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Effect of Marination Method, Holding Temperature and Time on Physicochemical Parameters, Sensory Attributes and Microbial Quality of Broiler Chicken Breast Meat

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ABSTRACT

We assessed the effect of holding temperature and time on physicochemical parameters, sensory attributes, and microbial quality of unmarinated and marinated broiler chicken breast meat. A factorial arrangement of treatments (4 x 2 x 2) was used in assessing four methods (unmarinated control, immersion, injection, and tumbling), two holding temperatures (4 °C and 8 °C), and two holding times (4 and 8 h). The Pectoralis major breast meat samples were marinated and randomly allocated into treatment combinations. The highest marinade uptake was reported from the injection method (P<0.05). Injection (4 °C - 4 h; 4 °C - 8 h, 8 °C - 4 h and 8 °C - 8 h), immersion (4 °C - 4h and 8°C - 8 h) and tumbling marination (4 °C - 4 h; 4 °C - 8 h and 8 °C – 4 h) resulted the highest cooking yield (P < 0.05). Injection and tumbling resulted from the minimum cooking loss. Marination improved the external surface b* value and reduced the internal surface L* value compared to the control (P<0.05). Holding meat at 8 °C for 8 h after tumbling marination reported the highest (P<0.05) score for aroma, surface color, marinade penetration, color penetration, and overall acceptability. The total microbial counts of all the treatments ranged between 3.30 and 4.45 log CFU/g. The present study concluded that holding meat at 4 °C for 8 h following injection marination was the best for the development of meat quality. The overall acceptability was highest when meat was held at 8 °C for 8 h after tumbling marination. All products tested were safe for human consumption within 42 days when stored at -18 °C.

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INTRODUCTION

The meat industry plays a significant role in the livestock sub-sector in Sri Lanka (Alahakoon *et al*., 2016). It provides a sound platform to a wide array of meat types such as chicken, pork, beef, and mutton. Of these, broiler chickens are the most popular meat type (Alahakoon *et al*., 2016). The broiler chicken industry has demonstrated phenomenal growth over the last few decades. The livestock sector in Sri Lanka recorded a rapid growth during 2019, with a 1 % contribution to the national gross domestic production (GDP), where the chicken meat made the highest contribution from the livestock sector (Livestock Statistical Bulletin, 2019). Of the various meat types available in the global and local markets, further processed meat products signify a high consumer demand. Further, processed products allow product diversification, convenience, and employee creativity. Sri Lankan meat processing plants produce a wide range of meat products at present, under three main categories; (i) comminuted products (e.*g.* sausage, luncheon meat, and hot dogs), (ii) cured meat products (e.*g.* bacon and ham), and (iii) formed meat products (e.*g.* nuggets, meat fingers, drumsticks, *etc.*), in addition to the marinated meat products (Alahakoon *et al.,* 2016).

Marination is one of the most popular trends in the global processed poultry meat industry. The purpose of marination includes (i) improving organoleptic properties of meat with consistent taste, aroma, flavor, texture, shelf life, and (ii) lowering the pH of meat (Capaccioni *et al*., 2011). Marinade mixtures generally consist of salt, phosphate, and water (Alvarado and McKee, 2007; Bowker and Zhuang, 2017), having a great influence on achieving the aforementioned properties (Buses, 2005). Commonly practiced marination methods include tumbling, vacuum tumbling, immersion, injection, and massaging using mechanical systems (Palang, 2004; Buses, 2005; Alvarado and McKee, 2007). The quality of marinated products can be greatly influenced by several factors, such as marination temperature, holding time, type of marinade, and the method of marination (Alvarado and McKee, 2007; Gamage *et al*., 2017).

Many studies have been conducted to find out the effect of type of marinade on physicochemical and sensory attributes of different meat types such as turkey (Alvarado and Sams, 2004), beef (Hinkle, 2010), and chicken (Alvarado and McKee, 2007). Moreover, Gao *et al*. (2015) investigated the effect of the tumbling method on the meat quality of pork chops. Fenton *et al*. (1993) investigated the interactive effect of holding time and temperature on the eating quality of broiler chicken breast meat. A study conducted by Gamage *et al*. (2017) revealed that holding marinated chicken thigh meat for 8 hours at 4°C improved the quality. However, to our knowledge, no or limited studies have been conducted so far to investigate the interactive effect between marination methods (injection *vs.* immersion *vs.* tumbling), temperature, and holding time on physicochemical, sensory, and microbial quality attributes of broiler chicken breast meat. Therefore, the present study was conducted to investigate the effect of two different marination temperatures (4 °C *vs.* 8 °C) and holding time (4 h vs. 8 h) on physicochemical, sensory, and microbial quality attributes of broiler chicken breast meat after marination by injection, immersion and tumbling.

METHODOLOGY

Research location and experimental design

The research was conducted in a large-scale commercial poultry processing plant in Sri Lanka. The experiment design was 4 x 2 x 2 factorial with four marination methods (unmarinated control, tumbling, injection, and immersion), two holding temperatures (4 and 8 °C), and two holding times (4 h and 8 h), arranged in a Complete Randomized Design.

Processing of meat samples

Fresh deboned breast meat obtained from 32-d old, Cobb-500 broiler chickens (1.7 ± 0.2 kg body weight) were manually processed immediately after slaughtering. The breast fillet (*Pectoralis major* muscle), without external fat and skin, was deboned and cut into 30 ± 5 g (5 cm x 3 cm x 2 cm) pieces. A total of 128 meat samples were randomly allocated to four treatments, unmarinated control, immersion, injection, and tumbling. Immediately after marination, meat samples from each treatment were subdivided into two holding temperatures (4 °C and 8 °C) and two holding times (4 h and 8 h).

Preparation of marinade

A commercial marinade mixture containing chili, pepper, garlic, ginger, nutmeg, and common salt was prepared to a solution of a 20 % concentration (200 g commercial marinade mixture: 1 L distilled water). The mixture was used in all three marination methods, in a ratio of 10:1 (w/w) of breast meat: solution. Injection of the marinade to chicken breast meat samples was practiced using 18-gauge needles. Tumbling was practiced at 10 rpm for 20 min at the room temperature of 28 °C using a tumbling machine (Model No: RGR 150-F, Jaixing Ribon Machine Engineering Co. Ltd. China). Immersion was practiced by dipping the meat in the 20 % marinade solution.

Marinade uptake

Marinade uptakes of samples were measured using an electrical balance (Model-XB 320M, PRECISA, Data Support Company, Panorama City, California) as described by Fenton *et al.* (1993). The excess marinade was removed by applying a paper towel gently on the meat surface. Percentage uptake of the marinade was determined by the difference between the weights of the meat sample before and immediately after marination.

Determination of pH value

The pH values of meat samples were measured using a Bench Top pH meter (Model HI-2210, HANNA instruments Cluj-Napoca, Romania). Samples were prepared by chopping 3 g of marinated breast meat samples using a mortar and a pestle and then mixing with 15 mL of distilled water at a ratio of 1:5 (w/w), and the pH was measured in the solution (Bharti *et al.,* 2011).

Marinade loss

The marinade loss was calculated as described by Fenton *et al.* (1993). Marinade loss was calculated using the formula below.

Marinade loss % = $[(W_1 - W_2) / W_1] \times 100$

Where, W_1 = weight after marination (g) and,

W_2 = weight of the marinated sample after holding at specified temperature and the holding time.

Cooking yield

The cooking yield was measured as described by Smith and Young (2007). After holding the marinated breast meat samples at appropriate holding temperatures and times, meat samples were cooked in an electric oven (Model UE 800, MEMMERT GmbH + Co.KG, Germany) at 218 °C till the core temperature reached 75 °C. The cooking yield was calculated using Equation 1.

Equation 1

Cooking yield % = $(W_2 / W_1) \times 100$

where, W_1 = Weight before cooking (g),

W_2 = Weight after cooking (g).

Cooking loss

Cooking loss was determined using Equation 2 (Fenton *et al.,* 1993; Latif *et al.,* 2010), where each weight (W1) was measured after slightly blotting the samples with a paper towel before cooking. The samples were cooked at the temperature of 218 °C in an oven (MEMMERT GmbH + Co.KG, Germany) until the internal temperature reaches 75 °C. The cooked meat samples were blotted, and the final weights were recorded (W2).

