Research Article

Optimization of Retort Pouch Processing for Indonesian Spiced Duck (Bebek Ungkep): Effects on Physicochemical, Texture, and Nutritional Characteristics

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Abstract | Bebek ungkep, a traditional Indonesian spiced duck, is renowned in Indonesia for its deep flavor penetration and distinctive spiciness. Appropriate packaging technologies, such as retort processing, are needed to extend the shelf life of bebek ungkep while preserving product quality and ensuring accessibility for small- and medium-scale enterprises. The primary objective of this study is to examine the effects of retort pouch sterilization at varying processing times on the physicochemical properties, texture, and nutrient composition of bebek ungkep. Peking duck breast meat was processed into bebek ungkep and subjected to retort sterilization for 10, 20, or 30 minutes, with a frozen control. Analyses of physicochemical, textural, and nutritional attributes were performed on days 0, 7, 14, and 21 of storage. The study demonstrated variations in the physicochemical characteristics among bebek ungkep treatments. Retort processing for 10 and 30 minutes significantly increased lightness (*L**) compared with frozen treatment ($p < 0.05$), while redness (*a**) values decreased ($p < 0.05$). Texture analysis revealed that frozen bebek ungkep consistently exhibited the highest hardness values relative to retort-processed samples ($p < 0.05$). TBARS values increased progressively with storage duration ($p < 0.05$), with the highest level observed in frozen samples after 21 days (1.59 mg MDA/kg; $p < 0.05$). Sensory evaluation indicated that only the 10-minute retort treatment-maintained acceptability comparable to frozen controls, whereas the 20- and 30-minute retort treatments received significantly lower scores, particularly after 7 days of storage ($p < 0.05$). In conclusion, retort processing for 10 or 20 minutes produced bebek ungkep with physicochemical and sensory characteristics comparable to those of frozen controls. In addition, retort treatment tended to suppress lipid oxidation, as reflected by lower TBARS values compared to frozen samples.

Keywords | Bebek ungkep, Physicochemical, Retort, Storage, Texture

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INTRODUCTION

Among Indonesia's traditional cuisines, bebek ungkep is particularly popular. It consists of duck meat cooked slowly at 92–96 °C, allowing the seasoning to penetrate the meat thoroughly (Mardiana *et al*., 2023). Nafisah *et al*. (2024) reported that the ungkepan technique, also known as slow boiling or braising, is a traditional Indonesian culinary practice preserved for generations. In this method, ingredients seasoned or marinated in spices are cooked gently over low heat for an extended period, allowing flavors to penetrate deeply into the food. The dish is particularly renowned in Java, Indonesia's most populous island, where its distinctive flavor profile and pronounced spiciness are highly appreciated. Nevertheless, Mardiana *et al*. (2023) highlighted a major drawback: the product's shelf life is relatively short, largely due to its moist characteristics and nutrient-rich composition, which make it susceptible to rapid deterioration. A suitable packaging technology is required to extend shelf life without compromising product quality or flavor. Moreover, such processing should remain accessible to small- and medium-scale enterprises. One promising option is the application of retort technology.

Syukri *et al*. (2025) reported that retortable pouches integrate the benefits of plastic films and metal cans, providing a practical, convenient, and economical packaging format. They are easy to open and ensure efficient heat transfer during thermal processing. Retorting is a thermal processing method that has gained increasing importance due to its multiple advantages, particularly its ability to inactivate spoilage microorganisms (Rather *et al*., 2024). The packaging material features a multi-layered, flexible structure that withstands high temperatures and pressure during sterilization or pasteurization (Nurhikmat *et al*., 2023). Retorting has become widespread globally, primarily to extend the shelf life of various traditional food products. In addition to supporting food preservation, retort pouch technology is already well recognized among consumers. Consumers show a growing preference for ready-to-eat foods with extended shelf life, particularly those produced through sterilization and packaged in retort pouches (Thephuttee and Theprugsa, 2020). Moreover, retorting is considered effective in preserving the texture and flavor of these foods. The application of retort pouch packaging to Rogan josh, a traditional Kashmiri meat curry, was reported to extend its shelf life to 12 months while maintaining acceptable sensory quality (Shah *et al*., 2017). Chettinad chicken, a traditional spicy curry from Tamil Nadu, processed in retort pouches, has been shown to tenderize tough meat while preserving sensory quality over a 180-day storage period (Rajan *et al*., 2014). Chuncheon Dakgalbi, a traditional Korean dish, when processed in retort pouches and cooked at 110 °C under 0.75 kgf/cm^2 pressure for 30 minutes, exhibited higher sensory scores for taste and texture (Muhlisin *et al*., 2013). Retort technology contributes to the popularization and effective utilization of heritage meat products, while ensuring a consistent supply of ready-to-eat convenience foods with cultural value (Rajkumar *et al*., 2010).

Several studies on the application of retort pouch technology to traditional meat-based foods have been conducted in Indonesia. For example, the use of retort pouch packaging in mutton tongseng, a traditional Indonesian dish, was shown to extend shelf life up to 93 days at ambient temperature (25 °C) (Sugiarto *et al*., 2024). Nurhikmat *et al*. (2023) developed innovations in retort processing for traditional foods such as ayam taliwang and sate rembiga, aiming to meet the qualifications of the Indonesian Food and Drug Authority (BPOM) as part of efforts to ensure consumer food safety. The quality of products after retorting is also influenced by the cooking duration applied during the retort process. Previous studies on retort processing of traditional foods have employed varying durations, including 10–30 minutes (Muhlisin *et al*., 2013), 36 minutes (Rajan *et al*., 2014), 7–11 minutes (Shah *et al*., 2017), 10–12 minutes (Thephuttee and Theprugsa, 2020), and 50 minutes (Rather *et al*., 2024). Regarding retorting time, it is essential to establish optimal conditions to ensure product safety, appearance, and taste. To date, no comprehensive information is available regarding the effects of varying retort processing times on the physicochemical properties, texture, and nutrient composition of bebek ungkep. Previous research on retort technology applied to bebek ungkep has primarily focused on consumer acceptance and nutrient conditions under a single retort treatment (Mardiana *et al*., 2023), without examining product characteristics across different retort durations. The findings of this study are expected to provide valuable insights for culinary industry practitioners in Indonesia who apply retort technology to bebek ungkep products. The primary objective of the research is to investigate the effects of retort pouch sterilization at different processing times on the physicochemical characteristics, texture, and nutrient composition of bebek ungkep.

MATERIALS AND METHODS

Material preparation

The raw material consisted of Peking duck breast meat, which was trimmed of feathers and excess fat before being cut into portion sizes. Marination was performed using a traditional Indonesian spice blend (garlic, coriander, galangal, bay leaves, and salt) homogenized with water, and samples were kept at ±4 °C for 3 hours. Cooking was conducted using the ungkep method, a traditional Indonesian technique of slow simmering in a closed vessel at 90–95 °C for 75 minutes, to achieve tenderness and uniform spice absorption. The prepared bebek ungkep was subsequently vacuum-sealed in airtight plastic packaging for frozen storage or retort sterilization treatments. In this study, we use the term "bebek ungkep" rather than "braised duck", as the former represents the commonly recognized designation for this traditional Indonesian dish.

