Hindawi
Journal of Food Quality
Volume 2022, Article ID 4788425, 12 pages
https://doi.org/10.1155/2022/4788425

Research Article

Influence of Bicarbonates and Salt on the Physicochemical and Sensory Properties of Meatloaf

Tracy Jaico,[1] Himanshu Prabhakar,[1] Koushik Adhikari,[2] Rakesh K. Singh,[1] and Anand Mohan[1]

[1]*Department of Food Science and Technology, University of Georgia, 100 Cedar Street, Athens, GA 30602, USA*
[2]*Department of Food Science and Technology, University of Georgia, Griffin Campus, Griffin, GA 30223, USA*

Correspondence should be addressed to Anand Mohan; anandmohan@uga.edu

Received 7 December 2021; Revised 1 March 2022; Accepted 11 March 2022; Published 12 April 2022

Academic Editor: Constantin Apetrei

The changing consumer attitude toward meat products warrants innovation. Recent years have seen a continuous rise in the consumer demand for ready-to-eat meat products that trigger innovations in the manufacture of restructured meat products. This study was designed to develop meatloaf with the intention of using the downgraded stream of trimmed meat and meat by-products, which are known to contain a higher quantity of connecting tissue that causes tenderness issues, moisture retention, mouthfeel, and perceived food quality. The physicochemical effects of sodium bicarbonate, potassium bicarbonate, and salt alone or in combination on physicochemical and sensory characteristics of cooked ground beef were investigated. The results obtained showed that cooked ground beef without salt had the lowest cooked yield. Instrumental textural and sensory analysis revealed that bicarbonate-treated meatloaf samples exhibited significantly better sensory and textural properties than the control ($p \leq 0.05$). Internal cooked color data revealed that meatloaf treated with sodium bicarbonate and potassium bicarbonate had a pinkish-red appearance with a significantly higher a^* value ($p \leq 0.05$). The findings provide evidence that inclusion of bicarbonates had a significant tenderizing and juiciness effects with improved sensory attributes of the meatloaf. The evidence presented clearly shows the potential of bicarbonate and salt will exert synergistic effects and improve eating quality and textural and sensorial attributes of meatloaf and other meat products.

1. Introduction

In recent years, increased consumer demand for beef products has prompted the meat industry to develop strategies to effectively use low-value meat cuts for product innovation and additional revenue. Innovations in ingredient technology and new processing methods for utilizing low-value meat cuts offer many advantages for both consumers and the meat industry. Beef trimmings originating from many different cuts from the animal carcass are generally classified as lower-grade meat cut due to food safety and visible quality defects [1]. The beef industry is continually striving to innovate and deliver high-quality beef products that meet consumer expectations for consistent eating quality [2].

Value-addition to mitigate differences in the eating quality of ground meat originating from low-value meat cuts is extremely important for improving palatability traits of beef products [3]. The beef trim originating from lower-quality muscles destined for ground beef must provide an acceptable and consistent eating quality and consumer acceptability. Mitigating the eating quality and sensory differences of ground beef originating from different muscle cuts is critical for the overall consumer acceptability of ground beef products. Recent food ingredient technology trends have shown functional properties of alternative nonmeat ingredients to optimize and improve functionality and sensorial characteristics of processed meat products.

Bicarbonate compounds are widely used as a food ingredient to improve the quality of food and palatability of meat products eating quality and palatability. The researchers have reported that the use of sodium bicarbonate during the curing process and formulating chicken meat batters have significantly decreased ($p < 0.05$) the cooking loss and yield, shear force, protein, solubility, and surface texture [4, 5]. Alkaline salts of bicarbonates have been reported to improve palatability attributes and minimize the problem of pale, soft, and exudative meat products in chicken meat [6, 7]. Furthermore, the researchers have demonstrated that salts of bicarbonate can reduce shear force and improve the cook yield of marinated chicken meat [8, 9]. The efficacy of bicarbonate salts is attributed to their ability to solubilize myofibrillar proteins and enhance their electrostatic repulsion [10]. Bertram et al. [11] found that sodium bicarbonate effectively increased myofibrillar hydration and reduced cook loss in marinated pork.

Recent studies have shown that nonmeat ingredients such as bicarbonates, sodium salts, potassium salts, and acid whey have been demonstrated for improving the textural and acceptable eating quality of comminuted meat products [2, 12, 13]. Some studies have shown that nonmeat ingredients are used in meats for reducing the cost and cook loss and improving water-holding capacity and textural and sensory quality including moisture retention, shear stability, and textural properties [14–20].

Bicarbonate salts improve the textural quality of meat products by improving product juiciness, overall palatability, reduced drip loss, and shear force [6, 8, 21–23]. Sodium bicarbonate and potassium bicarbonate are GRAS (generally recognized as safe) food ingredients used as a leavening agent, to control pH, as an antimicrobial, and to improve taste, texture, and tenderness characteristics [12, 24, 25]. Previous studies have reported that marinating chilled beef with bicarbonate and salt solution increased meat juiciness and water-holding capacity and reduced cook loss [26, 27]. However, the utilization of bicarbonates as a source of nonmeat ingredient on textural and sensory perception of meatloaf products has not been previously reported.

Given the rise in increased consumer demand for clean labeling, bicarbonate offers an excellent opportunity as an alternative functional ingredient for phosphate replacement and merits investigation [28]. Value-addition to reduce cost and improve acceptable eating of lower-quality beef trim could be utilized in ground beef to prepare meatloaf. This study was designed to evaluate meatloaf using beef trim destined for ground beef with bicarbonate, starch, and salt. We hypothesize that the application of sodium bicarbonate and potassium bicarbonate with salt would improve eating quality and sensory properties in cooked ground beef products. Therefore, the objective of this investigation was to investigate the interior color, expressible moisture, cooked loss, instrumental textural properties, and sensory properties of cooked ground beef with sodium bicarbonate, potassium bicarbonate, modified food starch, and potato starch. Additionally, correlation between the instrumental texture and sensory attributes was also studied.

2. Materials and Methods

2.1. Raw Materials and Chemicals. Fresh raw ground beef (lean/fat blend: 80/20; experimental unit) was obtained from a local beef purveyor (FPL Foods, Augusta, GA). Food-grade salt, sodium bicarbonate, and potassium bicarbonate were purchased from Fisher Scientific (Fisher Scientific, Fairlawn, NJ). Potato starch was obtained from National Starch (Novation 6600; National Starch, Bridgewater, NJ), and modified food starch was obtained from Grain Processing Corporation (PURE-GEL, B990; Grain Processing, Muscatine, IA).

2.2. Ground Beef Preparation, Processing, and Cooking. The ground beef was mixed with the treatment ingredients in a cold room at 4 ± 1°C. All treatment samples were mixed according to the formulation presented in Table 1. The levels of salt were determined based on preliminary experiments and literature. Ingredients were mixed with ground beef in a Hobart mixer (Model C-100 T; The Hobart Mfg. Co., Troy, OH). The modified food starch and the potato starch were mixed separately. The control treatment served as the ground beef portion without any added ingredients. The treated ground beef samples were packaged in disposable aluminum pans (5.3″ W × 7.8″ D × 1.8″ H; Countdown-To-Cook, Model CO524717) for cooking. All preparation, including mixing ingredients, patty making, and packaging, and further storage, was performed at 4 ± 1°C.

The treated ground beef samples were cooked to an internal temperature of 71°C. The cooking temperature was monitored and measured using a hollow meat spear and type-T wired thermocouples (Omega, Stamford, CT) in the geometric center of the ground beef pan. Each thermocouple was connected to a digital handheld thermometer (Model HH21A; Omega, Stamford, CT) (Model RDXL4SD; Omega, Stamford, CT). After ground beef samples were cooked, each tray was removed from the oven and placed at room temperature to cool and rest for 30 minutes. The ground beef samples were evaluated for the instrumental texture—Warner–Bratzler shear force (WBSF), texture profile analysis, and expressible moisture, cook yield, and internal cooked color. For the sensory test, ground beef samples were allowed 30 min to rest and cool and then cut into cubes (2 cm × 2 cm) for sensory evaluation.

2.3. Proximate Composition and pH. Proximate composition analysis was performed following the AOAC methods 930.15 for moisture, 942.05 for ash, and 990.03 for crude protein [29]. A 15 g sample of the ground beef was removed and analyzed for moisture using the CEM SMART (AOAC method 930.15). The crude fat was determined by using ANKOM^{XT15} Extractor (PVM 1:2003 and AOCS procedure Am 5-04; Ankom Technology, 2015) for fat. The total protein was analyzed by the Kjeldahl method (AOAC methods 4500-N_{org} C and 4500-NH_3 C), and the ash content was determined using a muffle furnace at 600°C (AOAC method 942.05). All experiments were replicated for a minimum of three times at different occasions.