Equation 2

Cooking loss % = $[(W_1 - W_2) / W_1] \times 100$

Drip loss

The drip loss was measured using the method described by Saelin *et al.* (2017). Meat samples were separately packed in covered polythene bags and sealed before hanging for two days at the refrigerator temperature (4 °C). Samples were then weighed up to three decimal points using an electronic balance (Model UE 800, MEMMERT GmbH + Co.KG, Germany), then the drip loss was expressed as a percentage and was calculated using Equation 3.

Equation 3

$$\text{Drip loss (\%)} = [(W_2 - W_3) / W_1] \times 100$$

Where, W1 = initial sample weight

W2 = sample weight before hanging in the polythene bag

W3 = sample weight after hanging for two days at 4 °C temperature

Texture analysis

The texture properties of uncooked breast meat samples [08 cubes (5 cm x 3 cm x 2 cm each) per each method x temperature x time combination) were evaluated by using a texture analyzer (Model-CT3 Brookfield Texture Analyzer, USA) according to the procedure described by Cho *et al.* (2016) and by Brookfield's catalog (Manual No. M/08-371) with slight modifications. The raw breast meat samples were equilibrated to room temperature, and then each sample was measured individually for hardness level. The analyzer was equipped with a 40.0 g trigger load and was set to a 4.0 mm target value distance penetration with 2.5 mm/s test speed. Needle type probe (Diameter 1.0 mm, Length 43 mm, TA9) was used to measure the peak force of the first compression cycle. A pre-test speed of 2 mm/s and a post-test speed of 3 mm/s were used (Santana *et al.,* 2015). The holding time was adjusted to two seconds. Texture Pro CT software was used in the data processing.

Color measurements

Based on the Complete International Commission on Illumination (CIE) system, the lightness (L*), redness (a*), and yellowness (b*) values of treated meat samples were measured by using a colorimeter (Model CR-400, Konica Minolta, USA). Both the surface color and the internal surface color were measured in uncooked samples.

Sensory evaluation

A sensory evaluation was carried out using 30 untrained panelists to compare the quality parameters of marinated breast chicken meat. All the treated samples were cooked in an electric oven (MEMMERT GmbH+Co.KG, Germany) at 218 °C till the internal temperature reached 75 °C. All cooked samples were cut into 3-cm cubes and placed on white plates. Toughness, color, aroma, flavor marinade penetration, and overall acceptability of breast meat samples were evaluated using a 6-point hedonic scale.

Evaluation of total microbial count

The breast meat samples held at -18 °C were evaluated three times (2nd, 4th, and 6th wk) for the microbial count during the 42-days storage period (Tan and Ockerman, 2006). Marinated breast meat samples (10 g) were homogenized with 90 mL of autoclaved distilled water in the Stomacher Blender Machine (Model-MS 800-25-400 CIRCULATOR, Seward Company, West Sussex, United Kingdom), and pour-plate method using Plate Count Agar medium was employed before the samples were incubated at 35 °C for 48 h. The total number of colonies was counted and expressed as CFU/g.

Statistical analysis

The data were statistically analyzed using a three-way ANOVA procedure using SAS 9.0 version (SAS, 2002). Significant differences ($P<0.05$) among treatment means of holding time, holding temperature, and their interactions were separated by the pdiff option. One-way ANOVA was used to analyze marinade uptake. The sensory data were analyzed using the Freidman test (Minitab 17 software), whereas the total plate count data were analyzed using one-way and two-way ANOVA procedures.

RESULTS AND DISCUSSION

Effect on marinade uptake: The percentage marinade uptakes in breast meat samples under different marination methods is presented in Figure 1. Marinade uptakes among treatments differed significantly (P<0.05) except between tumbling and immersion (P>0.05). The injection method resulted in the highest (P<0.05) marinade uptake of 2.67 %.

The present findings are in close agreement with the findings of Smith and Acton (2001), who explained that the injection of marinade maintains the regularity of the product without causing losses as in immersion. When the injection method is used, the marinade is forced to penetrate meat allowing a definite quantity of marinade to move into the meat (Xargayo´ *et al*., 2001; Gamage *et al*., 2017). Massaging effect during tumbling was also found to facilitate moving water into the meat (Alvarado and McKee, 2007) and loosening of muscle tissue structure resulting in a higher marinade absorption (Bowker and Zhuang, 2017). Tumbling is also known to enhance the contact surface area of meat within the stipulated time causing a higher marinade uptake (Bowker and Zhuang, 2017). Marinade uptake in the immersion method is affected by the surface area contact with the marinade and the dipping time (Owens *et al.* 2009). Marinade uptake can be reduced, when the surface area of meat is fully saturated with the marinade (Owens *et al*., 2009; Gamage *et al*., 2017).

Effect of different marination methods, holding temperatures and holding times on pH value, marinade loss (%), cooking yield (%), cooking loss (%), drip loss (%), and hardness (g) are indicated in Tables 1 and 2. Significant interactions were observed only for cooking yield and cooking loss (Tables 1 and 2).

Effect on pH: No significant interaction (P>0.05) was observed between the marination method, holding temperature, and holding time. Regardless of the holding temperature and the holding time, meat pH was significantly affected (P<0.05) by the method of marination (Table 1).

Chicken breast meat marinated using the tumbling method showed the highest pH value (P<0.05) (Table 2). This can be explained by the fact that the tumbling marination accelerates the activity of proteolytic enzymes facilitating meat protein degradation and increasing the pH value (Lawrie and Ledward, 2006; Gao *et al*., 2015; Gamage *et al*., 2017). Similarly, a study by Gamage and colleagues (Gamage *et al*. (2017)) also reported that the chicken thigh meat when marinated using the tumbling method has resulted in a higher pH value than that of unmarinated control. However, the pH of unmarinated meat and those marinated using immersion and injection methods were similar (P>0.05). The marinade mixtures are enriched with salt and phosphate, which can raise the pH of marinated products. The chloride ions present in the marinade can bind with protein filaments in muscle fibers to form ionic charges, resulting in a repulsive force inside the muscle fibers. This repulsive force may raise the pH value of meat (Cheng and Sun 2008; Gamage *et al*., 2017). However, low pH is known to increase drip loss and cooking loss of marinated chicken (Allen *et al*., 1998).

A significant interaction (P<0.05) was observed between the marination method and holding temperature for meat pH (Tables 1 and 2). Increasing holding temperature from 4 °C to 8 °C increased the pH of unmarinated chicken breast meat (P<0.05). In contrast, increasing holding temperature from 4 °C to 8 °C has reduced (P<0.05) the pH of the meat marinated by immersion method. Increasing holding temperature from 4 °C to 8 °C did not influence (P>0.05) the pH of the meat marinated by either injection or tumbling method. However, meat pH increased when holding time was increased from 4 h to 8 h at 4 °C and not at 8 °C.

In the present study, unmarinated control, injection, and immersion marination methods resulted in the lowest pH value. Carroll and Alvarado (2008) reported similar results, where the denaturation of sarcoplasmic protein causes a reduction in the meat pH in the immersion method.

Effects of holding temperature and time on physicochemical parameters of unmarinated and marinated broiler chicken breast meat.

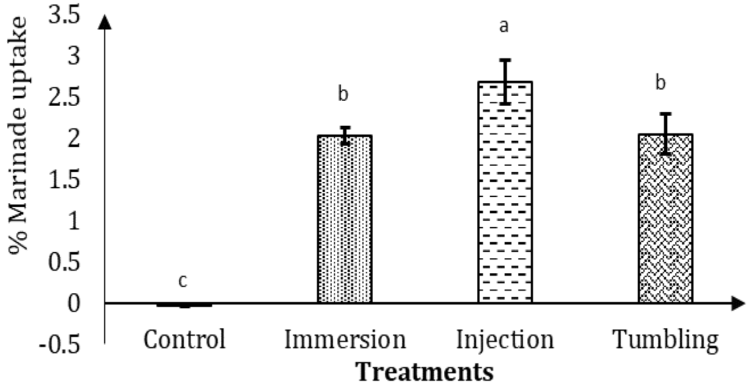

Figure 1: Marinade uptake in chicken breasts meat samples marinated with different marination methods.

