically different from each other ($P < 0.05$). C1: Control 1 group unmarinated, C2: Control 2 group standard marinated with water; PP Pineapple powder marination, KP Kiwi powder marination, PMP Pomegranate powder marination, PJ Pineapple juice marination, KJ Kiwi juice marination, PMJ Pomegranate juice marination

Fig. 3 Thermal denaturation temperatures of chicken meats marinated in different fruit powders and juices (C1. control 1 group unmarinated. C2. control 2 group standard marinated; C3. control 3 group. standard marinated with water; PP: Pineapple powder. KP: Kiwi powder. PMP: pomegranate powder. PJ: pineapple juice. KJ: kiwi juice)



after deformation was largely preserved regardless of marination medium, aligning with previous reports where enzymatic tenderization altered hardness more significantly than elastic resilience (Zhang et al., 2020).

In contrast, cohesiveness exhibited marked differences ($p < 0.001$). The highest values were observed in the *standard marinated control* (C3) and *pomegranate powder* (PMP) group (0.89 ± 0.04 and 0.87 ± 0.00 , respectively), while the *unmarinated control* (C1) showed the lowest (0.73 ± 0.01). Enhanced cohesiveness can be attributed to the stabilization of the protein network by polyphenolic compounds and by modified water–protein interactions promoted through acidification during marination. The improved internal bonding in PMP and KP samples signifies a denser matrix resistant to structural rupture during compression.

Similarly, gumminess and chewiness followed the trend of hardness, with generally higher values for marinated samples ($p = 0.033$ and $p = 0.053$, respectively). These parameters, which represent the energy required to masticate the sample until it is ready for swallowing, reflect both the deformation resistance and the cohesive strength of the tissue. Powder-based marinades (particularly KP and PMP) yielded tougher textures, possibly beneficial for products requiring higher mechanical resilience during processing and storage. Juice treatments, notably *kiwi* and *pomegranate*

juices, led to intermediate gumminess and chewiness, likely due to partial enzymatic softening counteracted by phenolic cross-linking during thermal denaturation.

Resilience values were also significantly different among groups ($p < 0.001$). The *kiwi powder* (KP) and *pomegranate powder* (PMP) treatments resulted in the most elastic systems (0.65 ± 0.01 and 0.55 ± 0.04 , respectively). Their higher resilience implies that the protein matrix could recover faster after deformation, consistent with previously reported synergistic effects of protease–phenolic interactions that lead to secondary cross-linking after cooking (Sun et al., 2021). In contrast, juice-based marinades yielded lower resilience, possibly reflecting less structured protein–polyphenol assemblies.

Overall, the results indicate that both the origin of the fruit and the physical form of the marinade play crucial roles in determining the microstructural and mechanical properties of marinated meat. Powder forms, with their higher concentration of bioactive compounds and solids, enhanced structural integration and elasticity, while juices acted more as tenderizing and hydrating agents. These findings underline the dual role of plant-derived marinades as enzymatic tenderizers and as functional binders through phenolic–protein interactions and highlight their potential to tailor the texture and sensory quality of meat products.

Thermal aspects

This study observed that applying water-based marinades increased the thermal denaturation temperature of chicken meat proteins (Fig. 3). This result goes against the usual expectation that higher water content lowers protein thermal stability, indicating that in some cases, water can actually help stabilize protein structure.

The thermal behavior of proteins is closely connected to water–protein interactions at the molecular level. According to Damodaran [43], the hydration shell formed by water molecules around proteins can enhance structural stability and increase the denaturation temperature. When sufficient water molecules are present, a more organized layer of hydrogen bonds can develop on the protein surface, preventing direct contact between hydrophobic regions and thus protecting the protein from thermal unfolding.

Additionally, the composition of the marinade—including water, salts, organic acids, or sugars—can greatly influence this behavior. At low salt levels, the so-called “salting-in” effect increases protein solubility and hydration, which then enhances thermal stability [44, 45]. These ionic interactions, especially in myofibrillar proteins, may prevent tight aggregation of protein chains and help maintain heat-resistant conformations.

Tornberg [46] reported that the thermal stability of muscle proteins is influenced by environmental factors such as pH, ionic strength, and water content. In this context, the increased water content in the marinade may have caused slower heat transfer within the meat matrix, delaying thermal transitions. In DSC thermograms, this effect could manifest as a shift of denaturation peaks toward higher temperatures.