Experimental design

This study employed a completely randomized design (CRD) with four treatments and three replications. Replications were defined as experimental runs conducted at different times. The treatments consisted of: (1) frozen bebek ungkep (control), (2) retort processing for 10 minutes, (3) retort processing for 20 minutes, and (4) retort processing for 30 minutes. Observations of physicochemical characteristics, texture, and nutrient composition were conducted on days 0, 7, 14, and 21 of storage. All samples were stored at 4 °C to simulate short-term preservation. The sequence of preparation, experimental design, and research procedures is illustrated in Figure 1.

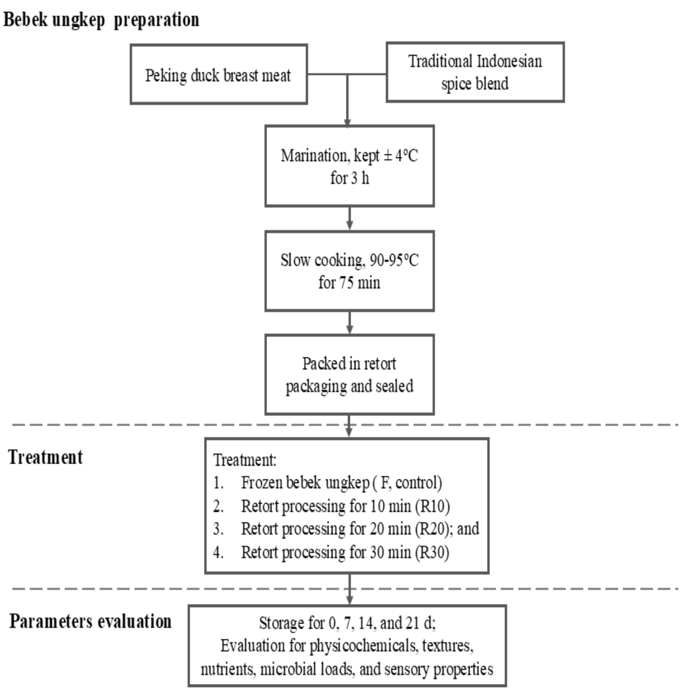

Figure 1: Research procedure illustration.

Sterilization: retort process

Bebek ungkep was packaged in food-grade aluminum foil containers (13 × 20 × 4 cm; 105 μm thickness), with approximately 100 g of product per unit. The samples were vacuum-sealed using a Wirapax DZ-500/2E vacuum sealer (vacuum time: 30 s; sealing time: 5.5 s; heating voltage level: 2). The sealed packages were then placed into retort pouches and subjected to thermal sterilization in a retort system. The retort process consisted of come-up and venting, holding at the target temperature, and pressure cooling. Sterilization was performed at 121 °C, with processing times determined by the applied treatments. Four sterilization conditions were evaluated: frozen (control), 10 min, 20 min, and 30 min. After unloading from the retort, samples were immediately cooled in water maintained at 2–8 °C. Samples were analyzed on day 0, and for storage treatments, packages were kept at room temperature (25–30 °C) for 7, 14, and 21 days prior to further evaluation.

pH measurement

The pH of meat samples was measured following the method described by Korkeala *et al.* (1986). A total of 10 g of finely minced meat was mixed with 10 ml of distilled water and homogenized. The pH of each sample was then determined using a PC700 pH meter (Eutech Instruments, Delhi, India), which had been calibrated prior to measurement.

Water activity measurement

The water activity (Aw) of meat samples was assessed using an AQUALAB 4TE instrument (AQUALAB, Panipat, India). Measurements were performed on samples with a surface diameter of approximately 4 cm, and the instrument provided an accuracy of ±0.003.

Color measurement

Color parameters evaluated included lightness (L^*), redness (a^*), and yellowness (b^*). Measurements were performed on the surface of meat samples with a diameter of approximately 3.5 cm. A Konica Minolta Color Reader CR-20 chromameter (Konica Minolta Inc., Tokyo, Japan) was used as the measuring instrument, based on the CIE color system.

Texture measurement

The texture profile of meat samples was determined by measuring hardness, cohesiveness, springiness, gumminess, and chewiness using a TA.XTplusC Texture Analyzer (Godalming, Surrey, UK). Following the protocol of Hariyadi *et al.* (2025), samples sized 4 cm × 3 cm × 1 cm were subjected to double compression with a P/6 cylindrical probe, which was operated at a crosshead speed of 5 mm/s and penetrated to 30% of the sample height.

Near-infrared spectroscopy (NIRS): Nutrient evaluation

Nutrient evaluations, including moisture, protein, fat, and collagen content, were conducted using near-infrared spectroscopy (NIRS): Foss FoodScan 78810 (Labexchange-Die Laborgerätebörse, Burladingen, DE). Measurements were performed on 30 g of finely chopped meat samples. The wavelength range was set to 700-2500 nm, with spectra averaged at 2 nm intervals. Each sample was tested three times, and results were expressed as percentages (g/100 g).

Prior calibration was performed using data from the near-infrared region (780–2500 nm).

Thiobarbituric acid reactive substances (TBARS) analysis

The thiobarbituric acid reactive substances (TBARS) value was determined according to the method of Sorensen and Jorgensen (1996), with slight modifications. A 4 M HCl solution and a TBA reagent (0.2883 g/100 ml glacial acetic acid, 90%) were used. The blank solution was prepared by mixing 5 ml distilled water with 5 ml TBA reagent. For distillate preparation, 10 g of minced meat sample was homogenized with 97.5 ml distilled water and transferred into a distillation flask. Subsequently, 2.5 ml of 4 M HCl and boiling chips were added, and distillation was continued until 15 ml of distillate was collected. For measurement, 5 ml of distillate was mixed with 5 ml of TBA reagent in a test tube, homogenized with a vortex mixer, heated in boiling water for 35 minutes, and then cooled. The sample solution was transferred into a cuvette, and absorbance (D) was recorded at 528 nm. The blank solution served as the zero reference. Absorbance values were then applied to the following calculation formula:

$$TBARS\ value\ (mg\ MDA/kg) = \frac{7,8\ x\ D\ x\ 3}{Sample\ weight\ (g)}$$

Microbial load analysis

Microbial load was assessed using the total plate count (TPC) method. A 5 mg sample was homogenized in 45 ml of sterile 0.86% NaCl solution, and serial dilutions were performed to a final concentration of 10^4. Bacterial enumeration was performed on Plate Count Agar (PCA; Merck, Germany) using the spread plate technique, with 100 µl of sample plated in triplicate at the final dilution (Damayanti *et al*., 2021). Inoculated plates were incubated in an inverted position at 37 ˚C for 24 h, after which colony counts were recorded. Results were expressed as colony-forming units per milliliter (CFU/ml), calculated as CFU/ml × dilution factor, and subsequently converted to Log_{10} values for treatment comparisons.