Table 1: Mixture formulations for ground beef treated with different levels of sodium bicarbonate, potassium bicarbonate, salt, modified food starch, and potato starch.

Treatment	Treatment composition of the ingredient formulation in the finished product, %				
	NaCl	$NaHCO_3$	$KHCO_3$	MFS	PS
None (control)	—	—	—	—	—
NaCl	0.5	—	—	—	—
$NaHCO_3$	—	0.5	—	—	—
$NaHCO_3$	—	1.0	—	—	—
$KHCO_3$	—	—	0.5	—	—
$KHCO_3$	—	—	1.0	—	—
$NaHCO_3$ + NaCl	0.5	0.5	—	—	—
$NaHCO_3$ + NaCl	0.5	1.0	—	—	—
$KHCO_3$ + NaCl	0.5	—	0.5	—	—
$KHCO_3$ + NaCl	0.5	—	1.0	—	—
NaCl + MFS	0.5	—	—	0.5	2.0
NaCl + PS	0.5	—	—	—	2.0

MFS = modified food starch; PS = potato starch; $NaHCO_3$ = sodium bicarbonate; $KHCO_3$ = potassium bicarbonate; NaCl = salt. All ingredients were dissolved in distilled water for better homogeneity and dispersibility. [b]No ingredients (salt, sodium bicarbonate, potassium bicarbonate, modified food starch, or potato starch) were added except distilled water.

The pH of the raw and cooked ground beef samples was measured using a pierce probe pH meter (Model H260G; IQ Scientific, HACH, Loveland, CO); measurements were taken before and after treatment [30]. The pH measurements on each treatment sample were replicated for a minimum of three times at different occasions.

2.4. Expressible Moisture and Cook Yield. Expressible moisture of the cooked samples was measured by the filter paper press method as described in [31] with minor modification. About five grams of accurately weighed cooked ground beef samples was placed on a preweighed Whatman #1 (9 cm diameter) and pressed between Plexiglas plates and compressed for 1 minute. The filter paper was later weighed to measure the increase in weight due to absorbed moisture. Expressible moisture was expressed as a percentage of the original weight of the meat sample. The cook yield was measured as the difference of weight in samples before and after cooking divided by the weight of the sample before cooking, expressed as a percentage. The tests were performed on four replicates and averaged for statistical analysis. The expressible moisture was calculated as a percentage using the following equation:

$$\%\text{Expressible moisture} = \left[\frac{W_{\text{final}} - W_{\text{initial}}}{\text{sample weight}}\right] \times 100, \quad (1)$$

where W_{final} = weight of the filter paper after compression and W_{initial} = initial weight of the filter paper.

The cook yield was measured as the difference of weight in samples before and after cooking divided by the weight of the sample before cooking, expressed as a percentage. The tests were performed in four different replicates performed on four independent occasions.

2.5. Internal Cooked Color Measurements. Instrumental internal cooked color parameters (*CIE* L^*, a^*, b^*, *Hue*, and *Chroma*) were measured using the HunterLab EZ Scan portable spectrophotometer (Illuminant A, 45/0 LAV, 2.54 cm diameter aperture, 10 observer; Hunter Associates Laboratory, Inc., Reston, VA) [32, 33]. The spectrophotometer was standardized using black and white tiles provided by the manufacturer, and the color measurement was replicated four times and averaged for statistical analysis. The hue angle was calculated using the following equation: hue angle (HA) = [arctangent (b^*/a^*)]. The chroma (saturation index) was calculated using the following equation: chroma or saturation index = $\sqrt{(a^* + b^{*2})}$ [34].

2.6. Instrumental Texture Profile Analysis. The treated and untreated ground beef samples were cooked and evaluated for Warner–Bratzler shear force (WBSF) and texture profile analysis (TPA). The procedure mentioned in the Guidelines for Cookery and Sensory Evaluation of Meat was used to measure WBSF [35–37]. The shear force was measured using a TA-XT2i texture analyzer (Texture Tech. Corp., Scarsdale, NY) with a 500 N load cell and TA-7 WB blade. The cut samples were placed on a slotted plate installed on a TA 90 platform. The plate position was adjusted so as to allow the blade to pass through the center of the cut sausage pieces. The cross-head speed was set to 3 mm/s, and the test was triggered by a force of 0.05 N. The pre- and post-test speed was 5 mm/s.

TPA was performed by the procedure of Mocanu et al. [38] and O'Sullivan and Kerry [39]. The settings of the texture analyzer were 5 mm/s pre- and post-test speeds, 50% deformation, trigger type auto, and 10 g force for the trigger. The cross-head speed was 2 mm/s. The parameters recorded were hardness, cohesiveness, springiness, and chewiness. Briefly, the test samples were placed on a plate that was installed on a heavy-duty platform. The conditions of the test for each sample included two cycles, a 50% strain, and a cross-head speed of 250 mm/min. The TPA hardness was calculated as the maximum force during the first compression cycle. Cohesiveness for TPA was the ratio of the area under the second curve to the area under the first curve and related to the strength of the samples of internal bonds. Springiness for TPA is the ratio of the distance traveled by the probe on the second cycle (from the sample contact point with a set compression percentage) to the distance the probe traveled on the first downstroke. Springiness is related to recovery from the first downstroke deformation. To calculate chewiness for TPA, three parameters are needed: hardness, cohesiveness, and springiness. Both the WBSF and TPA tests were performed on four different replicates performed on four independent occasions.

2.7. Sensory Evaluation. A panel ($n = 10$) of assessors (students and semiprofessional; age 22–65) was trained during multiple one-hour sessions to become acquainted with the three attributes juiciness, chewiness, and tenderness/hardness. These attributes were based on the Guidelines of the American Meat Science Association [36, 37], and the standards were developed by Meilgaard et al. [40]. The participants' recruitment procedures were reviewed and approved by the University of Georgia, Institutional Review Board (UGA-IRB). Each panelist evaluated the standards for all three sensory attributes. Sensory descriptive definitions and reference samples used for ground beef sensory evaluation on a 15-point interval hedonic scale are presented in Table 2. During training and orientation, five food examples were used. They were crispy chicken tenderloins, chicken breast strips grilled with fajitas, original meatballs, classic mini meatloaf, and mini meatloaf. During the four training/orientation sessions, each panelist was presented with the samples along with the reference standards and rated the products' three attributes on a 15-point scale.

A sensory evaluation was performed in triplicate in individual booths. During all evaluations, the references for each attribute were provided (Table 2). Each panelist was then asked to rate the ground beef sample on a 15-point hedonic scale. Water and unsalted crackers were provided as palate cleansers. The order of presentation consisted of four randomized samples coded with 3-digit random numbers, with each panelist undertaking three sittings during each session with a break of 10 min between each sitting. Blind evaluations were carried out on three consecutive days of testing.

2.8. Statistical Analysis. Statistical analysis was performed using SAS version 9 (SAS Institute, Inc., Cary, NC) using the GLM option. The experimental ($n = 3$ replications) design was a randomized complete block with repeated measurements. All three replications were conducted on three independent occasions. For the parameters pH, proximate composition, instrumental texture, expressible moisture, and cook yield, a completely random design was used and analyzed using one-way ANOVA. For the parameters instrumental cooked color and sensory analysis, wherein bicarbonate and starch concentrations were varied, a completely balanced factorial design was employed with the bicarbonate and starch concentrations as the main effects and analyzed using 2-way ANOVA. Satterthwaite adjustments were used for the degree of freedom. Pairwise comparisons of least-squares means were used to determine the significant differences when the respective F-tests were significant at $p < 0.05$.

To understand the relationships between instrumental texture data (active variables) and sensory attributes (supplementary variables), a scatter plot matrix and principal component analysis (PCA) in the correlation matrix were carried out using SAS version 9 (SAS Institute, Inc., Cary, NC) using the GLM option and XLSTAT (ver 2021.1.1; Addinsoft, New York, NY).