Table 1: Effect of marination method, holding time and holding temperature on physicochemical properties of broiler chicken breast meat[1].

Method	Temperature (°C)	Holding Time (Hours)	pH	Marinade Loss (%)	Cooking Yield (%)	Cooking Loss (%)	Drip Loss (%)	Hardness (N)
Control	4	4 h	5.80	1.40	48.42^{fg}	46.66^{b}	2.96	0.75
	4	8 h	6.03	2.96	54.03^{def}	43.36^{bcd}	2.97	0.85
	8	4 h	6.15	2.18	68.21^{ab}	36.87^{de}	1.57	0.84
	8	8 h	6.06	3.67	51.96^{efg}	45.09^{bc}	2.47	0.86
Immersion	4	4 h	6.03	0.87	64.88^{abc}	38.25^{cde}	5.35	0.34
	4	8 h	6.04	1.62	57.45^{cde}	46.79^{b}	3.62	0.30
	8	4 h	5.89	1.42	44.37^{g}	58.49^{a}	4.56	0.75
	8	8 h	5.90	2.50	67.64^{ab}	36.48^{de}	4.24	0.76
Injection	4	4 h	6.03	3.71	70.15^{a}	34.96^{e}	4.93	0.86
	4	8 h	6.09	3.01	70.50^{a}	35.36^{e}	1.52	0.81
	8	4 h	5.96	1.80	67.77^{ab}	37.67^{cde}	5.45	0.81

	8	8 h	6.04	1.31	67.01^{ab}	35.51^{e}	4.46	0.87
Tumbling	4	4 h	6.07	0.87	65.88^{abc}	38.03^{cde}	4.84	0.34
	4	8 h	6.10	2.02	64.71^{abc}	39.69^{bcde}	3.65	0.26
	8	4 h	6.25	2.42	65.80^{abc}	37.04^{de}	6.18	0.28
	8	8 h	6.06	3.60	60.98^{bcd}	38.39^{cde}	2.49	0.25
SEM			0.056	0.624	3.179	2.730	1.235	0.04
Probabilities, P<								
Method (M)			0.002	0.139	0.0001	0.0001	0.0001	0.0001
Temperature (T)			0.681	0.328	0.858	0.824	0.549	0.0001
Holding time (HT)			0.522	0.017	0.925	0.506	0.0001	0.875
M x T			0.0006	0.001	0.011	0.124	0.039	0.0001
M x HT			0.195	0.086	0.023	0.082	0.009	0.278
T x HT			0.029	0.839	0.749	0.047	0.396	0.423
M x T x HT			0.090	0.996	0.0001	0.0001	0.0543	0.495

a-g Means in a column not sharing a common superscript are significantly different ($P<0.05$); SEM=Pooled standard error of mean.; [1]Each value represents the mean of eight replicates.

Table 2: Main effects of marination method, holding time and temperature on physicochemical properties of broiler chicken breast meat[1].

Main Effects	Temperature (°C)	Holding Time (Hours)	pH	Marinade Loss %	Cooking Yield %	Cooking Loss %	Drip Loss %	Hardness (N)
Method								
Control			6.01^{b}	2.56	55.66	42.99	2.49^{b}	$0,83^{a}$
Immersion			5.97^{b}	1.60	58.58	45.00	4.44^{a}	0.54^{b}
Injection			6.03^{b}	2.46	68.85	35.87	4.09^{a}	0.84^{a}
Tumbling			6.12^{a}	2.23	64.34	38.29	4.28^{a}	0.28^{c}
SEM			0.028	0.312	1.589	1.365	0.330	0.02
Tem:	4		6.02	2.05	62.00	40.39	3.72	0.56^{b}
	8		6.04	2.36	61.71	40.69	3.92	0.68^{a}
SEM			0.020	0.220	1.124	0.965	0.233	0.02
Time:		4h	6.02	1.84^{b}	61.93	40.99	4.47^{a}	0.62
		8h	6.04	2.58^{a}	61.78	40.08	3.17^{b}	0.62

SEM			0.020	0.220	1.124	0.965	0.233	0.02
Method x Tem:								
Control	4		5.92^{c}	2.18^{abc}	51.23	45.01	2.97^{cd}	0.80^{ab}
	8		6.10^{ab}	2.93^{ab}	60.09	40.98	2.02^{d}	0.85^{a}
Immersion	4		6.04^{b}	1.25^{c}	61.17	42.52	4.49^{ab}	0.32^{c}
	8		5.89c	1.96^{bc}	56.00	47.48	4.40^{ab}	0.75^{b}
Injection	4		6.06^{ab}	3.36^{a}	70.32	35.16	3.22^{bcd}	0.83^{ab}
	8		6.00^{bc}	1.55^{c}	67.39	36.59	4.96^{a}	0.84^{ab}
Tumbling	4		6.09^{ab}	1.44^{c}	65.29	38.86	4.24^{abc}	0.30^{c}
	8		6.15^{a}	3.01^{ab}	63.39	37.71	4.33^{ab}	0.27^{c}
SEM			0.040	0.441	2.248	1.930	0.466	0.03
Method x Time								
Control		4h	5.97	1.79	58.32	41.76	2.27^{d}	0.79
		8h	6.05	3.32	52.99	44.23	2.72^{cd}	0.86
Immersion		4h	5.97	1.15	54.62	48.37	4.95^{ab}	0.55
		8h	5.97	2.06	62.54	41.64	3.93^{bc}	0.53
Injection		4h	5.99	2.76	68.95	36.31	5.19^{ab}	0.84
		8h	6.07	2.16	68.75	35.44	2.99^{cd}	0.84
Tumbling		4h	6.16	1.65	65.83	37.54	5.50^{a}	0.31
		8h	6.08	2.81	62.85	39.05	3.06^{cd}	0.26
SEM			0.040	0.441	2.248	1.930	0.466	0.03
Tem: x time								
	4	4h	5.99^{b}	1.71	62.33	39.47	4.52	0.58
	4	8h	6.07^{a}	2.40	61.67	41.31	2.94	0.55
	8	4h	6.07^{ab}	1.96	61.54	42.52	4.44	0.67
	8	8h	6.01^{ab}	2.77	61.89	38.87	3.42	0.69
SEM			0.028	0.312	1.589	1.365	0.330	0.02

$^{a-d}$ Means in a column not sharing a common superscript are significantly different (P<0.05); SEM= Pooled standard error of mean; [1]Each value represents the mean of eight replicates

When the main effects were concerned, increasing holding temperature from 4 °C to 8 °C had no influence (P>0.05) on meat pH. Yang and Chen (1993) reported that a positive correlation exists between meat pH and refrigerated storage time. In contrast, Marsh (1954) reported that the pH decreased with the increasing marinated temperature. It is well known that low temperatures enhance the reduction of the rate of glycolysis and lactic acid production. Santos *et al*. (2004) also reported that there is no significant effect of increasing temperature on meat pH. Increasing the holding time marinated meat was found to increase the pH due to the depletion of proteolytic enzymes. Increasing holding time, from 4 h to 8 h did not change (P>0.05) the meat pH. However, Gamage *et al*. (2017) showed that increasing holding time from 4 h to 8 h increased the pH value of thigh meat of broiler chicken.

Effect on marinade loss: Marinade loss was significantly affected by the marination holding time (P< 0.05). The highest marinade loss (2.6%) was reported in broiler chicken breast meat when held for 8 h. Similarly, a significant interaction was observed between the method of marination and holding temperature (P<0.05). Increasing holding time from 4 h to 8 h increased the marinade losses by 74%. No significant interactions were observed (P<0.05) between the marination method, holding temperature, and time for marinade loss (Tables 1 and 2).

The highest marinade loss was observed in the injection marinated meat when held at 4 ºC. Gamage *et al*. (2017) proposed that the needle holes formed during the injection marination method may act as channels to escape the marinade solution. However, tumbling marination at 8 °C also resulted in a similar loss (P>0.05). The highest marinade losses were also observed in unmarinated breast meat samples when increasing holding temperature from 4 °C to 8 °C. In both unmarinated control and immersion, the marinated meat samples did not improve the marinade loss when the temperature increased from 4 °C to 8 °C. The reduction of marinade loss in the injection method and increase of marinade loss in the tumbling method with the change of holding temperatures from 4 °C to 8 °C, might be due to the interaction between the marination method and the holding temperature.

