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Comparison between the Quality Traits of Phosphate and Bicarbonate-Marinated Chicken Breast Fillets Cooked under Different Heat Treatments

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ABSTRACT

Because the use of phosphates has being recently diminished in meat industry due to the nutritional drawbacks of phosphates, some researchers started to evaluate sodium bicarbonate as phosphate replacer in meat products. The aim of this study was to evaluate the effect of different temperature combinations of dry air-cooking treatments (Air and Core temperatures: 160 - 76, 160 - 80, 200 - 76 and 200˚C - 80˚C, respectively) on chemical composition, texture properties, water activity, freezable water and bound water, color, pH, and water binding capacity of phosphate and bicarbonate-marinated chicken breast. A batch of 24 h *post-mortem* broiler breast meat of 80 fillets was divided into two groups of marination treatments (0.3% sodium bicarbonate n = 40, 0.3% sodium tripolyphosphate n = 40) and was vacuum tumbled (45 min, −0.95 mbar, 20 rpm). Different temperature-combinations cooking treatments significantly modified the chemical composition. Bicarbonate marinated fillets showed higher ability to retain water (67.3% *vs.* 65.7%, P < 0.05) during severe heat treatment and lower cook losses (30.7% *vs.* 33.4%, P < 0.05) when compared with phosphate-marinated fillets. The effect of changing the cooking temperatures on Texture Profile Analysis (hardness, cohesiveness, gumminess, springiness, and chewiness) was more tangible in phosphate marinated fillets than bicarbonate. Bicarbonate-marinated fillets showed significant differences in the percentage of bound water, latent heat, and water activity after cooking in comparison to phosphate-marinated fillets. The results of this study revealed that phosphate-marinated fillets interacted with heat treatments in different patterns in comparison with bicarbonate-marinated fillets.

KEYWORDS

Chicken Meat; Marination; Sodium Bicarbonate; Heat Treatment; Quality Traits

1. Introduction

Marination is one of the most common techniques that usually used to improve the flavor, tenderness, juiciness, stability and safety of meat from an aspect and enhance the yield from other aspect [1]. Several studies have implemented on marinated meat to evaluate processing conditions: time and type of marination, salt and polyphosphate concentration, cooking methods, and other processing parameters by employing several quality measures like marinade uptake, water retention, water binding capacity, cooking loss, texture and sensorial properties [2,3]. Particularly, pyrophosphate and tripolyphosphate are frequently used to increase the water binding capacity of meat. Sodium tripolyphosphate accounts for approximately 80% of the phosphates used in further-processed meat products. In this context, phosphates offer a wide range of functional properties to the processed meat products which rendered them as a preferable choice for meat producers. Phosphates can impart the functional properties to meat products in several synchronized ways:

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by shifting the pH far away from isoelectric point, increasing the ionic strength, and improving the solubilization of myosin and actin by sequestering Mg and Ca ions which are involved during the formation of actomyosins complex. Dissociation of actomyosins enhances the solubilization and the functional properties of proteins during processing [4]. Phosphates also have strong synergistic effect in presence of sodium chloride. Sodium chloride is used in combination of phosphate in marinades to improve the texture and yield of muscle meat products [5,6].

Beside to the former unique characteristics, phosphates improve the oxidative stability, flavor and retard the microbial growth in meat products [7]. Recently, the use of phosphates has being diminished in meat industry due to some nutritional drawbacks of phosphates that come from their ability to interfere the absorption of some minerals in the gut by forming insoluble complexes with calcium and magnesium. Several countries have banned their use in raw meat production [8]. In response to these nutritional drawbacks, many studies started to evaluate some functional ingredients to replace the use of phosphate in meat products [9].

Carbonate and bicarbonate compounds are considered as a new promising agent as phosphate replacer. Some recent studies showed that bicarbonate compounds can be reduce by the drip loss and shear force, which improve the yield as well as phosphates. This effect could be explained because bicarbonates have higher buffering capacity and ionic strength than phosphates [9-11].

The impact of different heat treatments on the quality traits of marinated poultry meat had been evaluated. Air-steam treatment was one of the best methods for obtaining more tender chicken slices. It was found that the effect of cooking time on cooking loss was more than cooking temperature [12]. Low relative humidity-heat treatment showed higher quality traits for cooked turkey meat when compared to high steam treatment [13]. Cooking conditions (temperature and cooking time) have massive impact on physical characteristics of meat and eating quality.

Bicarbonate compounds have evaluated as a phosphate replacer under the same conditions of heat treatment [10,11]. Scarce in formations are available about the effect of bicarbonate in comparison to phosphates under different conditions of heat treatments. The aim of this study was to evaluate the effect of different heat treatments on breast fillets marinated with bicarbonate versus phosphates.

2. Materials and Methods

2.1. Collection and Preparation of the Samples

A batch of 80 skinless chicken breasts was obtained from commercial plant after 24 h *postmortem* from the same flock. The breast fillets were trimmed and adjusted to have the same raw weight (141.0 ± 0.9 g). The samples were reorganized in two groups (n = 40) having the same average lightness values (L^*, 51.0 ± 0.2 and (50.9 ± 0.2) for bicarbonate and phosphate marinating treatments, respectively.

The first group was marinated with sodium tripolyphosphate (P) and the second group marinated with sodium bicarbonate (B) by vacuum tumbling (45 min, −0.95 mbar, and 20 rpm) with target marination level 20% and 0.3% for each salt. Each type of marination treatment was divided into four groups (n = 10) and subjected to different heat treatments by air oven (oven-core temperatures: 160 - 76 (A), 160 - 80 (C), 200 - 76 (D) and 200 - 80˚C (E).