3. Results

3.1. Expressible Moisture and Cook Yield. The data in Table 3 show the results obtained for the expressible moisture and cook yield of the untreated and treated meatloaf samples. Meatloaf treated with salt, sodium bicarbonate, and potassium bicarbonate resulted in a significantly higher expressible moisture and cook yield ($p < 0.05$) compared with control. A similar trend was observed with meatloaf prepared with a combination of salt and starch (modified food starch and potato starch). Preparation of meatloaf with a combination of salt and sodium and potassium bicarbonate at concentrations of 0.5–1% resulted in a substantial increase in expressible moisture and cook yield compared with salt, sodium bicarbonate, and potassium bicarbonate alone. In general, a higher concentration of sodium and potassium bicarbonate with salt consistently resulted in a significantly higher expressible moisture ($p < 0.05$) and cook yield.

3.2. Texture Profile Analysis. Textural profile analysis was performed to obtain textural parameters such as hardness, cohesiveness, springiness, chewiness, and WBSF using an objective instrumental measurement method. The TPA was performed using a double compression process very similar to simulated mastication of the treated meatloaf samples. For the TPA, textural attributes such as hardness (the maximum force required to compress the meatloaf in the first compression cycle), cohesiveness (the extent to which meatloaf can be deformed prior to fracture), springiness (the ability of the meatloaf to recover its original form after the deformation force is removed), and chewiness (the work needed to chew the meatloaf to a steady state of swallowing) were evaluated, and the results are presented in Table 4. The results obtained indicate that the textural attributes of the cooked meatloaf with salt, sodium bicarbonate, and potassium bicarbonate alone or in combination are presented in Table 4.

The combination of salt and potassium bicarbonate at 1% level showed a significant influence ($p \leq 0.05$) on the hardness, cohesiveness, springiness, chewiness, and WBSF. It is apparent from the presented data (Table 4) that a treatment combination of salt and potassium bicarbonate at 1% level significantly decreased ($p \leq 0.05$) the hardness among all treatments evaluated. A similar trend of decreased hardness ($p \leq 0.05$) was observed with meatloaf prepared with a combination of salt and starches (modified food starch and potato starch) compared with control. However,

Table 2: Compilation of sensory descriptive definitions and reference created and used for this particular sensory study for the ground beef sensory evaluation.

Sensory descriptor	Definition/instruction	Reference sample	Preparation of samples	Intensity rating[a]
Juiciness	Amount of juice/moisture perceived in mouth or the amount of moisture leaving the product and into the mouth after 7–10 chews between molars	Banana	0.5 inch slice	1
		Cucumber	0.5 inch slice without skin	8
		Red delicious apple	0.5 inch wedge without skin	10
		Florida or Valencia orange	0.5 inch wedge	15
Tenderness/ hardness	Force to attain a given deformation such as force to compress between molars, first bite, or force required to bite through molars (very soft to very hard); 5 chews between molars	Cream cheese	One spoonful of Kraft Philadelphia Light or 1/3 fat	1
		Pasteurized yellow American cheese	0.5 inch cubed cheese	4
		Hebrew National frankfurter	0.5 inch slice cooked	7
		Carrots	0.5 inch slice, peeled, and raw	11
Chewiness	Measurement of chewiness utilizing molars on 2nd to 3rd chew	Jewish rye bread	0.5 square inch slice	2
		Orange slices[b]	1 piece	6
		Tootsie roll	1 piece	13

[a]Intensity rating of samples are based on a 0–15 hedonic scale. [b]Reference sample created for this particular sensory study. Meilgaard and others 2007; USDA; AMSA, 1995.

Table 3: Least-squares means for the proximate composition of cooked meatloaf treated with different levels of sodium bicarbonate, potassium bicarbonate, salt, modified food starch, and potato.

Treatment	Proximate composition, %		
	Treatment composition, %	Expressible moisture	Cook yield
None (control)	0	5.4[a]	16.1[a]
NaCl	0.5	5.8[a]	18.2[b]
$NaHCO_3$	0.5	8.7[b]	20.4[c]
$NaHCO_3$	1.0	10.8[c]	22.8[d]
$KHCO_3$	0.5	8.9[b]	20.8[c]
$KHCO_3$	1.0	11.1[c]	23.9[d]
$NaHCO_3$ + NaCl	0.5 + 0.5	14.1[d]	20.8[c]
$NaHCO_3$ + NaCl	1.0 + 0.5	16.8[e]	24.5[d]
$KHCO_3$ + NaCl	0.5 + 0.5	14.4[d]	21.2[a]
$KHCO_3$ + NaCl	1.0 + 0.5	19.2[f]	26.1[f]
NaCl + MFS	2.0 + 0.5	10.6[c]	19.9[c]
NaCl + PS	2.0 + 0.5	10.2[c]	20.2[c]

MFS = modified food starch; PS = potato starch; $NaHCO_3$ = sodium bicarbonate; $KHCO_3$ = potassium bicarbonate; NaCl = salt. Means not sharing a common letter (a–c) in a column are significantly different ($p \leq 0.05$). ±SE = 0.15 for expressible moisture and 0.26 for cook yield.

the meatloaf with salt and starch combination exhibited a hardness attribute comparable to the bicarbonates at 0.5% level. In general, a higher concentration of sodium bicarbonate and potassium bicarbonate with salt consistently resulted in significantly lower hardness values ($p \leq 0.05$).

Textural springiness results trended similar to the hardness (Table 4). A combination of salt and potassium bicarbonate treatment at a 1% level significantly decreased ($p \leq 0.05$) the springiness attribute among all other treatments evaluated. Interestingly, the springiness attribute of meatloaf samples treated with salt and starch (modified food starch and potato starch) was not significantly different ($p \leq 0.05$) compared with the control and salt treatment. The data trend showed that bicarbonate salts (sodium or potassium) at a 1% concentration level with salt were highly effective in reducing ($p \leq 0.05$) the springiness attribute of the meatloaf among all other treatments. In general, a higher concentration of sodium and potassium bicarbonate with salt consistently resulted in a significantly lower springiness ($p \leq 0.05$).

Among all treatments, meatloaf samples treated with salt were chewiest ($p \leq 0.05$) compared with the control (Table 4). Among all the treatments, 1% bicarbonates (sodium or potassium) with salt were less chewy ($p \leq 0.05$). The lower percentage (0.5%) of bicarbonates (sodium or potassium) with salt was less ($p \leq 0.05$) effective in reducing chewiness compared with 1% bicarbonates (sodium or potassium) with salt. Meatloaf prepared with a combination of 2% potato starch and salt showed lower properties ($p \leq 0.05$) compared with salt and control samples.

Table 4: Least-squares means for texture profile analysis (TPA) chewiness, hardness, and cohesiveness values of cooked ground beef treated with differing levels of sodium bicarbonate, potassium bicarbonate, salt, modified food starch, and potato starch.

Treatment	Ingredient, %	Texture profile analysis				
		Hardness, (N)^{y}	Cohesiveness^{z}	Springiness	Chewiness, (mJ)^{x}	WBSF*, N
None (control)	0	42.1^{d}	0.4^{b}	0.93^{f}	123.4^{d}	9.8^{cd}
NaCl	0.5	48.3^{e}	0.5^{c}	0.90^{f}	144.2^{e}	15.8^{e}
$NaHCO_3$	0.5	39.7^{d}	0.5^{c}	0.81^{e}	135.1^{de}	7.9^{abc}
$NaHCO_3$	1.0	35.4^{c}	0.5^{c}	0.78^{e}	127.3^{d}	10.9^{d}
$KHCO_3$	0.5	40.2^{d}	0.5^{c}	0.61^{b}	131.7^{de}	11.3^{d}
$KHCO_3$	1.0	33.5^{c}	0.5^{c}	0.68^{c}	98.2^{c}	9.3^{cd}
$NaHCO_3$ + NaCl	0.5 + 0.5	27.1^{b}	0.5^{c}	0.71^{c}	73.7^{b}	7.6^{abc}
$NaHCO_3$ + NaCl	1.0 + 0.5	21.5^{a}	0.5^{c}	0.67^{c}	50.1^{a}	6.5^{a}
$KHCO_3$ + NaCl	0.5 + 0.5	26.2^{b}	0.5^{c}	0.58^{b}	76.2^{b}	11.1^{d}
$KHCO_3$ + NaCl	1.0 + 0.5	22.7^{a}	0.5^{c}	0.51^{d}	52.8^{a}	5.9^{a}
NaCl + MFS	2.0 + 0.5	29.8^{b}	0.3^{a}	0.90^{f}	76.6^{b}	11.3^{d}
NaCl + PS	2.0 + 0.5	28.7^{b}	0.4^{b}	0.94^{f}	97.1^{c}	8.8^{bc}

MFS = modified food starch; PS = potato starch; $NaHCO_3$ = sodium bicarbonate; $KHCO_3$ = potassium bicarbonate; NaCl = salt. *WBSF = Warner–Bratzler shear force. ^{z} = TPA cohesiveness units are dimensionless and are the ratio of the area under the second curve to the area under the first curve of the TPA graph cycle. ^{x} = TPA chewiness units of millijoules. ^{y} = TPA hardness units of Newton; means not sharing a common letter (*a–f*) for a given texture parameter are different ($p \leq 0.05$). ±SE= 6.90 for chewiness; 1.22 for hardness; and 0.007 for cohesiveness.