Sensory assessment

Sensory evaluation of bebek ungkep samples included assessments of appearance, color, aroma, texture, and overall acceptability. The evaluations were conducted subjectively by 20 untrained panelists. Each sample was coded with randomly assigned numbers or letters to avoid bias. Consumer ratings were based on a 9-point hedonic scale, where 1 = extremely dislike, 2 = dislike very much, 3 = dislike, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like, 8 = like very much, and 9 = extremely like.

Statistical analysis

Data were presented as mean ± standard deviation. Statistical analysis was performed using two-way analysis of variance (ANOVA) with SPSS version 23.0 (IBM, Armonk, New York, USA). When significant differences were detected, Duncan's multiple range test (DMRT) was used as a post hoc analysis (Steel and Torrie, 1960). The level of significance was set at 95% ($p < 0.05$).

Table 1: Significance value of freeze or retort treatment, storage period, and their interactions.

				Physicochemical characteristics		
	pH	Water activity	WHC	L*	a*	b*
T	0.001	0.001	0.008	0.001	0.001	0.001
SP	0.001	0.001	0.001	0.001	0.001	0.001
T*SP	0.001	0.001	0.001	0.001	0.001	0.001
Texture characteristics						
			Hardness	Cohesiveness	Springiness	Gumminess
T			0.001	0.001	0.001	0.001
SP			0.001	0.001	0.001	0.001
T*SP			0.001	0.001	0.001	0.001
Nutrient characteristics and TBARS value						
		Collagen	Fat	Moisture	Protein	TBARS
T		0.001	0.001	0.001	0.001	0.001
SP		0.001	0.001	0.001	0.001	0.001
T*SP		0.001	0.001	0.001	0.001	0.001
Sensory properties						
		Appearance	Color	Flavor	Texture	Overall acceptability
T		0.001	0.001	0.001	0.001	0.001
SP		0.001	0.001	0.001	0.001	0.001
T*SP		0.001	0.010	0.001	0.001	0.087

T: freeze or retort treatments; SP: storage period; T*SP: interaction between freeze or retort treatments and storage period; WHC: water holding capacity; *L**: lightness; *a**: redness; *b**: yellowness; TBARS: Thiobarbituric Acid Reactive Substances.

RESULTS

Effects of retort pouch processing for bebek ungkep on physicochemical characteristics

The factorial statistical analysis of physicochemical characteristics across the four treatments is presented in Table 1. Both treatment type and storage duration significantly affected pH, water activity, WHC, and color properties ($p < 0.01$). Furthermore, a highly significant interaction between treatment and storage duration was observed for all physicochemical variables ($p < 0.01$). As summarized in Table 2, the mean comparisons across treatments and storage durations revealed significant differences in pH ($p < 0.05$). The pH of bebek ungkep ranged from 6.24 to 6.82, with the lowest value recorded in treatment R20 at 21 days of storage. Conversely, the highest pH values were observed in treatment R20 and the frozen control at 7 days of storage. A general trend was evident: retort-processed samples exhibited a decline in pH after 7 days of storage. On day 0, the water activity of bebek ungkep subjected to 20- and 30-minute retort treatments was significantly greater than that of the frozen treatment ($p < 0.05$). After 21 days of storage, all retort treatments yielded the highest water activity values, ranging from 0.979 to 0.980 ($p < 0.05$). WHC values differed significantly across treatments and storage durations ($p < 0.05$). The frozen control exhibited the highest WHC (57.87%) at 21 days of storage ($p<0.05$). In contrast, retort treatments of 10 and 20 minutes yielded relatively low WHC values through day 14 ($p<0.05$). Interestingly, by day 21, WHC values in these retort treatments increased significantly ($p<0.05$).

Table 2 illustrates the dynamics of color parameters under different treatments and storage durations. At day 0, L^* values were significantly higher in the 10- and 30-minute retort treatments compared to the frozen control, whereas the 20-minute treatment did not alter L^*. During subsequent storage (days 7, 14, and 21), L^* values declined significantly across all treatments. Conversely, a^* values decreased significantly in the 10- and 30-minute retort treatments at day 0, with further reductions observed until day 14. For b^* values, no immediate differences were detected among treatments. However, significant declines were observed in the 20- and 30-minute retort treatments at 14 and 21 days.

Effects of retort pouch processing for bebek ungkep on texture profiles

According to Table 1, retort treatment and storage duration significantly affected the texture profile of bebek ungkep, including hardness, cohesiveness, springiness, and gumminess ($p < 0.01$). In addition, a strong interaction between treatment and storage duration ($p < 0.01$) was observed. As summarized in Table 3, textural parameters varied significantly across treatments and storage durations. Frozen bebek ungkep consistently exhibited the highest hardness values compared with retort-processed samples ($p < 0.05$). Among retort treatments, 10- and 20-minute processes yielded lower hardness than the 30-minute process, although differences among retort treatments became negligible with prolonged storage.

Table 2: Physicochemical profile of bebek ungkep with frozen and retort treatments at 0, 7th, 14th and 21st days of storage.

Parameter	Treatments	Storage period (days)				SEM
		0	7	14	21	
pH	F	6.45^{g}	6.81^{m}	6.64^{k}	6.53^{i}	0.040
	R10	6.39^{e}	6.69^{l}	6.43^{f}	6.32^{d}	0.043
	R20	6.65^{k}	6.82^{n}	6.56^{j}	6.24^{a}	0.061
	R30	6.45^{g}	6.51^{h}	6.31^{c}	6.28^{b}	0.029
	SEM	0.029	0.037	0.038	0.034	
Water activity	F	0.983^{de}	0.984^{de}	0.986^{e}	0.975^{a}	0.001
	R10	0.979^{b}	0.982^{cd}	0.980^{bc}	0.979^{b}	0.001
	R20	0.989^{f}	0.985^{e}	0.975^{a}	0.980^{bc}	0.002
	R30	0.990^{f}	0.980^{bc}	0.982^{cd}	0.980^{bc}	0.001
	SEM	0.001	0.001	0.001	0.001	
WHC (%)	F	51.40^{def}	38.77^{a}	39.53^{a}	57.87^{g}	2.551
	R10	38.97^{a}	39.14^{a}	43.99^{abc}	51.24^{def}	1.722
	R20	43.88^{abc}	41.26^{a}	43.54^{ab}	53.71^{fg}	1.725
	R30	52.59^{ef}	40.33^{a}	46.63^{bcd}	48.63^{cde}	1.457
	SEM	1.909	0.785	0.904	1.148	
L*	F	76.07^{h}	50.93^{f}	49.77^{f}	56.03^{g}	3.276
	R10	82.63^{i}	37.60^{bcd}	47.80^{f}	41.87^{e}	5.366
	R20	75.50^{h}	42.77^{e}	34.77^{b}	39.47^{cde}	5.550
	R30	88.90^{j}	36.03^{bc}	40.97^{de}	29.57^{a}	7.095
	SEM	1.934	1.758	1.794	2.859	
a*	F	6.63^{ij}	6.23^{hi}	3.63^{bc}	1.27^{a}	0.663
	R10	5.73^{gh}	6.10^{ghi}	4.66^{de}	3.27^{b}	0.342
	R20	8.53^{k}	7.07^{j}	4.03^{cd}	3.57^{bc}	0.510
	R30	4.63^{de}	5.93^{gh}	5.50^{fg}	4.90^{ef}	0.177
	SEM	0.450	0.333	0.443	0.179	
b*	F	11.36^{def}	16.87^{h}	12.30^{f}	9.97^{cd}	0.785
	R10	11.90^{ef}	11.43^{def}	14.23^{g}	10.73^{de}	0.427
	R20	10.76^{de}	8.80^{bc}	9.30^{c}	8.93c	0.462
	R30	11.43^{def}	11.70^{ef}	7.50^{b}	3.93^{a}	0.973
	SEM	0.164	0.892	0.847	0.816	