2.2. Analysis of Quality Traits

The pH was determined using a modification of the iodoacetate method that was initially described by Jeacocke [14]. Approximately 2.5 g of meat sample before tumbling, after tumbling, and after cooking were used, minced by hand, homogenized in 25 mL of a 5 m*M* iodoacetate solution with 150 m*M* potassium chloride for 30 sec, and the pH of the homogenate was determined using a pH meter. Cooking loss was calculated from differences in the weights before and after cooking [15]. Marinade uptake was also determined by the difference in weights between marinated and green (fresh) meat, while purge loss was calculated by the difference in weight of the marinated meat before and after storage for 24 h under refrigerated conditions. Water activity (a_w) was measured at a constant temperature (25 ± 1˚C) by a water activity meter mod Aqualab (Decagon Devices Inc., Pullman, WA) that bases its measure on the chilled-mirror dew point technique. For each marination treatment, a_w was detected on 3 samples before tumbling, after tumbling, and after cooking. Proximate analysis (moisture, protein, lipid and ash contents) was performed according to the Association of Official Analytical Chemists procedure [16]. Moisture content of the cooked meat samples was determined by air-oven procedure, crude protein content was assessed by Kjeldahl method, lipid content was estimated by petroleum ether extraction using soxhlet method and total ash content was determined by the difference in weight after incineration at 525˚C for 4 h. The water holding capacity (WHC) of the raw breast cuts was measured by modified Van Laack method [17]. About 30 g of minced meat were homogenized with 90 ml of 1% sodium chloride. Each 20 g of homogenized solution was centrifuged for 1 min at speed 22,000 rpm and temperature 6˚C - 7˚C. The supernatant was removed to calculate the moisture uptake which was calculated as the difference in weight between fresh meat and the pellet after centrifugation.

The texture profile analysis was determined on cylindrical samples (3 cm diameter, 2 cm height) were axially compressed (load cell: 50 kg; crosshead test speed: 1 mm/s, distance: 5 mm, force: 100 g, time: 5 sec) to 50% of their initial height in a double compression cycle: hardness (kg, maximum force required to compress the sample), cohesiveness (A2/A1, extent to which the sample could be deformed prior to rupture, where A1 represents the total energy required for the first compression and A2 the total energy required for the second compression), springiness (D2/D1, the ability of sample to recover its original shape after the deforming force is removed where D1 represents the initial compression distance and D2 the distance detected for the second compression), gumminess (hardness × cohesiveness, the force needed to disintegrate a semisolid sample to a steady state of swallowing), chewiness (springiness × gumminess, the work needed to chew a solid sample to a steady state of swallowing). Shear force was determined on a meat strip (approximately 2 × 4 × 1 cm) which was excised from each cooked sample parallel to the fiber direction. Strips were sheared perpendicular to fiber direction using a TA.HDi Heavy Duty texture analyzer (Stable Micro Systems Ltd., Godalming, Surrey, UK) equipped with Allo-Kramer shear cell using the procedure described by Sams *et al.* [18]. Shear values are reported as kilograms of shear force per gram of sample.

The amount of Freezable water (FW) was evaluated by a Pyris 6 DSC (Perkin Elmer Corp., Wellesley, MA) on 3 samples per group after tumbling and after cooking. The DSC was equipped with a low-temperature cooling unit Intacooler II (Perkin Elmer Corp.). Temperature calibration was performed with ion-exchanged distilled water (melting point 0.0˚C), indium (melting point 156.60˚C), and zinc (melting point 419.47˚C). Heat flow was calibrated using the heat of fusion of indium (Δh = 28.71 J/g). For the calibration, the same heating rate used for sample measurements was applied, and a dry nitrogen gas flux of 20 mL/min was used. Each sample (about 20 mg) was weighed in a 50-μL aluminum pan with a small spatula, hermetically sealed, and then loaded onto the DSC instrument at room temperature, using an empty pan of the same type as a reference. Then samples were cooled at 5˚C /min to −60˚C, held for 1 h, and then scanned at 5˚C /min to 20˚C [19]. The FW was determined as follows:

$$FW = \frac{\Delta Hm}{\Delta Hw}$$

where ΔHw (325 J/g) is the latent heat of melting per gram of pure water at 0˚C [20], and ΔH (J/g) is the measured latent heat of melting of water per gram of sample obtained by the integration of the melting endothermic peak. The FW amount was expressed as grams per gram of fresh sample weight. Color (CIE L^* = lightness, a^* = redness, and b^* = yellowness) [21] was measured in triplicate on the bone-side surface of each fillet using a Chroma Meter CR-400 (Minolta Corp., Milan, Italy).

2.3. Statistical Analysis

The effect of marination and heat treatment on quality traits of chicken breasts were evaluated by ANOVA option of the GLM procedure (statistica 6). Means were separated using Duncan test with $P \le 0.05$ considered as significant.

3. Results and Discussion

3.1. Effect of Heat Treatment on Proximate Composition

The effect of heat treatment and marination process together on proximate composition was shown in **Table 1**. It was found that there were slight differences in ash and lipid contents in chicken breasts marinated with bicarbonate and cooked under different heat treatments (BA, BC, BD, BE). Low variability in moisture change between different heat treatments could explain the slight differences in ash and fat contents (**Table 1**), while the lowest moisture content and the highest protein content were observed in the most severe heat treatments for both bicarbonate and phosphate treatments (BE and PE).