From Table 4, it is evident that meatloaf treated with 0.5% salt had the highest WBSF compared with the control. Meatloaf samples treated with starch (modified food starch and potato starch) showed significantly higher ($p \leq 0.05$) WBSF than those treated with 1% bicarbonates (sodium or potassium) and salt. The preparation of meatloaf with bicarbonates (sodium or potassium) without added salt resulted in a significantly higher WBSF ($p \leq 0.05$) compared with those treated bicarbonates (sodium or potassium) and salt.

3.3. Sensory Analysis. The panelists evaluated chewiness, tenderness/hardness, and juiciness on a 9-point interval scale. The scores for each sensory attribute are presented in Table 5. Sensory evaluation scores showed that prepared meatloaf with 0.5% salt was the hardest and chewiest but exhibited a significantly higher ($p \leq 0.05$) juiciness score than the control. The meatloaf samples prepared with 0.5% and 1% bicarbonates without added salt exhibited relatively softness and juiciness attributes. For hardness, most of the samples showed a relatively similar hardness attribute except for control and the meatloaf treated with only salt ($p \leq 0.05$). This showed that bicarbonates, salt, modified food starch, or potato starch did improve the juiciness without a significant impact on hardness or chewiness. The scores also show that bicarbonates at 0.5% tend to be harder or less tender than those at 1.0%. The increase in sodium bicarbonate or potassium bicarbonate showed a trend of increasing tenderness among other treatments and the control. The type of bicarbonate forms with added salt used for meatloaf preparation did not significantly influence ($p \leq 0.05$) the sensory hardness, chewiness, and juiciness compared with control and only salt-treated meatloaf.

3.4. Instrumental Color Characteristics of Meatloaf. The cooked color measurement of meatloaf samples prepared with different treatments was used as an indicator of the degree of doneness. The results obtained from the instrumental color measurements are presented in Table 6. The L^* values of the cooked meatloaf (Table 6) prepared with sodium bicarbonate or potassium bicarbonate at concentrations (0.5 or 1%) with salt (0.5%) did not show significant difference ($p \leq 0.05$), which showed that L^* values did not ($p \geq 0.05$) change significantly across all treatment types compared with control (Table 6). Prepared meatloaf with 2% modified food starch or 2% potato starch showed significantly higher L^* values, whereas L^* values for the control or samples treated with 0.5% salt were significantly lower ($p \leq 0.05$)*. Meatloaf samples treated with 0.5 or 1% sodium bicarbonate or potassium bicarbonate exhibited similar L^*-values compared with other treatments (Table 6).

The a^* values for the prepared meatloaf with bicarbonates (sodium or potassium bicarbonate), modified food starch, and potato starch, with or without 0.5% salt, are presented in Table 6. In general, meatloaf-treated bicarbonates (sodium bicarbonate or potassium bicarbonate) and a combination of bicarbonates (sodium or potassium bicarbonate) with added salt were found to have significantly higher values of a^* ($p \leq 0.05$) compared with control and treatment with salt and starches. The prepared meatloaf samples with 0.5 or 1% potassium bicarbonate without 0.5% salt maintained significantly higher a^* values ($p \leq 0.05$) compared with 0.5 or 1% sodium bicarbonate. Furthermore, meatloaf prepared with modified food/potato starch also resulted in a lower ($p \leq 0.05$) a^* value than the bicarbonate-treated samples. Among the bicarbonate-treated samples, meatloaf prepared with 1% bicarbonates with added salt exhibited a significantly higher ($p \leq 0.05$) a^* value than meatloaf samples treated with starch and the control. A similar trend was observed for the instrumental chroma values (Table 6).

Results presented in Table 6 show that b^* values were tended to be significantly higher for most treatments compared with the control sample ($p \leq 0.05$). Treating meatloaf with sodium or potassium bicarbonate at a

Table 5: Least-squares means for sensory descriptive hedonic scores of cooked ground beef treated with different levels of sodium bicarbonate, potassium bicarbonate, salt, modified food starch, and potato starch.

Treatment	Treatments, %	Sensory characteristics*		
		Hardness	Chewiness	Juiciness
None (control)	0	6.5^{b}	3.7^{de}	3.0^{a}
NaCl	0.5	7.8^{d}	4.8^{g}	3.3^{ab}
$NaHCO_3$	0.5	6.2^{ab}	3.5^{de}	4.3^{bc}
$NaHCO_3$	1.0	5.6^{a}	2.9^{f}	5.6^{de}
$KHCO_3$	0.5	6.1^{ab}	3.3^{ef}	4.1^{bc}
$KHCO_3$	1.0	5.8^{ab}	3.0^{d}	4.7^{cd}
$NaHCO_3$ + NaCl	0.5 + 0.5	6.0^{ab}	3.3^{a}	5.7^{de}
$NaHCO_3$ + NaCl	1.0 + 0.5	5.8^{ab}	3.7^{bc}	6.3^{ef}
$KHCO_3$ + NaCl	0.5 + 0.5	6.4^{bc}	3.9^{bc}	5.0^{cd}
$KHCO_3$ + NaCl	1.0 + 0.5	6.1^{ab}	3.2^{ab}	6.4^{f}
NaCl + MFS	2.0 + 0.5	6.2^{ab}	3.4^{ab}	5.4^{de}
NaCl + PS	2.0 + 0.5	6.1^{ab}	4.2^{c}	5.0^{cd}

MFS = modified food starch; PS = potato starch; $NaHCO_3$ = sodium bicarbonate; $KHCO_3$ = potassium bicarbonate; NaCl = salt. Means with different superscripts (a–f) within a column are significantly different ($p \leq 0.05$). *Data based on hedonic scale scores of 0 to 15. ±SE = 0.2818 for hardness; 0.3510 for chewiness; and 0.3884 for juiciness.

Table 6: Least-squares mean for surface colorimeter readings of L^* (lightness), a^* (redness), b^* (yellowness), hue angle, and saturation index (chroma) of meatloaf treated with different levels of sodium bicarbonate, potassium bicarbonate, salt, modified food starch, and potato starch.

Treatment name	Treatment, %	Internal cooked color ($L^* a^* b^*$) of meatloaf				
		L^*	a^*	b^*	Hue angle	Chroma
None (control)	0	54.2^{d}	11.0^{a}	16.4^{a}	56.1^{c}	19.8^{a}
NaCl	0.5	50.5^{b}	27.3^{e}	21.9^{e}	38.7^{ab}	35.1^{h}
$NaHCO_3$	0.5	52.9^{cd}	20.6^{bc}	20.6^{bcde}	45.3^{b}	29.1^{de}
$NaHCO_3$	1.0	49.5^{ab}	22.4^{bcd}	19.8^{bcd}	41.9^{ab}	29.9^{def}
$KHCO_3$	0.5	48.3^{a}	26.1^{de}	20.3^{bcde}	38.1^{ab}	33.1^{fgh}
$KHCO_3$	1.0	50.1^{ab}	24.8^{cde}	18.5^{b}	36.8^{a}	30.9^{defg}
$NaHCO_3$ + NaCl	0.5 + 0.5	50.5^{ab}	25.3^{de}	20.0^{bcde}	38.4^{ab}	32.3^{efgh}
$NaHCO_3$ + NaCl	1.0 + 0.5	51.3^{bc}	23.1^{bcde}	18.5^{b}	38.7^{ab}	29.6^{de}
$KHCO_3$ + NaCl	0.5 + 0.5	50.7^{b}	25.6^{de}	21.3^{de}	39.5^{ab}	33.3^{gh}
$KHCO_3$ + NaCl	1.0 + 0.5	50.7^{b}	19.7^{b}	18.8^{bc}	45.2^{b}	27.7^{cd}
NaCl + MFS	2.0 + 0.5	56.4^{e}	14.8^{a}	20.8^{cde}	54.7^{c}	25.5^{bc}
NaCl + PS	2.0 + 0.5	54.9^{de}	13.3^{a}	19.2^{bc}	55.4^{c}	23.3^{b}

MFS = modified food starch; PS = potato starch; $NaHCO_3$ = sodium bicarbonate; $KHCO_3$ = potassium bicarbonate; NaCl = salt. Means with different superscripts (a–f) within a column are significantly different ($p \leq 0.05$). ±SE = 0.7854 for L^*; 1.6323 for a^*; 0.7255 for b^*; 2.5877 for hue angle; and 1.3249 for chroma. The sensory and other physical properties data used to support the findings of this study are included within the article.

concentration of 0.5 or 1% with 0.5% salt did not significantly change b^*-values significantly compared with other treatments. Table 6 shows the hue angle values were significantly higher ($p \leq 0.05$) for the meatloaf samples prepared with 2% of modified food/potato starch compared with other treatments. A similar trend was observed for the control sample. Treating meatloaf with sodium or potassium bicarbonate (at 0.5 or 1%) and 0.5% salt resulted in lower hue angle values compared with control.