F: frozen treatment; R10: retort treatment for 10 minutes; R20: retort treatment for 20 minutes; R30: retort treatment for 30 minutes; L^*: lightness; a^*: redness; b^*: yellowness; WHC: water holding capacity; SEM: the standard error of the mean. Different superscripts in the same row or column indicate significant differences ($p<0.05$).

Table 3: Texture profile of bebek ungkep with frozen and retort treatments at 0, 7th, 14th and 21st days of storage.

Parameter	Storage period (days)					SEM
	Treatments	0	7	14	21	
Hardness	F	160.91^{f}	164.17^{f}	78.16^{e}	74.48^{e}	13.562
	R10	39.17^{c}	37.14^{bc}	22.64^{ab}	17.79^{a}	3.110
	R20	30.83^{abc}	26.37^{abc}	22.59^{ab}	16.64^{a}	3.517
	R30	56.02^{d}	36.30^{bc}	17.11^{a}	15.51^{a}	4.998
	SEM	15.847	17.569	7.529	7.564	
Cohesiveness	F	1.09^{b}	1.07^{a}	1.07^{a}	1.22^{g}	0.019
	R10	1.25^{h}	1.21^{fg}	1.21^{fg}	1.22^{g}	0.007
	R20	1.15^{cd}	1.19^{ef}	1.19^{ef}	1.17^{de}	0.009
	R30	1.09^{b}	1.12^{c}	1.12^{c}	1.28^{i}	0.022
	SEM	0.019	0.017	0.017	0.012	
Springiness	F	111.52^{bc}	113.50^{f}	111.76^{cd}	114.81^{g}	0.409
	R10	111.52^{bc}	113.42^{f}	113.46^{f}	111.40^{bc}	0.347
	R20	110.74^{ab}	113.28^{ef}	111.79^{cd}	114.42^{g}	0.478
	R30	110.77^{ab}	112.54^{de}	110.48^{a}	112.50^{de}	0.312
	SEM	0.150	0.116	0.341	0.460	
Gumminess	F	176.39^{h}	171.09^{h}	94.99^{g}	79.41^{f}	13.776
	R10	53.58^{de}	44.74^{cd}	26.05^{ab}	22.14^{a}	4.119
	R20	35.43^{abc}	31.31^{abc}	33.08^{abc}	19.46^{a}	3.888
	R30	62.96^{e}	39.76^{bcd}	18.45^{a}	19.87^{a}	5.483
	SEM	17.619	17.127	9.171	7.721	

F: frozen treatment; R10: retort treatment for 10 minutes; R20: retort treatment for 20 minutes; R30: retort treatment for 30 minutes; SEM: the standard error of the mean. Different superscripts in the same row or column indicate significant differences (p<0.05).

Cohesiveness was highest in the 10-minute retort treatment across all storage intervals (0–21 days; $p < 0.05$), whereas frozen samples exhibited the lowest cohesiveness at 7 and 14 days ($p < 0.05$). Springiness values did not differ significantly between the frozen and retort treatments. Gumminess followed a pattern similar to hardness, with frozen samples exhibiting higher values than retort-treated samples ($p < 0.05$). Notably, gumminess decreased significantly across all treatments by day 21 ($p < 0.05$).

Effects of retort pouch processing for bebek ungkep on nutrient profiles

As summarized in Table 1, factorial analysis revealed that both processing method (frozen or retort) and storage duration had significant effects on all nutrient profile parameters (collagen, fat, moisture, and protein $p < 0.01$). Furthermore, a highly significant interaction between treatment and storage period was detected ($p < 0.01$). As shown in Table 4, the mean comparisons highlight the effects of both retort treatments and storage periods. Collagen content declined across all retort treatments after 21 days, with the lowest value recorded in the 20-minute treatment (1.27%). Fat levels in retort-processed samples were consistently lower than in frozen controls, and except for the 10-minute treatment, fat content decreased further after 14 days of storage. Moisture content exhibited significant variation among treatments and storage periods; increases were observed after 21 days in all treatments except the 10-minute retort. Protein content reached its minimum (19.72%) in frozen samples at 14 days of storage, while the highest protein level (28.41%) was found in the 30-minute retort treatment at day 0. Both frozen samples and the 30-minute retort treatment showed notable declines in protein content after 14 days of storage.

Table 4: Nutrient profile of bebek ungkep with frozen and retort treatments at 0, 7th, 14th and 21st days of storage.

Parameter	Storage period (days)					SEM
	Treatments	0	7	14	21	
Collagen (mg/100 mg)	F	2.30^{d}	1.93^{c}	3.44^{ij}	2.36^{de}	0.170
	R10	2.01^{c}	3.37^{i}	2.37^{de}	1.75^{b}	0.185
	R20	3.50^{j}	2.71^{g}	2.46^{ef}	1.27^{a}	0.234
	R30	2.58^{f}	3.02^{h}	1.93^{c}	1.66^{b}	0.163
	SEM	0.171	0.160	0.168	0.118	
Fat (mg/100 mg)	F	10.36^{i}	9.54^{h}	9.34^{h}	8.23^{f}	1.644
	R10	6.30^{b}	7.83^{e}	7.31^{d}	7.16^{cd}	0.426
	R20	7.51^{de}	7.88^{e}	5.66^{a}	5.63^{a}	1.251
	R30	9.49^{h}	9.20^{g}	7.21^{cd}	7.08^{c}	0.335
	SEM	1.235	0.520	1.659	0.499	
Moisture (mg/100 mg)	F	62.05^{e}	65.33^{f}	57.74^{b}	68.97^{k}	1.249
	R10	66.15^{g}	60.88^{c}	68.35^{j}	67.78^{h}	0.889
	R20	52.37^{a}	61.58^{d}	68.84^{k}	70.79^{l}	1.984
	R30	57.63^{b}	60.77^{c}	66.14^{g}	68.09^{i}	1.258
	SEM	1.545	0.565	1.346	0.354	
Protein (mg/100 mg)	F	25.47^{gh}	27.68^{k}	19.72^{a}	22.79^{b}	0.899
	R10	25.07^{ef}	26.41^{j}	23.42^{c}	23.99^{d}	0.347
	R20	24.92^{e}	26.40^{j}	24.13^{d}	25.31^{fg}	0.333
	R30	28.74^{l}	25.24^{efg}	25.91^{i}	25.76^{hi}	0.418
	SEM	0.473	0.265	0.681	0.357	
TBARS (mg MDA/kg)	F	0.22^{bc}	0.49^{f}	1.11^{g}	1.59^{h}	0.161
	R10	0.10^{a}	0.39^{e}	0.48^{f}	0.49^{f}	0.048
	R20	0.09^{a}	0.24^{cd}	0.27^{cd}	0.40^{e}	0.038
	R30	0.17^{b}	0.25^{cd}	0.27^{cd}	0.28^{d}	0.016
	SEM	0.017	0.033	0.104	0.158	