The minimal marinade loss observed in meat marinated using the injection method, and held at 8 °C temperature supports the finding by Palang (2004) who described that marinade absorption can be increased at higher temperatures, causing increased diffusivity of functional ingredients of the marinade into the meat. The present study demonstrated that a high marinade loss was recorded in the meat held at 4 °C, followed by injection marination. Regardless of the holding time, tumbling marination held at 4 °C and injection marination held at 8 °C resulted in the lowest marinade loss. As described by Smith and Acton (2001), the massaging effect exerted during tumbling may extract myofibrillar proteins to the meat surface promoting proper binding properties. These extracted myofibrillar proteins possibly act as a sealer for marinade retention (Smith and Acton, 2001). Increased marinade loss with increasing holding time from 4 to 8 h of the present study supports the findings of Gao *et al.* (2015) and Gamage *et al*. (2017), who demonstrated that prolonged marination could result in the destruction of muscle structure and encourage the marinade losses.

Effect on cooking yield: We observed significant interactive effects among marination method x holding temperature x holding time and between marination method x temperature (P<0.001) for cooking yield (Table 1). When the main effects are considered, the cooking yield of broiler chicken breast meat was affected by the method (P<0.001).

Regardless of the holding temperatures and holding times, injected marinated samples resulted in the highest cooking yields (P<0.001). Similarly, increasing holding temperature or holding time had no influence (P>0.05) on the cooking yield when tumbling marination was used. However, the tumbling treatments, except the treatment combination of 8 °C temperature and 8 h showed the highest cooking yields, and it was similar (P>0.05) to that of the injection method. The lowest cooking yield (44.4 %) resulted when meat was marinated by immersion and held at 8 °C for 4 h. Similar low cooking yields were also reported from unmarinated control (e.*g*. 4 °C, 4 h, and 8 °C, 8 h).

The high cooking yields observed in the injection and tumbling methods may be a result of the interaction effect among method x holding temperature x holding time (P<0.001) on cooking yield. As described previously (Smith and Acton (2001), and Gamage *et al.* (2017)), comparatively higher cooking yields observed in tumbling marination than in the unmarinated treatments in the present study may also result of extraction of myofibrillar proteins (*E.g.* actin and myosin) into the meat surface caused by massaging. Both the sealing and coagulation effects of these proteins may improve water retention in meat with increased cooking yields (Smith and Acton, 2001; Gamage *et al*., 2017).

However, absorption of a high quantity of marinade alone may not be responsible for maximum cooking yield. High cooking yield can be mainly determined by the factors such as (i) site of retention of water in meat (ii) water movement whether it is restrained by the surrounding structures, easily flow out (when squeezing) and extracellular spaces, and (iii) contraction of muscle fibers at heating so that, water can be squeezed out from the meat. Normally, water-bound with protein can be released during the protein denaturation process when heating (Palang, 2004).

Effect on cooking loss: A significant interaction effect of method x holding temperature x holding time was (P<0.001) observed for cooking loss (Tables 1 and 2). Immersion marinated samples held at 8 °C for 4 h resulted in the highest (P<0.05) cooking loss of 58.49 %. Regardless of the holding temperatures and holding times, both injection and tumbling methods resulted (P>0.05) the lowest cooking loss. Present results suggested that marination minimizes cooking loss (P<0.001) in broiler chicken breast meat.

Effect on drip loss: Drip loss of meat was affected significantly by both the method of marination (P<0.001) and holding time (P<0.001). There were significant interaction effects (P<0.05) of Method x temperature interaction and method x holding time interaction (Tables 1 and 2). Marination of chicken breast meat by immersion, injection, and tumbling have resulted in significantly a higher drip loss than the unmarinated samples. The drip losses were similar (P>0.05) among the marination methods (Table 2), and the drip loss of breast meat was affected (P<0.001) by the holding time (4 h *vs.* 8 h). Increasing holding time from 4h (4.47 %) to 8h (3.17 %) reduced drip loss in unmarinated and marinated samples.

Regardless of the holding time, increasing the holding temperature from 4 °C to 8 °C did not change the drip loss in unmarinated chicken breast meat. A similar trend was observed in immersion and tumbling methods which showed the highest drip loss. However, drip loss of injection marination method resulted in a high drip loss (P>0.05) at 8 °C. Increasing drip loss with increasing the holding temperature in the injection method could be a result of the interaction. Injection marinade at 8 °C showed a significantly higher drip loss than at 4 °C.

Regardless of the holding temperature, holding meat for 4 h after any form of marination resulted in the highest drip loss. In unmarinated control and meat marinated by immersion method, increasing holding time from 4 h to 8 h had no influence (P>0.05) on drip loss. However, injection and tumbling marination reduced (P<0.05) the drip loss when increasing holding time from 4 h to 8 h.

Water holding capacity (WHC) can also be expressed in terms of drip loss and cooking loss. According to Palang (2004), the holding temperature and time had different effects on moisture retention in the meat where increased cooking temperature results in poor moisture retention in meat. Previous studies revealed that increasing the pH value of the meat (Heath and Owens, 1987; Alvarado and McKee, 2007) and loosening of muscle fibers together with extraction of salt soluble protein may lower the drip loss and cooking loss. The actin and myosin proteins can act as binding agents in holding water in meat (Babji *et al*., 1982; Palang, 2004)

Effect on hardness: Hardness of breast meat was significantly affected by the marination method (P<0.001), holding temperature (P<0.001), and method x holding temperature interaction (Tables 1 and 2). The unmarinated control and the meat marinated by the injection method resulted in the highest hardness value for broiler chicken breast meat (Table 2). The tumble marination resulted in the lowest value (P<0.05) for hardness.

Regardless of both the method and the holding time, increasing the holding temperature from 4 °C to 8 °C significantly increased (P<0.05) the hardness value of unmarinated and marinated chicken breasts (Table 2). However, holding time had no influence (P>0.05) on the hardness of marinated samples. When each treatment was considered, regardless of the holding time, increasing temperature from 4 °C to 8 °C did not have influence (P>0.05) on unmarinated meat and meat marinated by injection and tumbling. In contrast, increasing temperature up to 8 °C in immersion marination increased the meat hardness. The unmarinated control and marination by injection yielded the highest hardness value for breast meat.

The interactive effect of the marination method, holding time, and temperature on colorimetric parameters of broiler chicken breast meat is presented in Tables 3 and 4. A significant method x temperature x holding time interaction (P<0.05) was found for the external yellowness and internal surface lightness values.

Effect on external surface color lightness (L*): Lightness values for external surface meat color were affected significantly (P<0.001) by the marination method. The surface color lightness was highest (P<0.05) in unmarinated control (56.41), and it is in an agreement with the finding of Zhuang and Bowker (2016), who found marination reduces lightness in pale broiler breast meat. The surface color lightness was similar (P<0.05) between immersion (37.61) and tumbling (38.61) marinated meat. This observation confirms the finding of Gamage *et al*. (2017), who found that the immersion method showed the maximum darkness in broiler chicken thigh meat. A significant interaction (P<0.05) was observed between method and holding temperature for L* value of surface color. The L* values of marinated meat were not affected (P<0.05) by increasing holding temperatures. In contrast, the increasing temperature significantly reduced the External L* value (P<0.05) in unmarinated control. A similar observation was reported by Allen *et al.* (1998), who explained that the lower L* value could result when meat is subjected to higher marination pickup, higher WHC, lower drip loss, and lower cooking loss. The tumble marination significantly reduced the L* value compared to the unmarinated control. These data are comparable with the findings of Allen *et al*. (1998), who described the relationship between broiler chicken breast meat color to meat quality and shelf life. Fletcher (1999) reported that pH and breast meat color have a close relationship. Probably the increase of pH in tumble marinated meat in the present study resulted in a decrease in L* value.

Effect on external surface color redness (a*): Regardless of the holding temperature and the time, external surface a* was (P<0.001) affected by the marination methods. The highest (15.88) and the lowest (1.96) a* values were obtained from the meat marinated by immersion, and the control, respectively. The redness was significantly increased (P<0.05) in all marinated samples compared to the control samples, and this could be due mainly to the presence of spices in the marinade mixture. Gamage *et al.* (2017) found that the highest a* was recorded when the immersion marination method was used while the lowest was found when meat was marinated by injection method.