Table 6 shows the chroma (saturation index) values of the prepared meatloaf with different treatments, including bicarbonates and starches. The control sample had significantly lower ($p \leq 0.05$) chroma values compared with all treatments. The meatloaf sample processed with sodium or potassium bicarbonate, alone or in combination with 0.5% salt, retained more chroma saturation than the control or samples treated only with 0.5% salt. Both modified food starch and potato starch exhibited lower chroma values compared with meatloaf samples processed with sodium potassium bicarbonate, alone or in combination with 0.5% salt.

3.5. Correlation between Texture Profile Parameters and Sensory Characteristics. To investigate the relationship between the sensory hardness and instrumental TPA measurement, scatter plot correlation matrix was performed. The scatter plot correlation matrix for hardness (Figure 1) showed control had the strongest positive correlation ($r = 0.98$). Overall, there was a good fitness of data as the data are within the 95% confidence limits. The correlation between ground beef treated with potassium bicarbonate and/or salt was higher than when mixed with only potassium bicarbonate. The meatloaf samples prepared with sodium bicarbonate (at 0.5 or 1%) and 0.5% salt showed a similar correlation with $r = 0.87$. On the contrary, the meatloaf

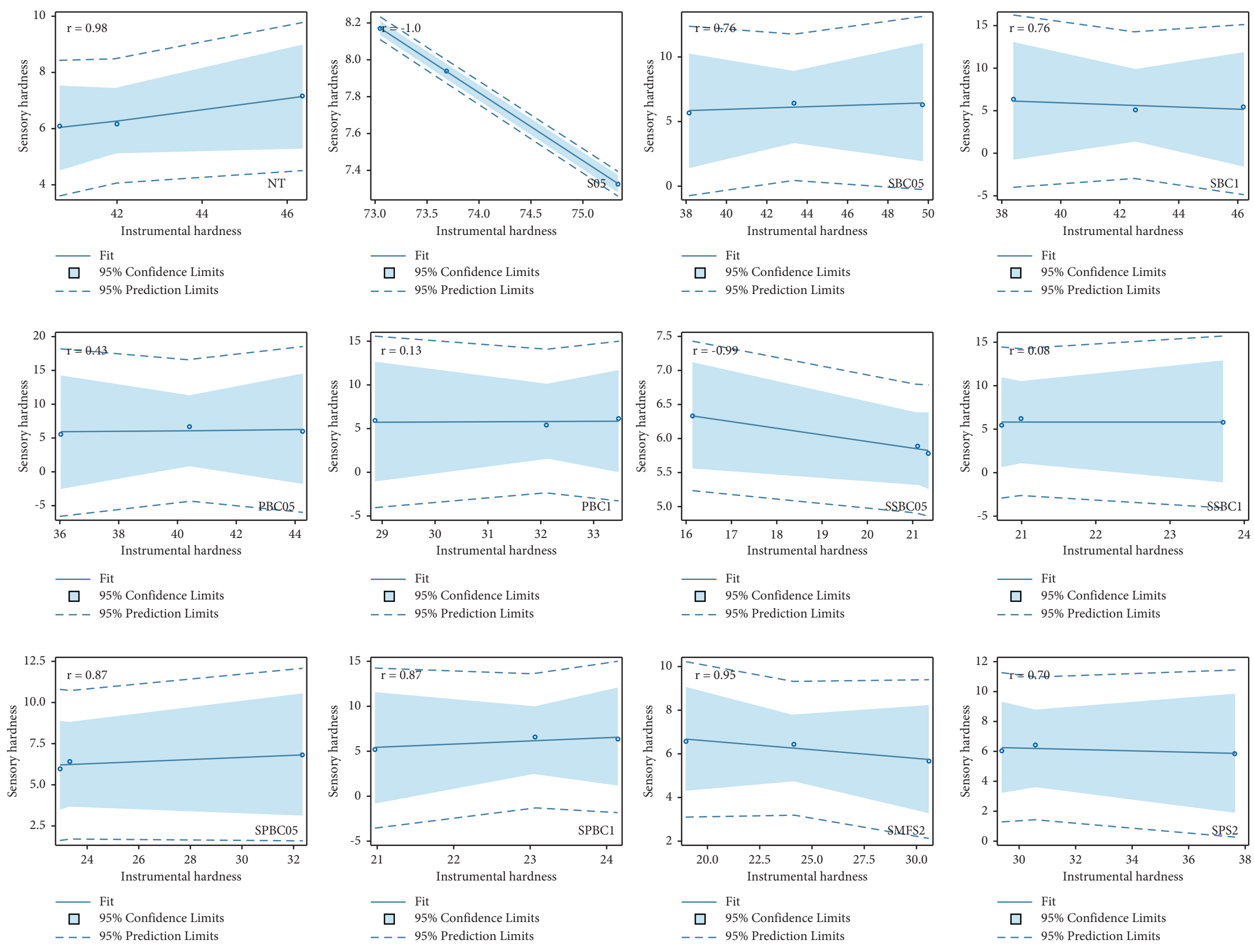

Figure 1: Scatter plot correlation matrix comparing the hardness sensory descriptive analysis and instrumental texture profile analysis of ground beef treated with different levels of sodium bicarbonate, potassium bicarbonate, salt, modified food starch, and potato starch. Control: NT; salt (0.5%): S05; sodium bicarbonate (0.5%): SBC05; sodium bicarbonate (1.0%): SBC1; potassium bicarbonate (0.5%): PBS05; potassium bicarbonate (1.0%): PBC1; sodium bicarbonate + salt (0.5% + 0.5%): SSBC05; sodium bicarbonate + salt (1.0% + 0.5%): SSBC1; potassium bicarbonate + salt (0.5% + 0.5%): SPBC05; potassium bicarbonate + salt (1.0% + 0.5%): SPBC1; modified food starch + salt (2.0% + 0.5%): SMFS2; potato starch + salt (2.0% + 0.5%): SPS2.

treated with modified food starch ($r = -0.95$) and potato starch ($r = -0.70$) had a strong negative correlation. The symbols used for the correlation matrix are presented in Table 1.

Figure 2 displays the scatter plot correlation matrix for the attribute chewiness. It examines the relationship between the sensory profile and TPA instrumental analysis. The scatter plot correlation matrix also displays the fit of the data within a 95% confidence limit. When adding potassium bicarbonate, a strong correlation can be seen in samples with potassium bicarbonate (0.5%; $r = 0.82$), potassium bicarbonate (1%; $r = 0.70$), potassium bicarbonate + salt ($r = 0.94$), and sodium bicarbonate (at 0.5; $r = -0.73$). After salt was added to the bicarbonates, a stronger correlation was observed in instrumental and sensory chewiness. The meatloaf samples with sodium bicarbonate had a lesser correlation than potassium bicarbonate. Similar to potassium bicarbonate, the addition of salt with sodium bicarbonate to ground beef also had a stronger correlation than with sodium bicarbonate alone. This was evident, as the chewiness r-values for 0.5% sodium bicarbonate and 1% sodium bicarbonate were −0.67 and −0.59, respectively. With sodium bicarbonate, the increase in concentration yielded a higher chewiness correlation. Without any treatments, the control was most strongly correlated ($r = -0.99$). The meatloaf treated with modified food starch with salt ($r = -0.85$) and potato starch with salt ($r = -0.79$) were also strongly correlated.