Treatment BA and BD had no significant differences in moisture and protein contents. The highest moisture content (71.4%) among all groups was in BC treatment. In general, the most severe heat treatment (highest set and core temperature) caused significant higher changes in proximate composition for both types of marinating treatments. The results also showed that breast fillets treated with bicarbonate and cooked at the most severe heat treatment (E) had higher ability to retain water than phosphate treatment (67.3 *vs* 65.7%, $P < 0.05$). The effect of heat treatments on the chemical composition of bicarbonate-marinated fillets was different from phosphate-marinated fillets. Overall, both marination and cooking treatments have resulted significant differences in proximate composition which could be explained by different factors: water evaporation, fats melting and loss of soluble proteins [22].

3.2. Effect of Heat Treatments on Texture Properties

Changing of heat treatments had significant effect on the texture profile of meat marinated with polyphosphate, while this effect was not clear in the fillets treated with bicarbonate (**Tables 2** and **3**). Both types of marination

Table 1. **Proximate composition (mean ± standard error) for chicken breast raw and marinated meat with bicarbonate (B) and phosphate (P) under different heat treatments (A, C, D and E represent different core and oven temperatures: 76 - 160, 80 - 160, 76 - 200 and 80°C - 200°C, respectively).**

Group	Total moisture (g/100g)	Total proteins (g/100g)	Total lipids (g/100g)	Total ash (g/100g)
PA	70.2 ± 0.4^{b}	26.9 ± 0.5^{bcd}	1.60 ± 0.30^{ab}	2.10 ± 0.07^{ab}
PC	69.9 ± 0.4^{b}	27.3± 0.5^{bc}	1.37 ± 0.12^{abc}	1.79 ± 0.09^{cb}
PD	69.2 ± 0.4^{b}	26.8 ± 0.9^{bcd}	1.39 ± 0.09 ^{abc}	1.79 ± 0.06^{cb}
PE	65.7 ± 0.2^{d}	31.1 ± 0.6^{a}	1.48 ± 0.17^{ab}	2.36 ± 0.26^{c}
BA	70.0 ± 0.4^{b}	26.8 ± 0.6^{cd}	1.60 ± 0.13^{ab}	1.44 ± 0.07^{d}
BC	71.4 ± 0.3^{a}	28.4 ± 0.7^{b}	1.70 ± 0.20^{a}	1.54 ± 0.10^{cd}
BD	70.0 ± 0.4^{b}	26.7 ± 0.7^{cd}	1.31 ± 0.22^{abc}	1.60 ± 0.20^{cd}
BE	67.3 ± 0.3^{c}	30.4 ± 0.6^{a}	1.59 ± 0.19^{ab}	1.76 ± 0.10^{bcd}

$^{a-c}$Different superscript letters within column mean significant difference (P < 0.05).

Table 2. **Shear force and texture analysis profile (mean ± standard mean error) of chicken breast meat marinated with phosphate (P) under different heat treatments.**

Quality traits	Heat treatment conditions (core-oven temperatures)			
	76 - 160°C (PA)	80 - 160°C (PC)	76 - 200°C (PD)	80 - 200°C (PE)
Shear force (kg/g)	2.11 ± 0.10^{c}	2.08 ± 0.11^{c}	2.39 ± 0.09^{b}	2.71 ± 0.10^{a}
Hardness (kg/g)	2.26 ± 0.20	2.25 ± 0.17	1.81± 0.31	2.44 ± 0.11
Cohesiveness	2.78 ± 0.07^{b}	2.83 ± 0.11^{b}	2.73 ± 0.11^{b}	3.12 ± 0.05^{a}
Gumminess (kg/g)	6.21 ± 0.43^{ab}	6.30 ± 0.36^{ab}	4.91 ± 0.78^{b}	7.60 ± 0.29^{a}
Springiness	1.64 ± 0.05	1.60 ± 0.04	1.65 ± 0.04	1.60 ± 0.04
Chewiness	10.1 ± 0.5^{ab}	10.0 ± 0.5^{ab}	8.0 ± 1.2^{b}	12.1 ± 0.3^{a}

$^{a-c}$Different superscript letters within a row mean significant difference (P < 0.05).

Table 3. **Shear force and texture analysis profile (mean ± standard mean error) of chicken breast meat marinated with bicarbonate (B) under different heat treatments.**

Quality traits	Heat treatment conditions (core-oven temperatures)			
	76 - 160°C (BA)	80 - 160°C (BC)	76 - 200°C (BD)	80 - 200°C (BE)
Shear force (kg/g)	2.52 ± 0.09^{ab}	2.41 ± 0.13^{b}	2.59 ± 0.14^{ab}	2.85 ± 0.09^{a}
Hardness (kg/g)	2.44 ± 0.13	2.25 ± 0.27	2.03 ± 0.12	1.88 ± 0.11
Cohesiveness	2.87 ± 0.09	3.16 ± 0.13	2.94 ± 0.06	3.11 ± 0.11
Gumminess (kg/g)	6.92 ± 0.22	7.01 ± 0.78	5.97 ± 0.35	5.79 ± 0.32
Springiness	1.48 ± 0.04^{ab}	1.44 ± 0.03^{b}	1.54 ± 0.04^{ab}	1.56 ± 0.02^{a}
Chewiness	10.25 ± 0.39	10.04 ± 1.00	9.14 ± 0.53	9.05 ± 0.48

$^{a-b}$Different superscript letters within a row mean significant difference (P < 0.05).

treatment did not show any change in hardness (resistance to deformation) at different heat treatment conditions (**Tables 2** and **3**). The effect of heat treatment was significant in PE treatment, where cohesiveness (the strength of the internal bonds making up the product), gumminess (the energy required to disintegrate a semisolid food to a state ready for swallowing), and chewiness (a low resistance to breakdown on mastication) values were significantly (P < 0.05) increased (**Table 2**).