A significant interaction effect of marination method x holding temperature (P<0.05) was found on a* value of marinated breast meat. Increasing holding temperature from 4 °C to 8 °C in the tumbling method reduced a* values (P<0.05). An opposite trend was observed for the immersion method. The control samples showed the lowest a* values compared to all other treatments. However, no difference was observed for surface a* in unmarinated control at 4 °C *vs.* 8 °C, and also meat subjected to injection method at 4 °C *vs.* 8 °C. When the individual marination method was considered the surface a* of broiler chicken breast meat of unmarinated control, immersion, and tumbling were similar and not affected by respective holding times. However, increasing holding time from 4 h to 8 h reduced (P<0.05) a* value of meat marinated using the injection method. The immersion method and tumbling for 4 h resulted in the highest a* value, while the unmarinated control resulted in the lowest (P<0.05).

Effect on external yellowness (b*): Colorimetric parameters of surface b* of broiler chicken breast meat were significantly affected by both the marination method (P<0.001), and holding time (P < 0.01). Two-way interactions between method x holding temperature (P<0.01), and method x holding time (P<0.01) were also observed. A significant interaction (P<0.01) of method x holding temperature x holding time was observed for the b* value (Tables 3 and 4). Regardless of the holding temperature and time, all three marination methods (P<0.05) increased b* value compared to unmarinated control. This finding is comparable with the finding of Gamage *et al.* (2017) who found that unmarinated chicken thigh poorly developed yellowness compared to the marinated thigh meat. The highest surface b* was obtained in meat exposed to injection marinade held at 8 °C for 4 h. Similar values (P>0.05) were also observed in meat marinated by tumbling (4 °C, 4 h) and immersion (4 °C, 8 h; 8 °C, 4 h; 8 °C, 8 h) methods. The external surface b* observed in meat marinated using immersion method were similar under all holding temperature and time combinations (P>0.05). In the tumbling marination, increasing either holding time or temperature resulted in a significant reduction (P<0.05) of b*, compared to meat tumbled at 4 °C for 4 h. Among marinated breast meat, holding meat at 4 °C for 8 h or 8 °C for 8 h after injection and holding meat at 8 °C for 4 h and 8 °C for 8 h after tumbling marination resulted in the best b*, (minimum yellowness) value.

Effect on internal surface color lightness (L*): Three-way interaction was significant (P<0.05) for internal L* value. Marination significantly reduced (P<0.05) internal surface L* compared to unmarinated control. Irrespective of the holding temperature and holding time the highest L* values were observed in unmarinated chicken breast meat. Among the meat marinated by different methods, the immersion method resulted in the highest internal L* value (P<0.05) when held at 8 °C for 8 h. Marination by injection (4 °C -4 h and 4 °C -8 h) and tumbling (4 °C -4 h, 4 °C -8 h and 8 °C -8 h) resulted in the best internal surface color L* (lowest) in marinated broiler chicken breast meat.

Effect on internal surface color redness (a*): The marination method showed a significant effect (P<0.001) internal redness value (a*) of marinated breast meat (Tables 3 and 4). Marination improved (P<0.05) the internal a* value compared to unmarinated control. The samples marinated by the injection method yielded the highest (P<0.05) internal a* value. The least internal a* (P<0.05) was observed from the unmarinated control. The internal a* values obtained in meat subjected to immersion and tumbling methods were similar (P>0.05).

Effect on the internal surface color yellowness (b*): Both the marination method (P < 0.001) and time (P<0.01) significantly influenced on b* value of broiler chicken breast meat (Tables 3 and 4). Besides, a significant interaction effect of method x time and holding temperature x time were for the b* value of marinated breast meat. Marination improved (P<0.05) internal surface b*. Significantly the highest b* (P<0.05) was recorded when the injection marination method was used.

Table 3: The effect of marination method, holding time and temperature on colorimetric parameters of broiler chicken breast meat[1].

Method	Tem: (°C)	Time (Hours)	External Surface Color Lightness L*	External Surface Color Redness a*	External Surface Color Yellowness b*	Internal Surface Color Lightness L*	Internal Surface Color Redness a*	Internal Surface Color Yellowness b*
Control	4	4 h	55.57	2.35	6.88^{f}	57.26^{a}	0.92	6.82
	4	8 h	54.99	1.68	4.57^{f}	56.70^{a}	0.92	5.03
	8	4 h	59.99	1.41	4.51^{f}	57.56^{a}	0.99	5.79
	8	8 h	55.08	2.41	6.20^{f}	57.71^{a}	0.73	5.36
Immersion	4	4 h	38.67	14.44	14.33^{bcd}	46.09^{c}	6.33	11.75
	4	8 h	38.61	15.23	15.75^{abc}	45.42^{cd}	4.55	4.55
	8	4 h	36.86	16.81	16.28^{ab}	45.14^{cd}	5.87	9.92
	8	8 h	36.29	17.06	16.24^{ab}	49.82^{b}	5.22	8.36
	4	4 h	41.57	13.71	14.83^{bcd}	41.44^{ef}	13.88	14.30
Injection	4	8 h	40.16	12.27	13.51^{cde}	40.85^{ef}	11.79	12.75
	8	4 h	39.28	14.56	17.82^{a}	45.12^{cd}	13.02	14.59
	8	8 h	41.36	10.73	11.13^{e}	43.69^{cde}	10.25	12.99
Tumbling	4	4 h	38.52	16.14	17.67^{a}	39.98^{f}	5.22	9.51
	4	8 h	37.67	15.69	15.09^{bcd}	42.74^{def}	5.68	10.07
	8	4 h	38.16	14.16	13.32^{cde}	45.28^{cd}	3.89	8.31
	8	8 h	40.09	13.14	12.63^{de}	41.64^{ef}	6.62	10.70
SEM			1.117	0.724	0.891	1.177	1.104	0.913

Probabilities P<						
Method (M)	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Temperature (T)	0.762	0.670	0.209	0.0014	0.539	0.734
Holding time (HT)	0.330	0.067	0.003	0.882	0.325	0.002
M x T	0.042	0.0007	0.002	0.482	0.837	0.710
M x HT	0.147	0.012	0.002	0.293	0.072	0.0003
T: x HT	0.753	0.527	0.793	0.804	0.581	0.017
M x T x HT	0.057	0.276	0.002	0.007	0.773	0.157

[a-f] Means in a column not sharing a common superscript are significantly different (P<0.05); SEM= Pooled standard error of mean; [1]Each value represents the mean of eight replicates.

Table 4: Main effect of marination method, holding time and temperature on colorimetric parameters of broiler chicken breast meat[1].

Main Effects	Tem:	Time	External Surface Color			Internal Surface Color		
			Lightness	Redness	Yellowness	Lightness	Redness	Yellowness b*
Method								
Control			56.41[a]	1.96[d]	5.54	57.31	0.88[c]	5.75[c]
Immersion			37.61[c]	15.89[a]	15.65	46.62	5.49[b]	8.65[b]
Injection			40.59[b]	12.82[c]	14.32	42.77	12.24[a]	13.65[a]
Tumbling			38.61[c]	14.79[b]	14.68	42.41	5.36[b]	9.65[b]
SEM			0.558	0.362	0.445	0.588	0.552	0.456

Temperature	4		43.22	11.44	12.83	46.31	6.16	9.35
(°C)	8		43.39	11.29	12.26	48.24	5.82	9.50
SEM			0.394	0.256	0.315	0.416	0.390	0.322
Time (Hours)		4h	43.58	11.69	13.20	47.23	6.27	10.12[a]
		8h	43.03	11.03	11.89	47.32	5.72	8.73[b]
SEM			0.394	0.256	0.315	0.416	0.390	0.322
Method x Tem:								
Control	4		55.28[b]	2.01[e]	5.72	56.98	0.92	5.92
	8		57.54[a]	1.91[e]	5.35	57.64	0.86	5.57
Immersion	4		38.64[def]	14.84[bc]	15.04	45.76	5.44	8.15
	8		36.58[f]	16.94[a]	16.26	47.48	5.54	9.14
Injection	4		40.86[c]	12.99[d]	14.17	41.15	12.84	13.52
	8		40.32[cd]	12.65[d]	14.47	44.40	11.63	13.79
Tumbling	4		38.09[ef]	15.92[b]	16.38	41.36	5.45	9.79
	8		39.12[cde]	13.65[cd]	12.98	43.46	5.26	9.51
SEM			0.789	0.512	0.630	0.832	0.780	0.645
Method x time								
Control		4h	57.78	1.88[e]	5.69	57.41	0.95	6.30[e]
		8h	55.04	2.04[e]	5.38	57.21	0.82	5.19[e]
Immersion		4h	37.76	15.62[ab]	15.30	45.62	6.10	10.84[c]