3.6. Principal Component Analysis on the Instrumental Texture Data. Principal component analysis on the instrumental texture data, using the sensory data as a supplementary variable, showed that the instrumental hardness and chewiness were positively related to the sensory hardness and chewiness (Figure 3). Juiciness, a sensory attribute, was opposite to both instrumental and sensory hardness and chewiness, suggesting that samples that were juicy were more tender and less chewy. Hardness (instrumental and sensory) was also highly related to WBSF, indicating that the latter is another measure of tenderness in meats (Figure 3). Cohesiveness (instrumental) did not

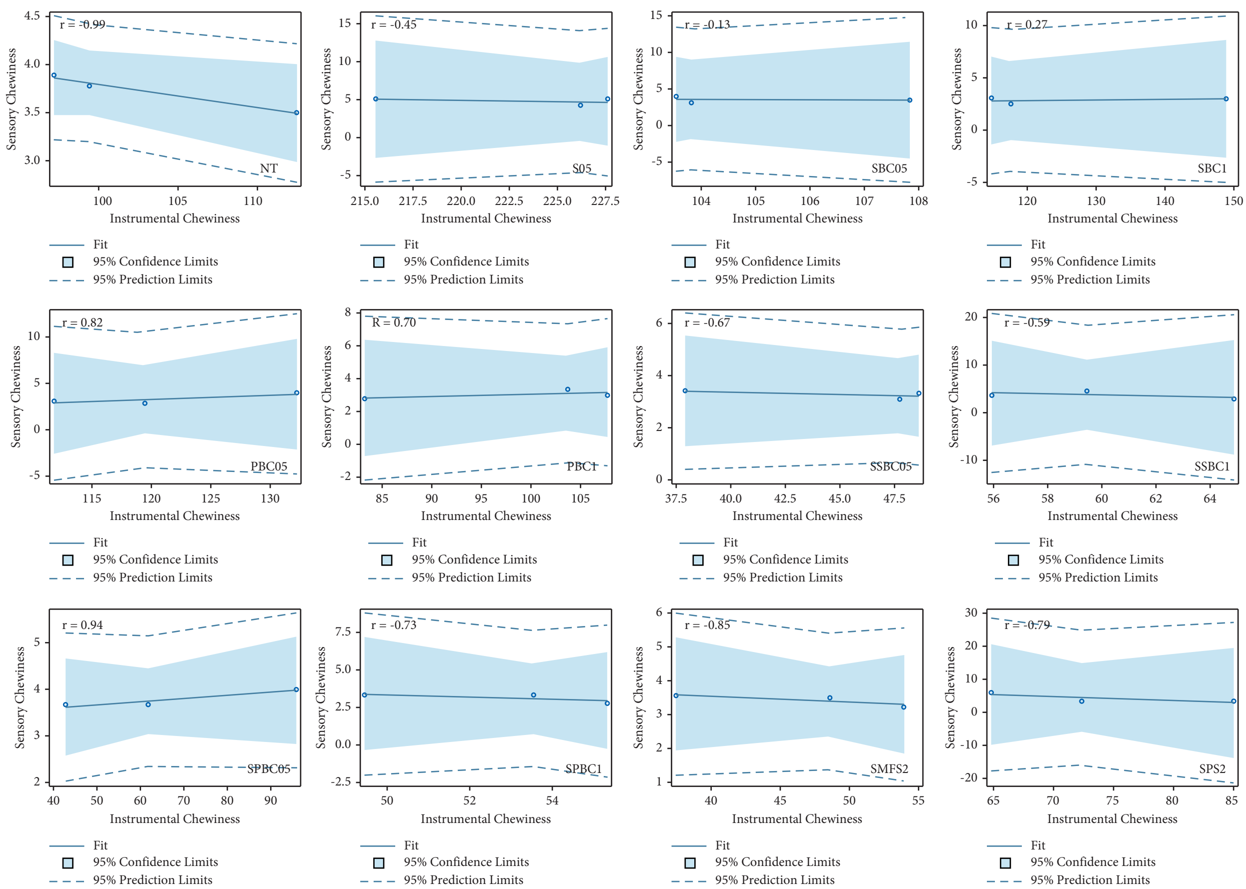

FIGURE 2: Scatter plot correlation matrix comparing the chewiness sensory descriptive analysis and instrumental texture profile analysis of ground beef treated with different levels of sodium bicarbonate, potassium bicarbonate, salt, modified food starch, and potato starch. Control: NT; salt (0.5%): S05; sodium bicarbonate (0.5%): SBC05; sodium bicarbonate (1.0%): SBC1; potassium bicarbonate (0.5%): PBS05; potassium bicarbonate (1.0%): PBC1; sodium bicarbonate + salt (0.5% + 0.5%): SSBC05; sodium bicarbonate + salt (1.0% + 0.5%): SSBC1; + salt (0.5% + 0.5%): SPBC05; potassium bicarbonate + salt (1.0% + 0.5%): SPBC1; modified food starch + salt (2.0% + 0.5%): SMSF2; potato starch + salt (2.0% + 0.5%): SPS2.

contribute to differences in any of the treatments, or all the samples had similar levels of cohesiveness, which was not very high. The two treatments containing the starches and the control treatment (partially) were characterized by the presence of springiness (Figure 3). Treatments containing both bicarbonates were juicier than those of the rest of the samples. The treatment containing salt was very hard and chewy.

4. Discussion

This study explored the effects of sodium or potassium bicarbonate and salt on the physicochemical properties and sensory and textural attributes of cooked meatloaf. Findings suggest that the bicarbonates with or without salt influenced the moisture content, including the perceived juiciness of the prepared meatloaves. The palatability of meatloaf is a function of many attributes: tenderness, texture, juiciness, and flavor profile [41]. Bicarbonate and salt combination enhanced the sensory and textural attributes of the meatloaf by improving product juiciness, cook yield, and reduced shear force. This finding is similar to reports from other studies [8, 21–23, 42]. These authors reported that bicarbonate salts enhanced the textural quality of beef by including palatability, perceived juiciness, and reduced shear force.

Despite the similar color and textural attributes, the meatloaf prepared with the bicarbonate and salt combination had a higher cook yield, greater perceived sensory juiciness, and moisture retention compared with the meatloaf prepared with the only salt or starch with the added salt combination. Samples enhanced with phosphate. A previous study by Mohan et al. [12] reported that the addition of the bicarbonates had a higher pH and water-holding capacity in raw ground beef. As expected, sodium bicarbonate or potassium bicarbonate are known to have a higher buffering capacity in water than salt that may have led to an increase in the cook yield and a higher moisture percentage in cooked meatloaf. Ultimately, this resulted in greater consumer juiciness without affecting flavor liking. We believe that this likely contributed to higher tenderness scores, as evidenced by the positive correlation between consumer tenderness and juiciness.

Studies have demonstrated that sodium bicarbonate acted as an excellent replacement ingredient for phosphate in meat [2, 22]. Others have reported that sodium bicarbonate has the potentials to enhance the physicochemical