It is known that during marination process using phosphates, myofibrillar proteins are extracted on the surface of meat. The extracted proteins have two functions during cooking process. First, they improve binding properties by coagulation. The second, they facilitate the retention of moisture in the meat tissue by sealing the micro-capillaries with coagulated proteins [23]. It is not known if marinated meat with bicarbonate shows the same behavior in comparison with phosphate-marinated meat. But in general, the higher water holding capacity and swelling of myofibrils are responsible about the mechanism of increased tenderness and juiciness [24]. Effect of bicarbonate on the texture properties needs further investigations.

Both type of marination treatments showed higher shear values in the most severe heat treatments (PE and BE). Heat treatments changed the elasticity of fillets treated with bicarbonate as represented by springiness values (**Table 2**).

The effect of heat treatments on the texture profile of bicarbonate-marinated fillets was less than phosphate-marinated fillets; this could be explained due to the generation of carbon dioxide produced during cooking and formation of air-filled pockets which could dilute the load-bearing material during the texture analysis [25].

Moreover, the lower hardness values (softness) could be attributed to the large amount of water retained in the meat. The role of phosphate in improving the tenderness of meat is known. Polyphosphates promote the weakening of the myosin heads to actin, and thus promote the dissociation of actomyosin, increase the electrostatic charge and therefore, they could allow more water to be retained or taken up by the meat. The increased tenderness might be attributed directly to the higher water content and weakened muscle structure [4].

3.3. Water Activity, Freezable and Bound Water

There are three different forms of water inside the meat tissues. The first one is the major part of water (more than 80%) retained in meat as free which can be expressed by water activity (a_w). The second part of water (10% - 15%) is immobilized and entrapped under the effect of net charge attraction. The third part of water is a minor part (around 4%) usually bound to the ionizable groups of amino acids of the proteins and other groups able to form H bonds [26]. The first two parts of water are affected or lost during processing like cooking, cutting, grinding, and storage. In our study, water activity (a_w) was used to estimate mainly the first two parts.

a_w was significantly higher in bicarbonate treated fillets when compared to phosphate marinated fillets (0.998 *vs* 0.995, $P < 0.05$). Water activity was reduced after cooking in all type of heat treatments in comparison to raw marinated meat (**Figures 1** and **2**) which may be explained by loss of major amount of free water due to evaporation by dry cooking. The most severe heat treatment (80˚C - 200˚C) exhibited the lowest a_w for both types of marination treatments.

There were no significant differences in water activity after marination process for both types of treatments in comparison to raw meat. Phosphate-marinated fillets showed the same trend in the change of water activity during different cooking treatments. The effect of core temperature on water activity was stronger than the effect of oven temperature in both of marination treatments.

There were significant differences in total latent heat and bound water among bicarbonate-marinated and phosphate-marinated fillets (**Table 4**). Bicarbonate-marinated fillets cooked at 76˚C - 200˚C exhibited the highest ($P < 0.05$) percentage of bound water (18.1%).

Marination process had minor effect on bound water for bicarbonate-marinated and phosphate-marinated fillets in comparison to raw fillets. Cooking treatments A, C and D for phosphate-marinated fillets showed slight significant differences in bound water. Phosphate-marinated fillets cooked by heat treatment (E: 80˚C - 200˚C) showed lowest latent heat value (160 J/g) and highest bound water percentage (25.0%) in comparison with other groups.

The freezable water content for raw fillets was about 93% of the total amount, while after marination it was 91% and 90% for phosphate and bicarbonate-marinated fillets respectively. The change in freezable water content after marination was slightly significant for both types of treatments. There were significant differences in freezable water after cooking in all groups of treatment but in different degrees (**Figure 3**). The most severe heat treatment (80˚C - 200˚C) for phosphate-marinated fillets showed the lowest value (0.75) of freezable water. According to these results there was no relation between freezable water values and water activity values. Changing the percentage of freezable and bound water during different cooking could be attributed to the loss of water by evaporation, loss of some soluble proteins due to cooking loss, and denaturation of proteins in which the type or the forms of bonds with water change.

3.4. Color, pH, Marinade Uptake, Drip and Cooking Loss and WHC (Pooled as Marination)

There were no significant differences in L* (lightness),

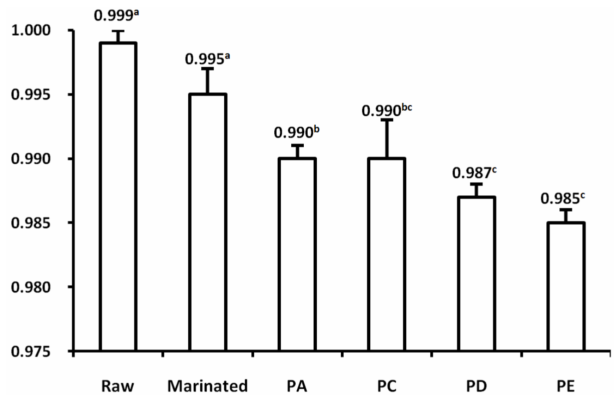

Figure 1. Water activity a_w (mean ± standard mean error) for chicken breast meat raw and marinated with phosphate (P) and cooked at different heat treatments (A, C, D and E represent different core and oven temperatures: 76 - 160, 80 - 160, 76 - 200 and 80 - 200˚C, respectively). [a-c]Different superscript letters mean significant difference ($P < 0.05$).