F: frozen treatment; R10: retort treatment for 10 minutes; R20: retort treatment for 20 minutes; R30: retort treatment for 30 minutes; TBARS: Thiobarbituric Acid Reactive Substances; MDA: Malondialdehid; SEM: the standard error of the mean. Different superscripts in the same row or column indicate significant differences (p<0.05).

Effects of retort pouch processing for bebek ungkep on TBARS

Based on factorial analysis (Table 1), both treatment and storage period significantly affected TBARS content in bebek ungkep samples ($p < 0.01$). Treatment factors (frozen vs. retort) also interacted significantly with storage duration ($p < 0.05$). Mean comparisons indicated that retort processing for 10 and 20 minutes resulted in lower TBARS values compared to frozen samples ($p < 0.05$). TBARS values increased progressively with longer storage ($p < 0.05$), with the highest value observed in frozen samples after 21 days (1.59 mg MDA/kg; $p < 0.05$).

Effects of retort pouch processing for bebek ungkep on microbial population

Figure 2 illustrates the impact of processing and storage on microbial load. At day 14, retort 30 minutes produced the lowest microbial counts, comparable to retort 10 minutes ($p < 0.05$). By day 21, microbial loads were minimized in frozen samples and the 30-minute retort treatment (5.17 and 5.19 log CFU/mL, respectively), highlighting their superior microbial stability. In contrast, the 10-minute retort treatment had the highest microbial population at day 21 ($p < 0.05$).

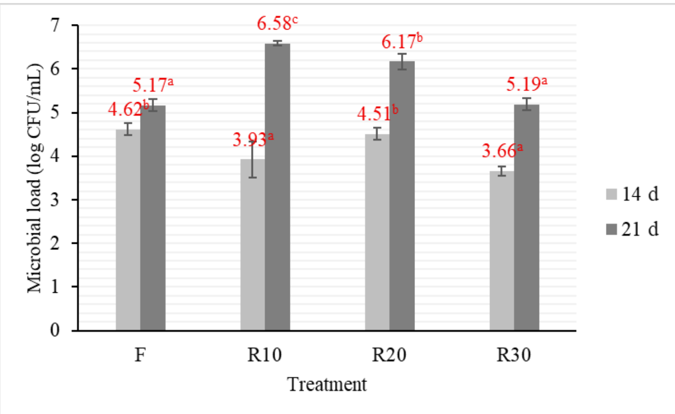

Figure 2: Microbial load of bebek ungkep with frozen and retort treatments at 14th and 21st days of storage. F: frozen treatment; R10: retort treatment for 10 minutes; R20: retort treatment for 20 minutes; R30: retort treatment for 30 minutes; Different superscripts in the same storage periods indicate significant differences (p<0.05).

Effects of retort pouch processing for bebek ungkep on sensory characteristics

Sensory evaluation results of the four bebek ungkep treatments during 0–21 days of storage are presented in Table 5. Based on sensory evaluation (Table 5), retort treatments yielded lower appearance scores compared to frozen bebek ungkep ($p < 0.05$). The highest retort score was observed with the 20-minute treatment, although it was not significantly different from that of the 10-minute treatment. Appearance scores declined progressively with longer storage ($p < 0.05$). The highest color scores were recorded in frozen samples at day 0 (7.60) and day 7 (7.85; $p < 0.05$), with significant decreases after day 14 across all treatments ($p < 0.05$). Flavor scores in retort 10- and 30-minute treatments were comparable to frozen controls, but declined in all treatments after 14 days ($p < 0.05$). Texture scores were consistently lower in retort samples compared to frozen controls ($p < 0.05$), although no significant differences were observed between frozen and retort 10-minute samples after 7 days. For overall acceptability, only the 10-minute retort treatment showed values not significantly different from those of frozen controls, whereas the 20- and 30-minute retort treatments had lower scores, particularly after 7 days of storage ($p < 0.05$). The lowest overall acceptability was recorded in the 20-minute retort treatment (5.10; $p < 0.05$).

Table 5: Sensory characteristics of bebek ungkep with frozen and retort treatments at 0, 7th, 14th and 21st days of storage.

		Storage period (days)				
Parameter	Treat-ments	0	7	14	21	SEM
Appearance	F	8.05^{j}	7.75^{ij}	7.45^{hij}	6.70^{defg}	0.107
	R10	7.00^{efgh}	6.55^{cdef}	6.00^{abc}	5.45^{a}	0.116
	R20	7.25^{ghi}	7.15^{fghi}	6.90^{efgh}	5.45^{a}	0.133
	R30	6.75^{defg}	6.40^{cde}	6.20^{bcd}	5.70^{ab}	0.125
	SEM	0.111	0.151	0.109	0.120	
Color	F	7.60^{fg}	7.85^{g}	6.80^{de}	6.20^{abc}	0.115
	R10	7.25^{ef}	6.80^{de}	5.90^{abc}	5.85^{ab}	0.107
	R20	6.80^{de}	6.40^{bcd}	6.20^{abc}	5.65^{a}	0.097
	R30	6.80^{de}	6.45^{cd}	6.00^{abc}	5.70^{a}	0.099
	SEM	0.094	0.107	0.100	0.088	
Flavor	F	7.50^{fg}	7.85^{g}	6.25^{bc}	5.60^{ab}	0.150
	R10	7.80^{g}	7.85^{g}	7.05^{def}	6.35^{cd}	0.130
	R20	6.45^{cd}	6.15^{bc}	6.05^{bc}	5.35^{a}	0.147
	R30	7.20^{efg}	6.80^{cdef}	6.55^{cde}	6.40^{cd}	0.106
	SEM	0.155	0.176	0.103	0.087	
Texture	F	7.80^{f}	6.85^{e}	7.10^{e}	7.05^{e}	0.120
	R10	7.00^{e}	6.45^{cde}	6.95^{e}	6.75^{e}	0.097
	R20	6.90^{e}	6.55^{de}	5.90^{bc}	5.80^{b}	0.114
	R30	6.70^{e}	6.00^{bcd}	4.50^{a}	4.85^{a}	0.147
	SEM	0.148	0.119	0.139	0.125	
Overall Ac-ceptability	F	7.60^{g}	7.40^{fg}	6.50^{bcd}	6.80^{cdef}	0.105
	R10	7.30^{efg}	7.15^{defg}	6.70^{cdef}	5.85^{b}	0.125
	R20	6.85^{cdef}	6.60^{bcde}	6.15^{bc}	5.10^{a}	0.150
	R30	6.50^{bcd}	6.60^{bcde}	6.30^{bc}	6.10^{bc}	0.125
	SEM	0.152	0.144	0.095	0.089	

F: frozen treatment; R10: retort treatment for 10 minutes; R20: retort treatment for 20 minutes; R30: retort treatment for 30 minutes; SEM: the standard error of the mean. Different superscripts in the same row or column indicate significant differences (p<0.05).