		8h	37.45	16.15^{a}	15.99	47.62	4.88	6.46^{e}
Injection		4h	40.43	14.13^{c}	16.32	43.28	13.45	14.44^{a}
		8h	40.76	11.50^{d}	12.32	42.27	11.02	12.86^{a}
Tumbling		4h	38.34	15.15^{abc}	15.49	42.63	4.56	8.91^{d}
		8h	38.88	14.42^{bc}	13.86	42.19	6.15	10.38^{cd}
SEM			0.789	0.512	0.630	0.832	0.780	0.645
Temperature x time								
	4	4h	43.58	11.66	13.43	46.19	6.59	10.59^{a}
	4	8h	42.86	11.22	12.23	46.43	5.74	8.10^{c}
	8	4h	43.57	11.73	12.98	48.27	5.94	9.65^{ab}
	8	8h	43.20	10.84	11.55	48.21	5.70	9.35^{bc}
SEM			0.558	0.362	0.445	0.588	0.552	0.456

$^{a-f}$ Means in a column not sharing a common superscript are significantly different (P<0.05); SEM=Pooled standard error of mean; [1]Each value represents the mean of eight replicates.

Immersion and tumbling methods recorded similar results (P>0.05) for b*. The least internal b* value was obtained in unmarinated meat samples.

Holding broiler chicken breast meat for 4 h resulted in the highest (P<0.05) internal surface b* value. Irrespective of the holding temperature, increasing holding time from 4 h to 8 h did not change the internal b* value in unmarinated samples, and the samples were marinated either by injection or tumbling methods. In contrast, immersion marination reduced (P<0.05) the internal b* when meat was held for 8 h. Marination by injection yielded the highest b* value (P<0.05) for broiler chicken breast meat. There was no difference in internal b* in all the methods of marination when the temperature increased from 4 °C to 8 °C at each holding period (P>0.05).

Meat color leaves a strong visual impression on the consumer. Upon cooking, the pink coloration of raw chicken meat no longer exists. If pink color exists, the consumers may assume the meat as undercooked (Palang, 2004). Therefore, different formulations have been assessed for marination as potential sources to resolve issues related to meat color. However, the role of marinade functional ingredients and pH of the marinade in relieving issues with pink color in cooked meat is yet to be interpreted (Palang, 2004). Qiao *et al.* (2001) reported strong relationship exists between pH and the fresh meat color. Lightness can be increased in marinated breast fillets, causing the collection of extracellular water in muscles. Both the external surface color and internal surface color of marinated meat exhibited higher redness and yellowness values than those of un-marinated breast meat. The present results are comparable with the findings of Bianchi *et al.* (2009).

Effects of holding temperature and time on sensory attributes of unmarinated and marinated broiler chicken breast meat

The sensory attributes of samples subjected to different marination methods, holding temperatures, and times are present in Figure 2. Of the sensory attributes tested, toughness, aroma, surface color, marinade penetration, and overall acceptability differed significantly (P<0.05) among treatments. According to the results, the highest sensory attributes were obtained by tumbling marinated broiler chicken breast meat held at 8 °C for 8 h (P<0.05). Meat subjected to injection marination kept under 8 °C for 4 h holding time obtained the lowest score for sensory attributes (P<0.05).

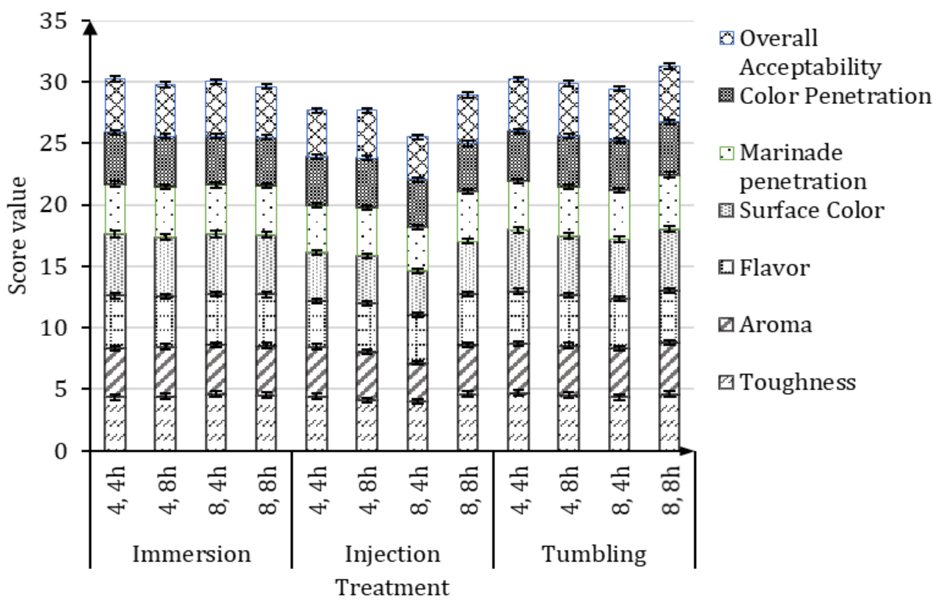

Figure 2: Evaluation of sensory attributes of marinated broiler chicken breast meat samples held at different holding temperatures and holding times.

Chicken breast meat subjected to tumble marination and held at 4 °C for 4 h obtained the highest toughness score (P < 0.05). When assessed for meat hardness, meat marinated using the injection method resulted in the highest value.

The lowest toughness score was recorded in injection marinated samples held at 8 °C for 4 h. However, previous studies demonstrated that marination improved the tenderness of broiler chicken breast meat (Saha *et al*., 2009; Lopez *et al*., 2012). Tumble marinated meat held at 8 °C for 8 h resulted in the highest score for aroma. The lowest score for aroma was given by injection marinated meat held at 8 °C for 4 h.

According to Sheard and Tali (2004) and Yusop *et al.* (2010), complex physicochemical and biochemical reactions that occur during tumbling might enhance the formations of aromatic compounds and flavor substances. Meat subjected to immersion marination held at 4 °C for 4 h improved (P<0.05) flavor. The lowest score (P<0.05) for meat flavor was recorded in injection marinated meat held at 4 °C for 4 h. However, Gamage *et al.* (2017) observed that the meat flavor was greatly enhanced by the injection method than immersion.

The high surface color (P<0.05) was observed in meat marinated by immersion (4 °C, 4 h), tumbling (4 °C, 4 h) and tumbling (8 °C, 8 h) methods. Meat marinated by injection method and held at 8 °C for 4 h showed the least surface colour. The highest marinade penetration and colour penetration were obtained in tumble marinated meat when held at 8 °C temperature for 8 h. Increased marinade pick-ups as a result of increasing holding temperature was also reported by Fenton *et al.* (1993). The lowest colour penetration (P<0.05) was observed when meat was subjected to injection marination method and held at 8 °C for either 4 h or 8 h. Marinade penetration was lowest in meat subjected to inject marination method and held at 8 °C for 4 h.

The highest overall acceptability was observed in tumble marinated meat held at 8 °C for 8 h while the lowest was from injection marinated meat held at 8 °C for 4 h. These results do not agree with the findings of Gamage *et al.* (2017), where the injection marination applied for 8 h resulted in the highest overall acceptability.

Effects of holding temperature and time on microbial quality of unmarinated and marinated broiler chicken breast meat

The total plate count was significantly differed (P<0.05) among treatments and storage periods (weeks). A significant treatment (marination method *vs.* holding temperature *vs.* holding time) and storage period interaction (P<0.05) was observed for the total microbial count of the marinated meat samples (Tables 5 and 6).