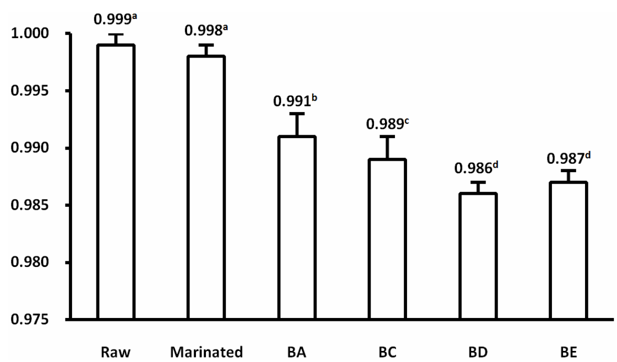

Figure 2. Water activity (a_w) (mean ± standard mean error) for chicken breast meat raw and marinated with bicarbonate (B) and cooked at different heat treatments (A, C, D and E represent different core and oven temperatures: 76 - 160, 80 - 160, 76 - 200 and 80 - 200˚C, respectively). [a-d]Different superscript letters mean significant difference ($P < 0.05$).

Table 4. The results of enthalpy and bound water (mean ± standard mean error) of chicken breast meat marinated with bicarbonate and phosphate.

	Phosphate		Bicarbonate	
	Bound water (%)	Latent heat (J/g)	Bound water (%)	Latent heat (J/g)
Before marination	7.2 ± 0.70^{c}	224.7 ± 1.8^{ab}	7.2 ± 0.7^{c}	224.7 ± 1.8^{a}
After marination	9.1 ± 3.7^{bc}	230.2 ± 9.4^{a}	10.4 ± 4.1^{abc}	227.6 ± 10.4^{a}
A (76 - 160˚C)	10.8 ± 4.7^{bc}	203.4 ± 10.8^{bc}	7.0 ± 1.9^{c}	211.5 ± 4.3^{a}
C (80 - 160˚C)	21.8 ± 2.2^{a}	177.7 ± 5.0^{de}	9.2 ± 3.4^{bc}	210.2 ±7.8^{a}
D (76 - 200˚C)	18.1 ± 1.8^{ab}	184.3 ± 4.0^{cd}	18.1 ± 3.1^{a}	186.8 ± 7.0^{b}
E (80 - 200˚C)	25.0 ± 3.8^{a}	160.0 ± 8.1^{e}	16.1 ± 0.7^{ab}	183.5 ±1.6^{b}

[a-e]Different superscript letters within a row mean significant difference ($P < 0.05$).

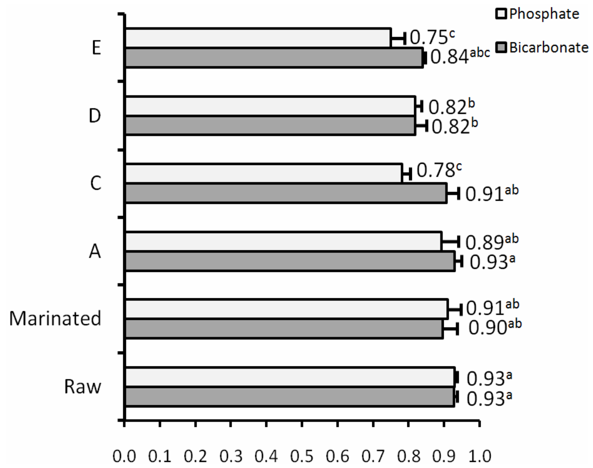

Figure 3. Freezable water (mean ± standard mean error) for chicken breast meat raw and marinated with phosphate and bicarbonate and cooked at different heat treatments (A, C, D and E represent different core and oven temperatures: 76 - 160, 80 - 160, 76 - 200 and 80 - 200˚C, respectively). a-cDifferent superscript letters mean significant difference (P < 0.05).

a^* (redness) and b^* (yellowness) values of raw meat chicken fillets which were dedicated for bicarbonate and phosphate treatments. The samples were dispersed in systematic way to obtain consistency of color between treatment groups. The consistency in the color is important because meat color extremes have been shown to affect marination uptake, cook yield, and texture [27]. After marination process, L^* (Lightness) values for bicarbonate (55.3 *vs.* 51.0) and phosphate (56.5 *vs.* 50.9) treatments were significantly ($P < 0.05$) increased in comparison to raw fillets while there were no significant differences in a^* and b^* values (Table 5). This increase in lightness could be due to the increase in extracellular water as a result of the marination process. In general, there was no consensus between the previous studies on the effect of marination process on the color values. Young *et al.* [28] found similar L^*, a^* and lower b^* values in marinated fillets in comparison to non-marinated fillets, while Lyon *et al.* [29] pointed out that marinated poultry muscles were less red (a^*) and less yellow (b^*) when compared to non-marinated meat. In another study, marinated meat showed slight significant decrease in L^* and a^* values [30]. It was found that both a^* and b^* values were decreased in marinated fillets [31,32]. It is not easy to resolve the changes in the color values of poultry muscle after marination because they depend on different factors, but the most important is the pH [33]. It was found also that vacuum tumble marination has resulted to increase cooked meat lightness and decrease cooked meat redness [34].