DISCUSSION

Effects of retort pouch processing for bebek ungkep on physicochemical characteristics

The physicochemical characteristics of *bebek ungkep* were observed, as they are closely associated with texture profile and consumer acceptance. The results indicated that the pH of bebek ungkep ranged from 6.24 to 6.82, with the lowest value observed in treatment R20 after 21 days of storage. This range was higher than the typical pH values reported for duck meat, which generally range from 5.5 to 6.3 (Wang *et al*., 2025). Ali *et al*. (2007) reported that the pH of duck meat ranged between 6.04 and 6.55, with values decreasing as storage time increased. The higher pH observed in bebek ungkep compared with reference values may be attributed to the influence of the herbal and spice mixtures used during the ungkep process, which tend to slightly elevate pH. Nevertheless, the pH values obtained from both frozen and retort treatments remained relatively stable even after 21 days of storage, indicating that the ungkep process contributes to stabilizing meat quality. This phenomenon is consistent with the findings of Nafisah *et al*. (2024), who reported that the pH of chicken ungkep subjected to freezer and retort treatments ranged from 6.19 to 6.43 at 0, 7, and 14 days of storage. Similarly, Mardiana *et al*. (2023) reported that retort-processed bebek ungkep exhibited pH values ranging from 6.18 to 6.90, with a tendency to decline during storage. In retort-treated samples, pH decreased after 14 days of storage. This decline may be attributed to: 1) glycolytic metabolism occurring in duck breast muscle (Ali *et al*., 2007), and 2) the dissolution of carbon dioxide within duck meat tissue (Mardiana *et al*., 2023). Praharasti *et al*. (2019) also reported that rendang, a traditional Indonesian beef-based dish, exhibited a decline in pH following storage at 34–55 °C. Alterations in pH are expected to affect additional physicochemical attributes, most notably color (Inada *et al*., 2025).

Water activity is a fundamental parameter, expressed on a scale from 0 to 1, that quantifies the availability of free water in a matrix for the growth of pathogenic and spoilage microorganisms (Mason *et al*., 2018). Acidity (pH) and water activity are the primary factors influencing food safety risks (Syukri *et al*., 2025). According to Mason *et al*. (2018), fresh meat typically has a water activity of 0.969, whereas dry-cured meat averages around 0.749. The values obtained in our study (0.975–0.995) were higher. Such high-water activity levels require careful consideration, as they pose challenges to food safety in packaged meat systems. Retort treatment of bebek ungkep in this study appears to increase water activity, which is a significant concern. Elevated water activity values can compromise sterilization effectiveness, as higher levels of free water facilitate microbial survival and growth. The variation in water activity values across treatments and storage durations reflects a distinctive interaction between these two factors, as shown in Table 1. Supamri and Radiati (2026) noted that no synergistic or antagonistic relationship exists between treatment type and storage period in determining the water activity of duck meat.

The findings demonstrated that retort treatments of 10 and 20 minutes yielded relatively low water holding capacity (WHC) values through day 14 compared with frozen bebek ungkep. Interestingly, by day 21, WHC values in these retort treatments increased significantly ($p < 0.05$). This observation is noteworthy, as it may affect the texture and overall quality of bebek ungkep. WHC, defined as the ability of a material to retain water, contributes to elevated moisture content within the matrix (Nafisah *et al*., 2024). The retort process, which involves exposure to high temperatures, tends to induce protein denaturation in meat, thereby reducing WHC (Triyannanto *et al*., 2019). Rajan *et al*. (2014) also reported that, during cooking, water, soluble proteins, and lipids are released from the meat tissue. The reduction in WHC observed in retort treatments of 10 and 20 minutes at day 0 may also be explained by pH values approaching the isoelectric point, which decreases the meat's WHC and promotes water leakage (Kim *et al*., 2020). Nevertheless, WHC values at days 7 and 14 in these retort treatments did not differ substantially from those of frozen bebek ungkep. This phenomenon is noteworthy because it may ultimately influence consumer preferences in sensory evaluations.

An interesting observation regarding the lightness parameter (L^*) in this study is that immediately after retort treatments of 10 and 30 minutes, bebek ungkep exhibited significantly higher L^* values compared with the frozen treatment ($p < 0.05$). However, following 7–21 days of storage, all retort treatments produced significantly lower L^* values than the frozen samples ($p < 0.05$). This phenomenon may be attributed to the heating effects of the retort process. The most pronounced decline in L^* was observed in the 30-minute retort treatment after 21 days of storage. This finding is consistent with Yang *et al*. (2022), who reported that L^* values of both stepwise and general retort processing methods were significantly lower than the control after sterilization ($p < 0.05$). Such changes are likely due to oxidative denaturation of myoglobin, leading to the formation of metmyoglobin (Rao *et al*., 2022), which, in turn, affects the a^* values. The variation in L^* values observed in bebek ungkep samples may also be influenced by interactions between the meat matrix and the herbal and spice components used during cooking. Such interactions could contribute to differences in oxidative activity, although this requires further investigation. The decline in L^* values across all bebek ungkep treatments during storage may additionally be attributed to Maillard reactions between reducing sugars and protein amines (Rajkumar *et al*., 2010; Rather *et al*., 2024).

The reduction in a^* and b^* values, compared with the frozen treatment, occurred in the 10- and 30-minute retort treatments at day 0, and in the 20- and 30-minute retort treatments after 14 and 21 days of storage (Table 2). Similar to the decline in L^* values, this phenomenon is closely associated with the heating effect during retort processing at 120 °C. The variation in color among treatments during the first seven days of storage may be attributed to the initial color of bebek ungkep, which absorbs pigments from the spices and herbs used in cooking. The reductions in a^* and b^* values following retort processing are likely associated with diminished light reflectance resulting from heat exposure (Rajkumar *et al*., 2010). This phenomenon can be attributed to the thermal denaturation of myoglobin during cooking, which causes its color to shift from bright red or pink to a dull brown or a lighter shade (Rao *et al*., 2022). Barbosa-Cánovas *et al*. (2014) reported that variations in heating duration during microwave processing produced significant alterations in meat color. As thermal denaturation of myoglobin and other proteins progresses, the characteristic redness of the meat diminishes. Rapid heating during retort processing accelerates the Maillard reaction, resulting in the formation of brown to black macromolecules that contribute to the darkening of meat tissue (Syukri *et al*., 2025). In retort processing, the preparation stage of the meat must be carefully managed, particularly for products with high liquid content, to minimize pigment degradation and prevent undesirable color changes during sterilization (Chysirichote *et al*., 2025).