When considering the main effects, increasing the storage period from 2 to 4 weeks significantly increased (P<0.05) the number of colony-forming units (Table 6). Further, the increase of storage period up to the 6th week reduced (P<0.05) the microbial count but did not exceed (P>0.05) the microbial count in the 2nd week. During storage, chicken meat can be stored chilled at 1-4 °C or frozen at -12 °C or -18 °C (Atanassova *et al*., 2018). Though freezing is well known and widely accepted as an excellent method to preserve the keeping quality of chicken meat, the possible growth of psychotropic bacteria at a temperature below -18 °C may leave many undesirable changes in the meat (Atanassova *et al.,* 2018). The long-term frozen storage is also known to release the enzymes from the product making the environment unsuitable for growing the microorganisms (Woods and Chuch, 1999).

Increasing holding period from 4 h to 8 h in the control and marinated meat held at 4 °C, yielded the highest microbial count. Similar results were observed by Xargayo *et al.* (2001) for the immersion method. However, when the holding temperature was maintained at 8 °C also resulted in similar counts for control, injection, tumbling marinated meat, to those held for 4 °C, 4 h, and 8 h. Microbial plate counts were minimal in immersion marinated meat when held at 8 °C for 4 h. Tan and Ockerman, (2006) reported that spoilage was visible when the bacterial number exceeded 108 CFU/g.

In the current study, the total microbial count of all the treatments was approximately 4.5 log CFU/g. Therefore, all the products tested in the present study are considered suitable for human consumption within the 42 days of -18 °C storage conditions.

Table 5: Total plate count (log CFU/g) of marinated breast chicken *vs.* the storage time at -18°C.

Method	Temperature (°C)	Holding Time (h)	Storage Period (Weeks) 2nd week	4th week	6th week
Control	4⁰C	4 h	4.38 ± 0.05[aA]	4.51 ± 0.10[cdA]	4.47 ± 0.01[abA]
	4⁰C	8 h	4.46 ± 0.01[aA]	4.57 ± 0.03[bcdA]	4.17 ± 0.06[abB]
	8⁰C	4 h	4.25 ± 0.21[abA]	4.07 ± 0.17[eA]	4.41 ± 0.30[abA]
	8⁰C	8 h	3.71 ± 0.24[bcB]	4.40 ± 0.06[dA]	3.69 ± 0.09[bcB]
Immersion	4⁰C	4 h	4.10 ± 0.20[abcA]	4.56 ± 0.07[cdA]	3.98 ± 0.50[bcA]
	4⁰C	8 h	4.43 ± 0.08[aA]	4.96 ± 0.01[aA]	3.97 ± 0.67[bcA]
	8⁰C	4 h	3.57 ± 0.27[cA]	3.85 ± 0.15[eA]	3.30 ± 0.00[cA]
	8⁰C	8 h	3.54 ± 0.24[cB]	4.40 ± 0.14[dA]	3.95 ± 0.05[bcAB]
Injection	4⁰C	4 h	4.13 ± 0.29[abcA]	4.53 ± 0.06[cdA]	4.33 ± 0.13[abA]
	4⁰C	8 h	4.17 ± 0.22[abcA]	4.59 ± 0.02[bcdA]	4.07 ± 0.17[abcA]
	8⁰C	4 h	3.94 ± 0.17[abcB]	4.51 ± 0.02[cdA]	4.85 ± 0.06[aA]
	8⁰C	8 h	3.69 ± 0.08[bcB]	4.58 ± 0.02[bcdA]	4.12 ± 0.17[abcAB]
Tumbling	4⁰C	4 h	4.18 ± 0.07[abcB]	4.86 ± 0.06[aA]	4.47 ± 0.17[abAB]
	4⁰C	8 h	4.44 ± 0.10[aB]	4.76 ± 0.08[abcA]	4.08 ± 0.00[abcC]
	8⁰C	4 h	3.58 ± 0.11[Cb]	4.35 ± 0.05[dA]	4.14 ± 0.14[abA]
	8⁰C	8 h	4.45 ± 0.34[aA]	4.83 ± 0.04[abA]	4.29 ± 0.14[abA]

Means of replicate ± Standard error (SE); Means followed by different small letters in the same column (effect of treatments) are significantly differed (P<0.05); Means followed by different capital letters in the same raw (effect of storage period) are significantly differed (P<0.05).

Table 6: Total plate count (log CFU/g) of marinated chicken breast during the storage at -18°C[1].

Main effects		TPC[2] log CFU/g
(a) Treatments		
Control	4°C 4h	4.45[ab]
	4°C 8h	4.39[ab]
	8°C 4h	4.24[abcd]
	8°C 8h	3.93[d]
Immersion	4°C 4h	4.21[abcd]
	4°C 8h	4.45[ab]
	8°C 4h	3.57[e]
	8°C 8h	3.96[d]
Injection	4°C 4h	4.32[abc]
	4°C 8h	4.27[abcd]
	8°C 4h	4.43[ab]
	8°C 8h	4.12[bcd]

Tumbling	4°C 4h	4.50[a]
	4°C 8h	4.42[ab]
	8°C 4h	4.02[cd]
	8°C 8h	4.52[a]
SEM[3]		0.184
(b) Storage Period (Days)		
14		4.06[b]
28		4.51[a]
42		4.14[b]
SEM[3]		0.046
Probabilities, P<		
Treatment		0.0001
Storage Period		0.0001
Treatment x Storage Period		0.0463

[a-e] Means in a column not sharing in a common superscript are significantly different ($P < 0.05$); [1]Each value represents the mean of two replicates; [2] Total plate count; [3] Pooled standard error of mean.

CONCLUSIONS

Among the treatments, holding broiler chicken breast meat at 4 °C for 8 h after injection marination facilitated the development of the best meat quality. The highest overall acceptability was reported when the broiler chicken breast meat was held at 8 °C for 8 h after tumbling marination. All the products tested in the present study are suitable for human consumption within 42 days when stored at -18 °C.

CONFLICT OF INTEREST DECLARATION

The authors declare there is no conflict of interest.

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REFERENCES

Alahakoon, A. U., Jo, C. & Jayasena, D. D. (2016). An overview of meat industry in Sri Lanka: A comprehensive review. *Korean Journal Food Science of Animal Resources*, 36 (2), 137-144. https://dx.doi.org/10.5851%2Fkosfa.2016.36.2.137

Allen, C. D., Fletcher, D.L., Northcutt, J.K. & Russell, S.M. (1998). The relationship of broiler breast color to meat quality and shelf-life. *Poultry Science*, 77 (2), 361-366. https://doi.org/10.1093/ps/77.2.361

Alvarado, C.Z. & McKee, S. (2007). Marination to improve functional properties and safety of poultry meat. *Journal of Applied Poultry Research*, 16 (1), 113-120. https://doi.org/10.1093/japr/16.1.113

Alvarado, C.Z. & Sams, A.R. (2004). Turkey carcass chilling and protein denaturation in the development of pale, soft, and exudative meat. *Poultry Science*, 83 (6), 1039-1046. https://doi.org/10.1093/ps/83.6.1039

Atanassova, S., Stoyanchev, T., Yorgov, D. & Nachev, V. (2018). Differentiation of fresh and frozen-thawed poultry breast meat by near infrared spectroscopy. *Bulgarian Journal of Agricultural Science*, 24 (1), 162-168.

Babji, A. S., Froning, G. W., & Ngoka, D. A. (1982). The effect of preslaughter environmental temperature in the presence of electrolyte treatment on turkey meat quality. *Poultry Science*, *61*(12), 2385-2389. https://doi.org/10.3382/ps.0612385

Bharti S. K., Anita B., Das S. K. & Biswas, S. (2011). Effect of vacuum tumbling time on physico-chemical, microbiological and sensory properties of chicken tikka. *Journal of Stored Products and Postharvest Research*, *2* (7), 139-147.

Bianchi, M., Petracci, M. & Cavani, C. (2009). The use of marination to improve poultry meat quality. *Italian Journal of Animal Science*, *8* (2), 757-759. https://doi.org/10.4081/ijas.2009.s2.757

Bowker, B. & Zhuang, H. (2017). Freezing-thawing and sub-sampling influence the marination performance of chicken breast meat. *Poultry Science*, 96 (9), 3482-3488. https://doi.org/10.3382/ps/pex117

Buses, H.M. (2005). *Acid Treatments have an effect on Salmonella enteritidis, Shelf-life, and Quality Attributes in Poultry Breast Fillets*. Master Thesis, Graduate Faculty of Texas Tech University, Texas, USA.