As expected, meat pH was increased after both types of marination treatment because both marinating ingredients are alkaling agents. Phosphate alone increased significantly ($P < 0.05$) meat pH by approximately 0.15 units, whilst bicarbonate alone increased the pH by 0.34 units (Table 5). Bicarbonate showed higher effect on the pH than phosphate and these results are in consistent with the previous studies [35]. The differences in buffering capacity and ionic strength between phosphate and bicarbonate may be explain the difference in the ultimate pH [36]. The greater effect of bicarbonates may be due to a higher buffering capacity and ionic strength than phosphates.

Table 5. Color values, pH, marinade uptake, drip loss, WHC and cooking loss (mean ± standard error) for raw and cooked chicken breast meat marinated with bicarbonate and phosphate (pooled as marination treatment).

Quality traits		Marination treatment: Phosphate	Bicarbonate
L^*	raw	50.9 ± 0.2^{x}	51.0 ± 0.2^{x}
	marinade	$56.5 \pm 0.4^{a,y}$	$55.3 \pm 0.3^{b,y}$
a^*	raw	0.77 ± 0.08	0.46 ± 0.08
	marinade	0.84 ± 0.10^{a}	0.33 ± 0.09^{b}
b^*	raw	9.55 ± 0.24	9.50 ± 0.24
	marinade	10.19 ± 0.32^{a}	9.05 ± 0.28^{b}
pH	raw	5.92 ± 0.02^{x}	5.92 ± 0.02^{x}
	marinade	$6.07 \pm 0.01^{b,y}$	$6.26 \pm 0.02^{a,y}$
	cooked	$6.15 \pm 0.01^{b,y}$	$6.24 \pm 0.01^{a,y}$
Marinade uptake (%)		16.0 ± 0.4^{b}	17.3 ± 0.3^{a}
Drip loss (%)		2.74 ± 0.10^{b}	3.24 ± 0.11^{a}
WHC (%)		-2,38 ±1.61	-2.43± 1.05
Cooking loss (%)		27.0 ± 0.8	26.3 ± 0.5

a-bDifferent superscript letters within a row mean significant difference ($P < 0.05$). x-yDifferent superscript letters within a column mean significant difference ($P < 0.05$).

The pH of meat treated with bicarbonate and phophate was not affected after cooking. This result was not in agreement with Sindelar *et al.* [37] who found that the pH of marinated sow loins with bicarbonate and polyphosphate increased after cooking. Bicarbonate-marinated fillets had significantly ($P < 0.05$) higher values of marinade uptake (17.3% *vs.* 16.0%) and drip loss (3.24% *vs.* 2.74%) in comparison with phosphate-marinated fillets respectively.

Joo *et al.* [38] found that drip loss was correlated with protein solubility, increase the solubility of myofibrillar, sarcoplasmic, and total proteins reduced the drip loss. The causes of the difference in the drip loss between phosphate and bicarbonate are not known, and so the protein solubility should be evaluated when bicarbonate uses in comparison to phosphate.

The increase in marinade uptake can be attributed to the increased net negative charge associated to bicarbonate. Water holding capacity and cooking loss did not show any significant differences among the treatments (**Table 5**).

When the results of cooking loss were pooled taking in consideration just effect of marination process, there were no significant differences in the cooking loss, while the differences were present when the results were classified according to the type of heat treatment.

3.5. Effect of Heat Treatments on the Color and pH Values

Because the pH has great impact on tenderness, color, WHC and meat protein binding ability; raw chicken fillets were distributed in a way to obtain no significant differences in the initial pH and lightness (L^*) among different groups of treatments (**Table 6**). Lightness was significantly ($P < 0.05$) increased after marination and after cooking in all treatment groups of bicarbonate-marinated and phosphate-marinated fillets. Even all groups of each treatment (bicarbonate or phosphate) were separately marinated in one batch; they showed different lightness values between groups within the same batch after marination and after cooking. In general, bicarbonate-marinated fillets cooked under different heat treatments exhibited slightly higher lightness values than phosphate-marinated fillets; in spite of that, bicarbonate shifts the pH higher than phosphate and also it is well known that meat with high ultimate pH will appear darker because its surface scatters less light than meat with a low ultimate pH [39]. Nevertheless, the color of bicarbonate-marinated fillets became lighter.

Redness (a^*) and yellowness (b) values did not change after marination in all the groups of treatment. On another hand, after cooking redness (a^*) and yellowness (b) values were significantly ($P < 0.05$) increased in all groups (**Table 6**). These results are in agreement with Resurrección [40] who found that the marinated cooked samples were generally lighter (higher L^*) and more yellow (higher b^*), whereas a^* (red color) increased as temperature and cooking time increased.