Similarly, Zhang et al. [46] demonstrated that environments with high water activity can restrict the conformational flexibility of proteins, thereby increasing their thermal denaturation temperature. This finding aligns well with the results of the current study. Overall, the rise in denaturation temperature observed in water-containing marinades can be explained by multiple factors, including protein hydration dynamics, ionic interactions, pH buffering effects, and the heat transfer properties of the marinade. These results highlight that marinade formulations should be optimized not only for sensory and textural qualities but also for protein stability and heat resistance during processing.

Descriptive profile characteristics

Comparing the information in the descriptive profile analysis with the physicochemical analysis provides insight into the process’s accuracy (Fig. 4). Regarding surface properties, control 3 shows the highest values. When examining the samples, it is clear that the marinades in liquid and powder form are very similar. However, for a single sample, the PMP sample has higher surface values than its liquid counterpart, PMJ. A similar trend is seen with KP. The highest values for physical properties such as chewability, hardness, moisture, and brittleness belong to control 3. Overall, liquid marinades had higher physical property values. Juice marinades scored higher in taste and aroma, probably because juice leaves a better flavor and aroma. In the hedonic test, significant increases are observed in the other samples compared to control 1, indicating that the marinade treatment positively affected the panelists. Additionally, samples prepared with juice marinades generally received higher hedonic test scores.

Conclusion

Overall, the findings of this study highlight the considerable potential of natural fruit-based liquid marinades as multifunctional ingredients for industrial poultry processing and consumer-oriented product development. Juice-based marinades, particularly those formulated with pomegranate, pineapple, and kiwi, not only improved physicochemical and textural properties but also enhanced sensory quality and consumer acceptance compared with powder-based systems. The observed improvements in color intensity, moisture retention, tenderness, juiciness, and flavor perception demonstrate the technological advantages of liquid marinades in producing high-quality poultry products with superior eating characteristics. From an industrial perspective, these formulations may contribute to improved process efficiency, product consistency, and yield while simultaneously supporting clean-label production approaches through the utilization of natural ingredients. Furthermore, the strong consumer preference and increased willingness for repeated consumption associated with juice-marinated samples emphasize their commercial relevance for the development of innovative, premium-value poultry products tailored to evolving market expectations for naturalness, sensory satisfaction, and enhanced eating quality.