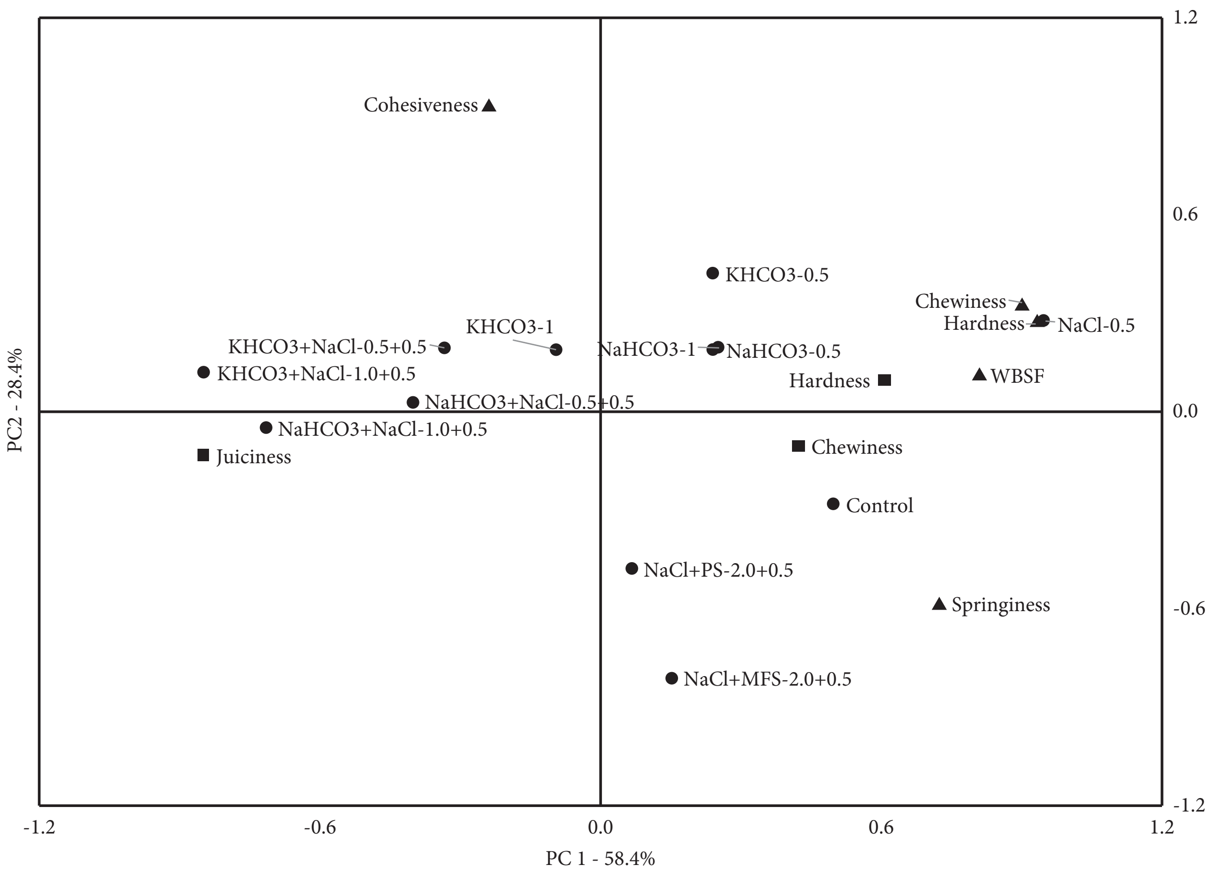

Figure 3: PCA biplot showing the relationship between the instrumental texture data (▲) and sensory attributes (■) and the treatment (●) positions in relation to both set of variables.

properties and eating quality attributes of meat. Hardcastle et al. [43] demonstrated that beef enhanced with sodium bicarbonate resulted in improved consumer palatability scores, compared with sodium phosphate-treated samples. The meat industry demands innovation to add value to inferior quality or downgraded meat trimmings that could be utilized in developing new products such as meatloaf. Similar studies by Hardcastle et al. [43] and Garmyn et al. [2] demonstrated that beef muscles enhanced with sodium bicarbonate were the most tender, were juicier, and had improved overall liking. Given the increasing demand for clean labeling by consumers, the application of bicarbonates as an alternative functional ingredient to phosphate is the basis of this investigation. Recent trends in the meat industry have shown an increased interest in evaluating alternative ingredients to enhance sensory properties and add value to downgraded meat products. Lee et al. [6] and Alvarado and Sams [7] reported that the application of bicarbonates in chicken improved palatability characteristics and minimized meat quality defects.

Sheard and Tali [22] have shown that pork containing sodium bicarbonate had reduced shear force values. The bicarbonate-treated pork developed air-filled pockets during the cooking process. The researchers believed that the air-filled pockets decreased the load-bearing meat muscle and therefore decreased the shear force value. Other studies suggested that salt had an impact on the hardness of ground beef as it can extract the myofibrillar proteins [44–46]. Myofibrillary proteins are soluble in salt solutions, and their extraction can create a sticky exudate. This allows for the meat to be more easily formed into desired meat products such as hamburgers, meatballs, and meatloaves. The shear value of ground beef with only bicarbonates was slightly higher than when combined with salt. This was also seen with pork loins done by Sheard and Tali [22]. Ruusunen et al. [47] reported that salt increased the cohesiveness of the meat batter. Cohesiveness did not follow the same pattern as chewiness and hardness. There was not much difference between the bicarbonate-treated and bicarbonate with salt-treated ground beef. In cod sausages, cohesiveness increased with increasing amounts of sodium bicarbonate from 0.15% to 0.30% [48].

5. Conclusions

Meatloaf treated with salt only at 0.5% was the chewiest and hardest compared with control and bicarbonate treatments. Instrumental texture profile (TPA and WBSF) and sensory analysis showed that bicarbonate-treated meatloaf samples exhibited superior sensory and textural properties. Internal cooked color data revealed that meatloaf treated with sodium bicarbonate and potassium bicarbonate had a higher a^* value and was pinkish red. Overall, the bicarbonates decreased the hardness, shear value, and shear work compared with the control. This shows that bicarbonates had a significant tenderizing effect and increased juiciness within the ground beef. Therefore, to create various types of food products such as hamburgers, meatloaves, or meatballs, the application of bicarbonates will improve tenderness, juiciness, and sensory qualities of the meatloaf. The evidence presents an opportunity for improving the acceptable quality and improved texture and sensory attributes using bicarbonates as an alternative to phosphate in the meatloaf.

Data Availability

The sensory and other physical properties data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] S. Sorapukdee and P. Tangwatcharin, "Quality of steak restructured from beef trimmings containing microbial transglutaminase and impacted by freezing and grading by fat level," *Asian-Australasian Journal of Animal Sciences*, vol. 31, no. 1, pp. 129–137, 2018.

[2] A. Garmyn, N. Hardcastle, C. Bendele, R. Polkinghorne, and M. Miller, "Exploring consumer palatability of Australian beef fajita meat enhanced with phosphate or sodium bicarbonate," *Foods*, vol. 9, no. 2, p. 177, 2020.

[3] E. Jung, Y. Hwang, and S. Joo, "Muscle profiling to improve the value of retail meat cuts," *Meat Science*, vol. 120, pp. 47–53, 2016.

[4] G. Xiong, X. Fu, D. Pan, J. Qi, X. Xu, and X. Jiang, "Influence of ultrasound-assisted sodium bicarbonate marination on the curing efficiency of chicken breast meat," *Ultrasonics Sonochemistry*, vol. 60, Article ID 104808, 2020.

[5] F. Lu, Z.-L. Kang, L.-P. Wei, and Y.-P. Li, "Effect of sodium bicarbonate on gel properties and protein conformation of phosphorus-free chicken meat batters," *Arabian Journal of Chemistry*, vol. 14, no. 2, Article ID 102969, 2021.

[6] N. Lee, V. Sharma, N. Brown, and A. Mohan, "Functional properties of bicarbonates and lactic acid on chicken breast retail display properties and cooked meat quality," *Poultry Science*, vol. 94, no. 2, pp. 302–310, 2015.

[7] C. Alvarado and A. Sams, "Injection marination strategies for remediation of pale, exudative broiler breast meat," *Poultry Science*, vol. 82, no. 8, pp. 1332–1336, 2003.

[8] A. Sen, B. Naveena, M. Muthukumar, Y. Babji, and T. R. K. Murthy, "Effect of chilling, polyphosphate and bicarbonate on quality characteristics of broiler breast meat," *British Poultry Science*, vol. 46, no. 4, pp. 451–456, 2005.

[9] M. Petracci, M. Bianchi, S. Mudalal, and C. Cavani, "Functional ingredients for poultry meat products," *Trends in Food Science & Technology*, vol. 33, no. 1, pp. 27–39, 2013.

[10] Y. Zou, H. Shi, P. Xu et al., "Combined effect of ultrasound and sodium bicarbonate marination on chicken breast tenderness and its molecular mechanism," *Ultrasonics Sonochemistry*, vol. 59, Article ID 104735, 2019.

[11] H. C. Bertram, R. L. Meyer, Z. Wu, X. Zhou, and H. J. Andersen, "Water distribution and microstructure in enhanced pork," *Journal of Agricultural and Food Chemistry*, vol. 56, no. 16, pp. 7201–7207, 2008.

[12] A. Mohan, T. Jaico, W. Kerr, and R. Singh, "Functional properties of bicarbonates on physicochemical attributes of ground beef," *Lebensmittel-Wissenschaft & Technologie*, vol. 70, pp. 333–341, 2016.

[13] K. M. Wójciak, P. Kęska, A. Okoń, E. Solska, J. Libera, and Z. J. Dolatowski, "The influence of acid whey on the antioxidant peptides generated to reduce oxidation and improve colour stability in uncured roast beef," *Journal of the Science of Food and Agriculture*, vol. 98, no. 10, pp. 3728–3734, 2018.

[14] V. Verrez-Bagnis, B. Bouchet, and D. Gallant, "Relationship between the starch granule structure and the textural properties of heat-induced surimi gels," *Food Structure*, vol. 12, no. 3, 1993.

[15] M. Wu, T. Lanier, and D. Hamann, "Thermal transitions of admixed starch/fish protein systems during heating," *Journal of Food Science*, vol. 50, no. 1, pp. 20–25, 1985.