The increase in lightness (L^*) values after cooking could be explained by meat proteins denaturation during heating process which leads to increased the reflection and scattering of light giving more lighter meat [34], while the increase in redness (a^*) and yellowness (b) values in all groups could be explained by sugar-amine browning reaction that occurs on the dehydrated surface due to the dry heating, amine groups in the muscle proteins react with any available reducing sugars, such as free glucose, giving brown color derivatives. Browning occurs normally at high temperatures (more than 90˚C); in our experiment the surface temperature was higher than 160˚C. Another cause which may change redness (a^*) and yellowness (b^*) values is formation of cooked meat pigments which show the brown color of metmyoglobin because of oxidation and denaturation of globular protein from heat [41]. Redness (a^*) values for bicarbonate-marinated fillet were slightly higher than phosphate-marinated fillets. Trout [42] pointed out that increase the pH of the meat decreased heat denaturation of myoglobin during cooking, therefore resulting to increase pinkness or redness value. He observed also that the phosphate ion increases the susceptibility of myoglobin to heat denaturation, but the increase of pH due to the addition of tripolyphosphate compensates the effect of susceptibility to denaturation.

3.6. Marinade Uptakes, Drip Loss, Cooking Loss and Yield versus Heat Treatments

There were no significant differences in marinade uptake and drip loss among the groups assigned for different cooking conditions for both of bicarbonate and phosphate-marinated treatments. The most severe heat treatment (80˚C - 200˚C) showed the highest cooking loss (30.68% and 33.43%; $P < 0.05$) and the lowest yield (69.32% and 66.57%; $P < 0.05$) for both type of bicarbonate and phosphate-marinated treatments respectively (**Table 7**). At this type of heat treatment, bicarbonate-marinated fillets showed higher ability to retain the moisture than phosphate which can be seen by the results of cooking loss and yield. The rest of the heat treatment did not show any effect on cooking loss and yield in all of the groups.

By and large, fillets treated with bicarbonate showed higher ability to retain water in comparison of phosphates. Actin (thin filament), myosin (thick filament), and their combined structure actomyosin are the most important protein which play a major role in water binding capacity. Phosphates solubilize and unfold myofibrillar proteins due to electrostatic repulsion, and so more the amount of water that can be retained by the muscle due to increase the size of the space between filaments. Therefore, anything that changes the spaces between the thick and thin filaments or the ability of the proteins to bind water can affect water-holding properties of the meat [39,43]. The roles of phosphates in improving the water binding are well known and they work in different ways: due to their buffering capacity phosphates are able to shift pH far away from the isoelectric point of the myofibrillar proteins, unfolding muscle proteins which lead to more charged sites for water binding, and cleavage actomyosin bonds that formed in post rigor, thereby increasing the potential for swelling of the filaments [4].

On another hand, the exact mechanisms for the roles of bicarbonate in improving the water binding-holding capacity are not well known. In our results, bicarbonate

Table 6. **Color and pH values (mean ± standard error) of chicken breast meat marinated with bicarbonate (B) and phosphate (P) cooked under different heat treatments (A, C, D and E represent different core and oven temperatures: 76 - 160, 80 - 160, 76 - 200 and 80 - 200˚C, respectively).**

Quality trait	Phosphate				Bicarbonate			
	76˚C - 160˚C (PA)	80˚C - 160˚C (PC)	76˚C - 200˚C (PD)	80˚C - 200˚C (PE)	76˚C - 160˚C (BA)	80˚C - 160˚C (BC)	76˚C - 200˚C (BD)	80˚C - 200˚C (BE)
L^*_{raw}	51.0 ± 0.9^{x}	50.4 ± 0.9^{x}	51.7 ± 0.7^{x}	50.6 ± 0.9^{x}	49.8 ± 1.1^{x}	52.2 ± 0.8^{x}	51.6 ± 0.4^{x}	50.5 ± 0.7^{x}
$L^*_{marinade}$	$56.7 \pm 0.7^{abc;y}$	$54.5 \pm 0.7^{c;y}$	$57.3 \pm 0.4^{ab;y}$	$57.5 \pm 0.7^{a;y}$	$55.2 \pm 0.9^{bc;y}$	$54.6 \pm 0.6^{c;y}$	$55.6 \pm 0.6^{abc;y}$	$55.8 \pm 0.7^{abc;y}$
L^*_{cooked}	$77.0 \pm 0.5^{c;z}$	$78.7 \pm 0.7^{abc;z}$	$77.1 \pm 0.8^{c;z}$	78.0 ± 0.8^{bc}	$77.5 \pm 0.6^{bc;z}$	$79.3 \pm 0.6^{ab;z}$	79.3 ± 0.5^{ab}	$80.0 \pm 0.3^{a;z}$
a^*_{raw}	0.91 ± 0.34^{x}	0.82 ± 0.10	0.72 ± 0.25^{x}	0.62 ± 0.21^{x}	0.98 ± 0.27^{x}	-0.06 ± 0.34^{x}	0.65 ± 0.21^{x}	0.28 ± 0.20^{x}
$a^*_{marinade}$	$0.77 \pm 0.27^{ab;x}$	$0.96 \pm 0.12^{a;x}$	$0.91 \pm 0.19^{a;x}$	$0.71 \pm 0.18^{ab;x}$	$0.50 \pm 0.23^{abc;x}$	$0.10 \pm 0.32^{bc;x}$	$0.89 \pm 0.32^{a;}$	$-0.19 \pm 0.14^{c;x}$
a^*_{cooked}	$2.13 \pm 0.16^{cde;y}$	$2.39 \pm 0.14^{bcd;y}$	$2.73 \pm 0.14^{ab;y}$	$1.69 \pm 0.15^{e;y}$	$2.65 \pm 0.24^{abc;y}$	$2.20 \pm 0.24^{bcde;y}$	$2.93 \pm 0.16^{a;y}$	$1.85 \pm 0.20^{de;y}$
b^*_{raw}	10.46 ± 0.88^{x}	8.42 ± 0.73^{x}	9.77 ± 0.62^{x}	9.53 ± 0.64^{x}	8.19 ± 0.79^{x}	10.88 ± 0.66^{x}	8.84 ± 0.86^{x}	10.07 ± 0.95^{x}
$b^*_{marinade}$	$11.02 \pm 0.98^{a;xy}$	$8.20 \pm 0.18^{b;x}$	$10.77 \pm 0.40^{a;x}$	$10.77 \pm 0.39^{a;x}$	$8.10 \pm 0.86^{b;x}$	$10.07 \pm 0.61^{ab;x}$	$9.04 \pm 0.78^{ab;x}$	$8.99 \pm 0.83^{ab;x}$
b^*_{cooked}	13.3 ± 0.8^{y}	14.0 ± 0.3^{y}	14.6 ± 0.4^{y}	14.6 ± 0.6^{y}	13.2 ± 0.6^{y}	14.9 ± 0.6^{y}	15.3 ± 0.5^{y}	14.9 ± 0.5^{y}
pH_{raw}	5.92 ± 0.02^{x}	5.92 ± 0.02^{x}	5.92 ± 0.02^{x}	5.92 ± 0.02^{x}	5.92 ± 0.02^{x}	5.92 ± 0.02^{x}	5.92 ± 0.02^{x}	5.92 ± 0.02^{x}
$pH_{marinade}$	$6.05 \pm 0.02^{c;xy}$	$6.09 \pm 0.03^{bc;y}$	$6.07 \pm 0.03^{c;y}$	$6.05 \pm 0.02^{c;y}$	$6.21 \pm 0.087^{ab;y}$	$6.34 \pm 0.05^{a;y}$	$6.21 \pm 0.02^{ab;y}$	$6.26 \pm 0.02^{a;y}$
pH_{cooked}	$6.16 \pm 0.02^{d;y}$	$6.17 \pm 0.02^{bd;y}$	$6.14 \pm 0.02^{d;y}$	$6.14 \pm 0.01^{d;y}$	$6.23 \pm 0.03^{abc;y}$	$6.28 \pm 0.04^{a;y}$	$6.21 \pm 0.02^{bcd;y}$	$6.24 \pm 0.02^{abc;y}$