Effects of retort pouch processing for bebek ungkep on texture profiles

Differences in texture profiles among bebek ungkep treatments were strongly influenced by preceding parameters such as pH and WHC. Texture and WHC are strongly correlated with meat tenderness, which is also influenced by pH (Gault, 1985). Overall, the results presented in Table 3 indicate that hardness and gumminess values in all retort treatments were consistently lower than those in frozen bebek ungkep. These changes in hardness and gumminess can be explained by microstructural alterations in muscle tissue (Thephuttee and Theprugsa, 2020). It has been established that prolonged cooking time reduces meat hardness (Muhlisin *et al*., 2013), as protein denaturation and muscle cell disruption during thermal processing decrease hardness values (Majumdar *et al*., 2017). Heat-induced modifications in meat components are known to affect texture, one of the most critical attributes of muscle foods, with connective tissue changes contributing to tenderization (Barbosa-Cánovas *et al*., 2014). Furthermore, hardness and gumminess values declined progressively across all treatments with increasing storage duration, which may be attributed to oxidative processes during storage. The deterioration of product texture has been linked to oxidative effects on proteins, peptides, and amino acids (Shah *et al*., 2017). Storage under refrigeration may also influence the time-temperature interaction, further affecting meat quality. The combined effects of storage duration and temperature are known to impact color, flavor, and texture, which are commonly regarded as key determinants of overall product quality (Praharasti *et al*., 2019).

The cohesiveness trends across the four bebek ungkep treatments highlight the delicate balance between protein matrix stability and moisture retention during retort processing. Higher cohesiveness in the 10-minute retort treatment suggests that shorter thermal exposure preserves the gel-forming ability of myofibrillar proteins, whereas prolonged heating (30 minutes) weakens structural integrity through excessive denaturation. Heat-treated samples generally exhibit reduced solubility of total proteins (TP), myofibrillar proteins (MP), and sarcoplasmic proteins (SP), supporting the observed decline in cohesiveness with extended heating (Xia *et al*., 2021). Interestingly, springiness values remained statistically similar across treatments, indicating that elasticity is less sensitive to retort duration and more dependent on intrinsic muscle composition. Comparable findings were reported in retort-processed prawn, where springiness stability was unaffected by increasing heating time, although other texture parameters changed significantly (Majumdar *et al*., 2017). Collectively, these results suggest that retort duration is crucial for balancing the texture profile in bebek ungkep, ensuring consumer-acceptable texture while maintaining product safety.

Effects of retort pouch processing for bebek ungkep on nutrient profiles

In this study, collagen content decreased across all retort treatments after 21 days of storage, with the most pronounced reduction observed in the 20-minute process. This indicates that collagen in duck meat is highly sensitive to retort heating, further compounded by the effects of storage temperature. The reduction in collagen content also contributes to the decline in water-holding capacity observed after retort treatment. Collagen breakdown, which disrupts protein bonds within muscle fibers, can reduce the water-holding capacity of meat products (Triyannanto *et al*., 2019). Palka (1999) reported that exposure to retort temperatures ranging from 80 to 121 °C resulted in a marked reduction in total collagen in meat structures. The observed changes in physicochemical and textural parameters can be attributed to alterations in collagen stability following heat treatment and to fiber contraction (Xia *et al.*, 2021), both of which inevitably affect the sensory properties consumers perceive. The reduction in fat content across all retort treatments may be linked to the heating process itself. Thermal exposure for several minutes could either (1) lower fat levels or (2) relatively increase other nutrients that undergo degradation. The issue of lipid oxidation following heating will be discussed in the TBARS subsection. Regarding point (2), the nutrient most likely to show a relative increase is protein. During heating, lipid oxidation, protein oxidation, and protein solubility in meat products are interrelated, with reduced protein solubility closely associated with the extent of protein oxidation (Xia *et al.*, 2021). Fat plays a crucial role in meat and meat products, primarily influencing their sensory qualities and textural characteristics in the finished product (Barbosa-Cánovas *et al.*, 2014). From another perspective, the reduced fat content of retorted bebek ungkep may be beneficial to consumers seeking healthier products.

A noteworthy observation was a surge in protein content after 30 minutes of retort treatment, which may reflect excessive nutrient modification due to protein and lipid oxidation during heating. This phenomenon deserves attention, as certain fractions could alter product color and texture. A decline in protein levels was also detected in frozen bebek ungkep after storage. Longer cooking times tend to accelerate protein degradation, whereas elevated storage temperatures promote protein deterioration in retorted meat over three weeks (Muhlisin *et al.*, 2013). Variations in protein values across the four treatments may also stem from relative calculations after storage, since moisture release into the gravy during protein denaturation could contribute to sampling inconsistencies (Rajan *et al.*, 2014). This was evidenced by the significant interaction observed between retort treatment and storage duration. Theoretically, post-cooking protein changes are not primarily quantitative but involve structural modifications and the integrity of myofibrillar proteins (Rather *et al.*, 2024). This aspect warrants further study.

Effects of retort pouch processing for bebek ungkep on TBARS

TBARS analysis was conducted to estimate the extent of lipid oxidation that may occur during food processing (Sorensen and Jorgensen, 1996). Lipid oxidation generates free radicals that can promote the degradation of meat pigments, leading to rancid odors and flavors as well as the formation of potentially harmful compounds (Shah *et al.*, 2017). Two key findings emerged from this study: (1) retort treatments of 10–20 minutes were effective in suppressing lipid oxidation in bebek ungkep compared with frozen storage, and (2) TBARS values increased progressively with longer storage duration. The relatively low TBARS values observed in the retort treatments may be attributable to the formation of natural antioxidants in bebek ungkep. We assume that both duck meat and the herbal–spice components of the product could generate antioxidant compounds following thermal processing in the retort. Nevertheless, this hypothesis requires further investigation. Previous studies have reported that the production of antioxidants in meat at high sterilization temperatures contributes to oxidative stability (Devadason *et al.*, 2014).