[16] J. F. Kerry, P. A. Morrissey, and D. J. Buckley, "The rheological properties of exudates from cured porcine muscle: effects of added polysaccharides and whey protein/polysaccharide blends," *Journal of the Science of Food and Agriculture*, vol. 79, no. 10, pp. 1260–1266, 1999.

[17] Z. Pietrasik, "Effect of content of protein, fat and modified starch on binding textural characteristics, and colour of comminuted scalded sausages," *Meat Science*, vol. 51, no. 1, pp. 17–25, 1999.

[18] L. Zhang and S. Barbut, "Effects of regular and modified starches on cooked pale, soft, and exudative; normal; and dry, firm, and dark breast meat batters," *Poultry Science*, vol. 84, no. 5, pp. 789–796, 2005.

[19] J. Carballo, G. Barreto, and F. J. Colmenero, "Starch and egg white influence on properties of bologna sausage as related to fat content," *Journal of Food Science*, vol. 60, no. 4, pp. 673–677, 1995.

[20] F. J. Colmenero, J. Carballo, and M. T. Solas, "The effect of use of freeze-thawed pork on the properties of Bologna sausages with two fat levels," *International Journal of Food Science and Technology*, vol. 30, no. 3, pp. 335–345, 1995.

[21] R. G. Kauffman, R. L. Van Laack, R. L. Russell et al., "Can pale, soft, exudative pork be prevented by postmortem sodium bicarbonate injection?" *Journal of Animal Science*, vol. 76, no. 12, pp. 3010–3015, 1998.

[22] P. Sheard and A. Tali, "Injection of salt, tripolyphosphate and bicarbonate marinade solutions to improve the yield and tenderness of cooked pork loin," *Meat Science*, vol. 68, no. 2, pp. 305–311, 2004.

[23] E. Wynveen, B. Bowker, A. Grant et al., "Pork quality is affected by early postmortem phosphate and bicarbonate injection," *Journal of Food Science*, vol. 66, no. 6, pp. 886–891, 2001.

[24] D. M. Curran and T. J. Montville, "Bicarbonate inhibition of Saccharomyces cerevisiae and Hansenula wingei growth in apple juice," *International Journal of Food Microbiology*, vol. 8, no. 1, pp. 1–9, 1989.

[25] Y.-P. Li, X.-H. Zhang, F. Lu, and Z.-L. Kang, "Effect of sodium bicarbonate and sodium chloride on aggregation and conformation of pork myofibrillar protein," *Food Chemistry*, vol. 350, Article ID 129233, 2021.

[26] G. Froning and B. Sackett, "Effect of salt and phosphates during tumbling of Turkey breast muscle on meat characteristics," *Poultry Science*, vol. 64, no. 7, pp. 1328–1333, 1985.

[27] A. Sultana, A. Nakanishi, B. C. Roy et al., "Quality improvement of frozen and chilled beef biceps femoris with the

application of salt-bicarbonate solution," *Asian-Australasian Journal of Animal Sciences*, vol. 21, no. 6, pp. 903–911, 2008.

[28] A. Garmyn, *Consumer Preferences and Acceptance of Meat Products*, Multidisciplinary Digital Publishing Institute, Basel, Switzerland, 2020.

[29] N. Thiex, "Evaluation of analytical methods for the determination of moisture, crude protein, crude fat, and crude fiber in distillers dried grains with solubles," *Journal of AOAC International*, vol. 92, no. 1, pp. 61–73, 2009.

[30] K. D. Kuffi, S. Lescouhier, B. M. Nicolai, S. De Smet, A. Geeraerd, and P. Verboven, "Modelling postmortem evolution of pH in beef *M. biceps femoris* under two different cooling regimes," *Journal of Food Science and Technology*, vol. 55, no. 1, pp. 233–243, 2018.

[31] J. K. Mwove, L. A. Gogo, B. N. Chikamai, M. Omwamba, and S. M. Mahungu, "Principal component analysis of physicochemical and sensory characteristics of beef rounds extended with gum arabic from *Acacia senegal* var. *kerensis*," *Food Sciences and Nutrition*, vol. 6, no. 2, pp. 474–482, 2018.

[32] I. Tomasevic, I. Djekic, M. Font-i-Furnols, N. Terjung, and J. M. Lorenzo, "Recent advances in meat color research," *Current Opinion in Food Science*, vol. 41, pp. 81–87, 2021.

[33] H. Prabhakar, C. H. Bock, W. L. Kerr, and F. Kong, "Pecan color change during storage: kinetics and modeling of the processes," *Current Research in Food Science*, vol. 5, pp. 261–271, 2022.

[34] Z. Liu and Y. Guo, "The effect of munsell neutral value scale on the color of yellow jadeite and comparison between AP and K-means clustering color grading schemes," *Crystals*, vol. 12, no. 2, p. 241, 2022.

[35] B. Berry, A. Deithmers, and T. Gillett, "Guidelines for sensory, physical and chemical measurements in ground beef," in *Proceedings of the 56th Reciprocal Meat Conference*, Columbia, MO, USA, 1995.

[36] M. Colle, *AMSA Research Guidelines for Cookery, Sensory Evaluation, and Instrumental Tenderness Measurements of Meat*, American Meat Science Association, Savoy, IL, USA, 2015.

[37] A. E. D. A. Bekhit, D. L Hopkins, F. T. Fahri, and E. N. Ponnampalam, "Oxidative processes in muscle systems and fresh meat: sources, markers, and remedies," *Post-Harvest Influences on Beef Flavor Development and Tenderness*, vol. 12, no. 5, pp. 565–597, 2013.

[38] G.-D. Mocanu, M. Barbu, O.-V. Nistor, D. G. Andronoiu, and E. Botez, "The effect of the partial substitution of pork back fat with vegetable oils and walnuts on the chemical composition, texture profile and sensorial properties of meatloaf," *The Annals of the University of Dunarea de Jos of Galati*, vol. 39, no. 1, pp. 58–69, 2015.

[39] M. O'Sullivan and J. Kerry, "Instrumental assessment of the sensory quality of meat, poultry and fish," in *Instrumental Assessment of Food Sensory Quality*, pp. 355–373, Elsevier, Amsterdam, Netherlands, 2013.

[40] M. C. Meilgaard, B. T. Carr, and G. V. Civille, *Sensory Evaluation Techniques*, CRC Press, Boca Raton, FL, USA, 1999.

[41] M. F. Miller, M. Carr, C. Ramsey, K. L. Crockett, and L. C. Hoover, "Consumer thresholds for establishing the value of beef tenderness," *Journal of Animal Science*, vol. 79, no. 12, pp. 3062–3068, 2001.

[42] E.-S. Lee, S. Y. Park, Y.-G. Jeong, B. C. Jo, M. Kim, and S. O. Ha, "Quality evaluation and estimation of shelf life of retort-pouched tomato-based and Korean traditional fermented food-based sauces," *Journal of the Korean Society for Applied Biological Chemistry*, vol. 58, no. 2, pp. 229–236, 2015.

[43] N. C. Hardcastle, A. Garmyn, and M. F. Miller, "Effect of enhancement on three beef muscles with phosphate or alternative functional ingredients on the eating quality of Australian beef," *Meat and Muscle Biology*, vol. 3, no. 2, p. 49, 2019.

[44] J. D. Rios-Mera, E. Saldaña, M. L. Cruzado-Bravo et al., "Impact of the content and size of NaCl on dynamic sensory profile and instrumental texture of beef burgers," *Meat Science*, vol. 161, Article ID 107992, 2020.

[45] G. Villamonte, H. Simonin, F. Duranton, R. Chéret, and M. de Lamballerie, "Functionality of pork meat proteins: impact of sodium chloride and phosphates under high-pressure processing," *Innovative Food Science & Emerging Technologies*, vol. 18, pp. 15–23, 2013.

[46] D.-Y. Zhu, Z.-L. Kang, H.-J. Ma, X.-L. Xu, and G.-H. Zhou, "Effect of sodium chloride or sodium bicarbonate in the chicken batters: a physico-chemical and Raman spectroscopy study," *Food Hydrocolloids*, vol. 83, pp. 222–228, 2018.

[47] M. Ruusunen, J. Vainionpää, M. Lyly et al., "Reducing the sodium content in meat products: the effect of the formulation in low-sodium ground meat patties," *Meat Science*, vol. 69, no. 1, pp. 53–60, 2005.

[48] C. M. Cardoso, R. Mendes, and M. L. Nunes, "Instrumental texture and sensory characteristics of cod frankfurter sausages," *International Journal of Food Properties*, vol. 12, no. 3, pp. 625–643, 2009.