4. Descriptive Profile Analysis (DPA) Heatmap of Marinated Chicken Breast Samples

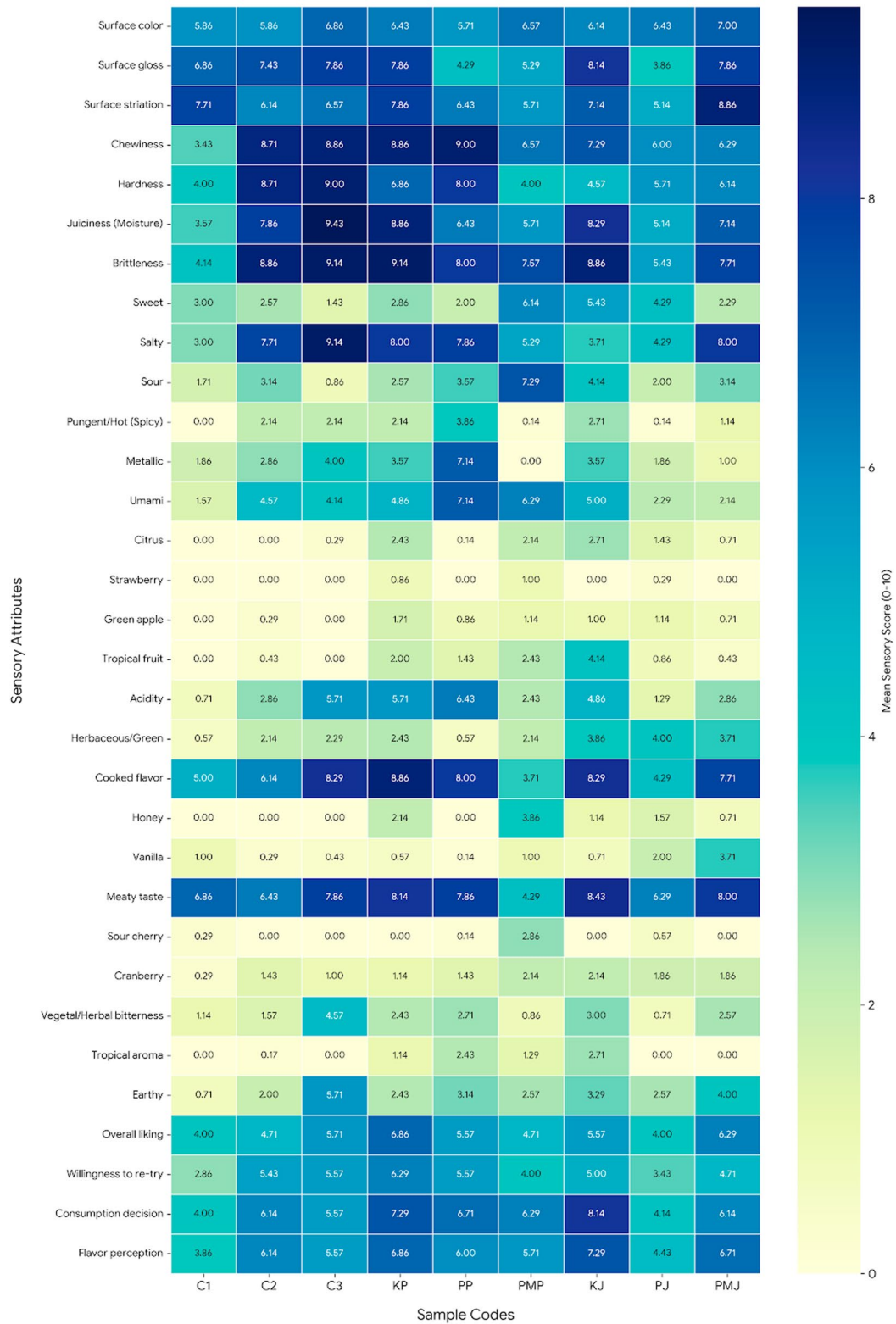


Fig. 4 Descriptive profile analysis characteristics of juice and powder marinated chicken meat samples (Mean ± std. Error)

Appendix

Table 5 Descriptive Profile Analysis Scale

Descriptive Profile Analysis Form

| | |
|--|--|
| Sample Code: | Occupation: |
| Name-Surname: | Gender: |
| Age: | Education: |
| Evaluate each sample from left to right for each attribute. On the line scale, assign a score from 0 to 10 by marking a vertical line | |
| A. Appearance Attributes | |
| 1. Surface color: Indicates the change in the surface color after cooking from pink to dark brown. | |
| Reference: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 1.1. Raw chicken meat: Pink (0) | |
| 1.2. Cooked chicken meat: Dark brown (10) | |
| 2. Surface brightness: Indicates the degree of light reflection after cooking. | |
| Reference: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 2.1. Dull dark brown (0) | |
| 2.2. Bright dark brown (10) | |
| 3. Surface line structure: Indicates the prominence of the marks formed during cooking. | |
| Reference: | |
| 3.1. Cooking marks on the surface of cooked chicken meat are not prominent (0) | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 3.2. Cooking marks on the surface of cooked chicken meat are prominent (10) | |
| B. Texture Attributes | |
| 1. Chewiness: Indicates the ease of chewing. | |
| Reference: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 1.1. Difficulty during chewing (0) | |
| 1.2. Easy chewing (10) | |
| 2. Hardness: Indicates the degree of force applied during chewing. | |
| Reference: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 2.1. High force required during chewing (0) | |
| 2.2. Low force required during chewing (10) | |
| 3. Moistness: Indicates the perceived moisture level based on the water present in the product after chewing. | |
| Reference: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 3.1. Dryness perceived after chewing (0) | |
| 3.2. Moistness perceived after chewing (10) | |
| 4. Fibrousness (friability): Indicates the amount of particles formed during chewing. | |
| Reference: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 4.1. Does not break into small pieces during chewing (0) | |
| 4.2. Breaks into small pieces during chewing (10) | |
| C. Taste Attributes | |
| 1. Sweetness: Indicates the degree of sweetness given to the product by sugar and other sweeteners. | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 2. Saltiness: Indicates the intensity of the basic taste associated with salt. | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 3. Sourness: Indicates the amount of lactic acid perceived in the product. | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 4. Bitterness: Indicates the harsh and sharp taste produced by compounds such as caffeine, aloin, or hops. | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 5. Metallic taste: Indicates the sensation of metal in the mouth produced by iron, zinc, or other metals. | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 6. Umami: Indicates a savory and satisfying taste, such as broth or soy sauce, provided by compounds such as glutamate, inosinate, or guanylate. | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| D. Aroma Attributes | |
| 1. Citrus: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 2. Strawberry: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 3. Green apple: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 4. Tropical: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 5. Acidity: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 6. Herbal-green: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 7. Cooked flavor: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 8. Honey: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 9. Vanilla: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |
| 10. Meat flavor: | 0 - 1 - 2 - 3 - 4 - 5 - 6 - 7 - 8 - 9 - 10 |

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Data availability Data will be made available on request.

Declarations

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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