Retorted bebek ungkep processed for 10–30 minutes and stored for up to 21 days exhibited TBARS levels below 0.5 mg MDA/kg. These values were below the threshold reported by Xue *et al.* (2025), although it should be noted that various standards exist for acceptable TBARS limits in meat products. This finding demonstrates that retort-processed bebek ungkep yields a healthier product compared with frozen bebek ungkep. A progressive increase in TBARS values with extended storage has also been reported in retorted buffalo meat blocks (Devadason *et al.*, 2014), Chettinad chicken (Rajan *et al.*, 2014), Rogan josh curry (Shah *et al.*, 2017), and meatballs (Rather *et al.*, 2024). These results indicate that lipid oxidation persists throughout storage. In retort-packaged products, the increase in TBA values may be attributable to residual oxygen trapped within the pouch, as the packages were not vacuum-sealed (Rajan *et al.*, 2014).

Effects of retort pouch processing for bebek ungkep on microbial population

Microbial population monitoring was conducted to evaluate the effectiveness of retort treatment in maintaining the freshness of bebek ungkep. Based on the summarized results, frozen storage remained the most effective method up to 21 days of shelf life. However, from a microbial control perspective, the 30-minute retort treatment could be considered a comparable option. Nevertheless, this must be weighed against the accompanying changes in the product's texture and physicochemical properties, which are critical determinants of consumer acceptance. According to retort processing procedures, F_0 measurement should ideally be conducted to validate sterilization effectiveness in bebek ungkep. However, this study was based on previous work by Mardiana *et al.* (2023), who used a temperature of 121 °C for 20 minutes; thus, we assumed that retort durations of 10–30 minutes would be sufficient to sterilize the product. Due to the high temperature and low-oxygen environment, static retorts are effective at eliminating approximately half of microbial colonies in animal-based foods packaged in retort pouches (Nurhikmat *et al.*, 2023).

Muhlisin *et al.* (2013) further reported that autoclaving for 10 minutes was adequate to destroy bacteria but not spores, which can regrow under ambient conditions. After 21 days of storage, all treatments yielded microbial populations of log 5, which may be attributed to the relatively moist characteristics of bebek ungkep. Bacterial growth is influenced by water availability and moisture content in food samples (Nafisah *et al.*, 2024).

Effects of retort pouch processing for bebek ungkep on sensory characteristics

According to Zahidah *et al.* (2024), if meat is not precooked prior to retort processing, it may become more tender due to collagen and connective tissue breakdown. Muhlisin *et al.* (2013) further noted that extending cooking duration can reduce meat toughness and enhance its sensory texture profile. Therefore, substantial textural changes would not be expected following retort treatment of bebek ungkep. As described in the preparation method for bebek ungkep, the product is traditionally cooked by slow simmering in a closed vessel at 90–95 °C for 60–90 minutes. Furthermore, in this study, consumer acceptance (texture, flavor, color, and appearance) declined noticeably after 30 minutes of retort processing, with a slight reduction also observed at 20 minutes. Only the 10-minute retort treatment, and to some extent the 20-minute treatment, produced quality comparable to frozen bebek ungkep. These outcomes reflect the influence of earlier parameters such as texture and color. Color, flavor, and texture are widely recognized as the dominant sensory attributes shaping consumer acceptance of meat products (Zahidah *et al.*, 2024). The decline in flavor scores may also be attributed to excessive heating during retort processing, particularly when the duration exceeds 20 minutes. Heating can promote the oxidation of muscle proteins by enhancing free radical formation, thereby degrading the product's sensory quality (Barbosa-Cánovas *et al.*, 2014). However, this phenomenon also depends on the type of product subjected to retort processing. Majumdar *et al.* (2017) reported that freshwater prawn curry products subjected to longer heating times exhibited improved sensory properties, particularly color and flavor, due to changes that occurred during thermal processing.

A decline in sensory parameters of retorted products, particularly in overall acceptability influenced by storage duration, has also been documented by Rajan *et al.* (2014), Shah *et al.* (2017), Mardiana *et al.* (2023), Rather *et al.* (2024), and Nafisah *et al.* (2024). The reduction in texture and consumer acceptance after certain storage periods may be associated with minor protein degradation and oxidative alterations within the product (Rajan *et al.*, 2014; Shah *et al.*, 2017). Exposure to high thermal processing temperatures may accelerate protein degradation, leading to the release of greater amounts of free amino acids during storage (Devadason *et al.*, 2014). This observation is further supported by the increase in TBARS values (Table 4), reflecting the progression of lipid oxidation during extended storage. However, TBARS levels did not appear to strongly influence consumer acceptance of bebek ungkep. Frozen bebek ungkep consistently achieved the highest overall acceptability scores. Even so, retort treatments of 10 minutes and, to a lesser extent, 20 minutes maintained sensory profiles comparable to those of the frozen product.

CONCLUSIONS

The physicochemical characteristics of retorted bebek ungkep varied considerably. Retort treatments of 10 and 20 minutes generally resulted in lower WHC than the frozen product. Similar trends were observed for color attributes (L^* and a^*), with 10- and 30-minute retort treatments yielding values lower than those of frozen bebek ungkep. These physicochemical differences were reflected in texture parameters such as hardness and gumminess, with frozen samples consistently exhibiting higher values than all retort treatments. A notable nutritional change was a reduction in collagen content in retorted samples after 21 days of storage. Storage at 4 °C tended to decrease several quality indicators, including pH, lightness (L^*), hardness, gumminess, and protein content, while only TBARS values increased during storage. Overall, retort treatments of 10 and 20 minutes are recommended to achieve consumer acceptance comparable to that of frozen bebek ungkep. Moreover, retorting effectively suppressed lipid oxidation, as indicated by the low TBARS values. Further investigation into modifications to the cooking process or the incorporation of antioxidants may be necessary to preserve the physicochemical and textural properties of bebek ungkep.

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NOVELTY STATEMENT

Several studies have reported the application of retort processing to bebek ungkep. However, these investigations have not provided a comprehensive characterization. In our study, bebek ungkep was subjected to retort treatment across varying time durations, and its physicochemical properties, texture, nutrient composition, and sensory preferences were systematically evaluated. This integrated assessment constitutes the principal novelty and strength of the present work.

AUTHOR'S CONTRIBUTION

Rusman supervised the experiment, wrote the first draft manuscript and revised the manuscript, Endy Triyannanto designed and supervised the experiment, analyzed the data, and wrote the first draft manuscript, Oktafiandani Darmawan prepared the raw sample, collected the data, and wrote the first draft manuscript; Ikhwan Arya Laksamana performed the sample preparation, laboratory analysis and wrote the first draft manuscript, Aulia Puspita Anggraini performed the laboratory analysis, data analysis, and wrote the first draft manuscript, Sri Rahayu Waniningsih prepared the raw sample, resources, and administration; Wijaya Prima Saputra performed the sample preparation and validation; Hasmo Sadewo prepared the raw sample, resources, and administration; Gumelar Retno Palupi prepared the raw sample, validation, and administration, Arif Rahman Hakim performed laboratory analysis, data analysis, and wrote the first draft manuscript; Rina Wahyuningsih performed laboratory analysis, and analyzed the data, and Teguh Wahyono designed and supervised the experiment, laboratory analysis, data analysis, visualization, wrote the first draft, and revised the manuscript.

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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