Capaccioni, M. E., Casales M. R. & Yeannes M. I. (2011). Acid and salt uptake during the marinating process of *Engraulis anchoita* fillets influence of the solution: Fish ratio and agitation. *Ciência e Tecnologia de Alimentos*, *31*(4), 884-890. https://doi.org/10.1590/s0101-20612011000400009

Carroll, C. D. & Alvarado, C. Z. (2008). Comparison of air and immersion chilling on meat quality and shelf life of marinated broiler breast fillets. *Poultry Science, 87* (2), 368-372. https://doi.org/10.3382/ps.2007-00213

Cheng, Q. & Sun, D. W. (2008). Factors affecting the water holding capacity of red meat products: A review of recent research advances. *Critical Reviews in Food Science and Nutrition*, 48 (2), 137-159. http://dx.doi.org/10.1080/10408390601177647

Cho, H.C., MacMartin, J.M. & Bordi, P.L. (2016). Influence of tasting spots on texture of chicken breast fillets. *International Journal of Food Processing Technology*. 3 (2), 43-47. http://dx.doi.org/10.15379/2408-9826.2016.03.02.02

Fenton, F.L., Hand, L.W. & Berry, J.G. (1993). *Effect of marination holding time and temperature on chicken breast halves*. Oklahoma Agricultural Experimental Station. pp. 89-94.

Fletcher, D.L. (1999). Broiler breast meat color variation, pH, and texture. *Poultry Science*, 78 (9), 1323-1327. https://doi.org/10.1093/ps/78.9.1323

Gamage, H.G.C.L., Mutucumarana, R.K. & Andrew, M.S. (2017). Effect of marination method and holding time on physicochemical and sensory characteristics of broiler meat. *Journal of Agricultural Sciences*, 12 (3), 172-184. http://dx.doi.org/10.4038/jas.v12i3.8264

Gao, T., Li, J., Zhang, L., Jiang, Y., Li, Y. Zhang, X., Gao, F. & Zhou, G. (2015). Effect of different tumbling marination method and time on the quality characteristics of prepared pork chops. *Food Science and Technology*, 35 (3), 445-451. https://dx.doi.org/10.1590/1678-457X.6710

Heath, J.L. & Owens, S.L. (1987). Yield and shear values of *Pectoralis superficialis* after tumbling in various solutions. *Poultry Science*, 66 (12), 1949-1956. https://doi.org/10.3382/ps.0661949

Hinkle, J. B. (2010). *Acid Marination for Tenderness Enhancement of Beef Bottom Round*. Theses and Dissertations in Animal Science, European Food Research and Technology. University of Nebraska - Lincoln. http://dx.doi.org/10.2527/1992.70103081x

Latif, S.S. (2010). Effect of marination on the quality characteristics and microstructure of chicken breast meat cooked by different methods. *Lucrări Stiintifice*, *54*, 314-324.

Lawrie, R. A. & Ledward, D. A. (2006). The eating quality of meat. In: R.A. Lawrie, & D.A. Ledward (Eds.) *Lawrie's Meat Science* (pp. 279-337). Woodhead Publishing Limited, England. http://dx.doi.org/10.1201/9781439833094

Livestock Statistical Bulletin-Department of Animal Production and Health (2019). Peradeniya, Sri Lanka.

Lopez, K., Schilling, M. W., Armstrong, T. W., Smith, B. S. & Corzo, A. (2012). Sodium chloride concentration affects yield, quality, and sensory acceptability of vacuum-tumbled marinated broiler breast fillets. *Poultry Science*, *91* (5), 1186-1194. https://doi.org/10.3382/ps.2011-01733

Marsh, B. B. (1954). Rigor mortis in beef. *Journal of the Science of Food and Agriculture*, *5* (2), 70-73. https://doi.org/10.1002/jsfa.2740050202

Owens, C. M., Alvarado, C. & Sams, A. R. (2009). *Poultry Meat Processing*, 2nd Edition. Taylor & Francis, LLC. pp.454. http://dx.doi.org/10.1201/b15805

Palang E. Y. (2004). *The Role of Ingredients and Processing Conditions on Marinade Penetration, Retention and Color Defects in Cooked Marinated Chicken Breast Meat*. PhD Thesis. Graduate Faculty of the University of Georgia. Athens, Georgia.

Qiao, M., Fletcher, D. L., Smith, D. P. & Northcutt, J.K. (2001). The effect of broiler breast meat color on pH, moisture, water-holding capacity, and emulsification capacity. *Poult.ry Science*, *80* (5), 676-680. https://doi.org/10.1093/ps/80.5.676

Saelin, S., Wattanachant, S. & Youravong, W. (2017). Evaluation of water holding capacity in broiler breast meat by electrical conductivity. *International Food Research Journal, 24* (6), 2593-2598.

Saha, A., Lee, Y., Meullenet, J. F. & Owens, C. M. (2009). Consumer acceptance of broiler breast fillets marinated with varying levels of salt. *Poultry Science*, *88* (2), 415-423. https://doi.org/10.3382/ps.2008-00230

Santana, P., Huda, N. & Yang, T. A. (2015). Physicochemical properties and sensory characteristics of sausage formulated with surimi powder. *Journal of Food Science and Technology*, 52 (3), 1507-1515. https://doi.org/10.1007/s13197-013-1145-1

Santos, H. C., Brandelli, A. & Ayub, M. A. Z. (2004). Influence of post-mortem aging in tenderness of chicken breast fillets. *Ciência Rural*, *34* (3), 905-910. http://dx.doi.org/10.1590/S0103-84782004000300038

SAS Institute INC. (2002). SAS/Stat 9.0 User's Guide. Cary, NC: SAS Institute Inc.

Sheard, P. R. & Tali, A. (2004). Injection of salt, tripolyphosphate and bicarbonate marinade solutions to improve the yield and tenderness of cooked pork loin. *Meat Science*, *68* (2), 305-311. http://dx.doi.org/10.1016/j.meatsci.2004.03.012

Smith, D. P. & Acton, J. C. (2001). Marination, cooking, and curing of poultry products. In: A.R. Sams (Ed.) *Poultry Meat Processing* (pp. 257-280). CRC Press, Boca Raton.

Smith, D. P. & Young, L. L. (2007). Marination pressure and phosphate effects on broiler breast fillet yield, tenderness and color. *Poultry Science*, *86* (12), 2666-2670. https://doi.org/10.3382/ps.2007-00144

Tan, F. J. & Ockerman, H. W. (2006). Applicability of nisin and tumbling to improve the microbiological quality of marinated chicken drumsticks. *Asian Australasian Journal of Animal Sciences. 19* (2), 292-296. https://doi.org/10.5713/ajas.2006.292

Woods, L. F. & Chuch, P. N. (1999). Strategies for extending the shelf-life of poultry meat and products. In: R. I. Richardson (Ed.) *Poultry Meat Science* (pp. 297-310*)*. Poultry Science Symposium Series*,* Abingdon: Carfax Publishing Company.

Xargayó, M., Lagares, E., Fernández, E., Ruiz, D. & Borrell, D. (2001). Marination of fresh meats by means of spray effect: influence of spray injection on the quality of marinated products. [on line]. [Accessed on 09.02.2018]. http://en.metalquimia.com/upload/document/article-en-7.pdf.

Yang, C. C. & Chen, T. C. (1993). Effects of refrigerated storage, pH adjustment, and marinade on color of raw and microwave cooked chicken meat. *Poultry Science*. *72* (2), 355-362. https://doi.org/10.3382/ps.0720355

Yusop, S. M., O'Sullivan, M. G., Kerry, J. F. & Kerry, J.P. (2010). Effect of marinating time and low pH on marinade performance and sensory acceptability of poultry meat. *Meat Science*, *85* (4), 657-663. http://dx.doi.org/10.1016/j.meatsci.2010.03.020

Zhuang, H. & Bowker, B. (2016). Effect of marination on lightness of broiler breast fillets varies with raw meat colour attributes. *LWT-Food Science and Technology*. *69* (7), 233-235. https://doi.org/10.1016/j.lwt.2016.01.054