[a-e]Different superscript letters within a row mean significant difference ($P < 0.05$). [x-z]Different superscript letters within a column mean significant difference ($P < 0.05$).

Table 7. **Marinade uptake, drip loss, cooking loss and yield (mean ± standard error) of chicken breast meat marinated with bicarbonate (B) and phosphate (P) cooked under different heat treatments (A, C, D and E represent different core and oven temperatures: 76 - 160, 80 - 160, 76 - 200 and 80 - 200˚C, respectively).**

Quality traits	Phosphate				Bicarbonate			
	76˚C - 160˚C (PA)	80˚C - 160˚C (PC)	76˚C - 200˚C (PD)	80˚C - 200˚C (PE)	76˚C - 160˚C (BA)	80˚C - 160˚C (BC)	76˚C - 200˚C (BD)	80˚C - 200˚C (BE)
Marinade uptake (%)	16.2 ± 0.8	14.7 ± 0.7	16.7 ± 0.9	16.5 ± 0.8	16.2 ± 0.6	17.2 ± 0.8	18.1 ± 0.9	17.6 ± 0.9
Drip loss (%)	2.64 ± 0.09	2.35 ± 0.15	3.10 ± 0.23	2.87 ± 0.19	3.52 ± 0.39	2.74 ± 0.61	3.60 ± 0.20	3.10 ± 0.13
Cooking loss (%)	25.2 ± 0.6^{c}	24.4 ± 0.6^{c}	25.0 ± 1.7^{c}	33.4 ± 0.5^{a}	24.6 ± 0.5^{c}	25.4 ± 0.8^{c}	24.6 ± 0.7^{c}	30.7 ± 0.6^{b}
Yield (%)	74.8 ± 0.6^{a}	75.6 ± 0.6^{a}	74.9 ± 1.8^{a}	66.6 ± 0.5^{c}	75.4 ± 0.5^{a}	74.6 ± 0.8^{a}	75.3 ± 0.7^{a}	69.3 ± 0.6^{b}

[a-c]Different superscript letters within a row mean significant difference ($P < 0.05$).

exhibited higher water binding capacity than phosphates which could be explained because bicarbonate increased more the pH and showed higher ionic strength [10]. Therefore it could increase the spaces between the thick and thin filaments more than phosphate. Sodium bicarbonate also produced holes during cooking due to generation of carbon dioxide leading to coarser microstructure which could also improve the physical entrapment of water [44].

4. Conclusion

Chicken breast fillets treated with phosphates exhibited different quality traits (texture profile analysis, shear force, water activity, freezable water and chemical compositions) when compared with fillets treated with bicarbonate. Bicarbonate-marinated fillet showed better water binding capacity and texture properties. The exact roles that stand behind these differences between bicarbonate and phosphate are not well known, but the main discriminated feature of bicarbonate is the ability to raise the pH higher than phosphate and generation of carbon dioxide gases during cooking. The findings of this study suggest that phosphate marinated fillets interact with heat treatments in different way in comparison with bicarbonate manated fillets. Overall, bicarbonate could be a promising agent to replace phosphate in meat formulation buthere is a necessity to evaluate the use of bicarbonate der different processing conditions and formulations.

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