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Effects of $NaHCO_3$ on the colour, tenderness, and water distribution of raw and cooked marinated beef

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Abstract

Effects of $NaHCO_3$ addition (0.2-0.8%) on the colour, shear force, and water distribution of raw and cooked marinated beef were investigated. The pH and cooking yield were found to be significantly increased ($P < 0.05$), and the shear force, L^* and b^* values were significantly decreased with increasing $NaHCO_3$ amounts, except for samples with 0.6% and 0.8% $NaHCO_3$, for which the cooking yield and shear force remained unaffected. Furthermore, the initial relaxation times T_{21} and T_{22} of marinated beef were, and the mobility of water in the raw marinated beef was reduced ($P < 0.05$) with increasing $NaHCO_3$ content. This was due to the carbon dioxide production disrupting the beef structure during heating process. The mobility of water in the cooked marinated beef was found to be improved. In conclusion, $NaHCO_3$ addition improved the water holding capacity and tenderness of marinated beef.

Keywords: $NaHCO_3$; shear force; tenderness; colour; water mobility.

Practical Application: This study provides a method of using $NaHCO_3$ to improve the colour, tenderness, and water holding capacity of marinated beef, and should be expanded its use in meat products processing.

1 Introduction

Tenderness is an important quality measure for beef. Improving the tenderness can thus significantly improve beef quality and palatability. Tenderness is also regarded as one of the major factors affecting customer perception when purchasing meat products. A favourable profile of tenderness and juiciness is also needed for customer acceptance of marinated beef (Madhusankha & Thilakarathna, 2021). Phosphate is often used as water-retaining agent and tenderizer in processing of marinated beef. Phosphate improves the pH and ionic strength, chelates metal ions, and facilitates the dissociation of actomyosin. Phosphate is also cheap, effective, and easy-to-handle (Pinton et al., 2020; Leng et al., 2021). However, phosphate addition to meat products may also disrupt the optimal proportion of calcium and phosphorus in human body (Isiuku & Enyoh, 2020; Saito et al., 2021). Several studies found that $NaHCO_3$ might be used instead of phosphate to improve the water holding capacity and tenderness of meat and seafood products (Wachirasiri et al., 2016; Xiong et al., 2020; Kang et al., 2021).

$NaHCO_3$ is a commonly used and low-cost food material with a good buffering capacity due to the formation of bicarbonate ions (HCO_3^-) between pH 6.4 and 10.3. $NaHCO_3$ is weakly alkaline in aqueous solution, and heat labile: it begins to decompose into carbon dioxide and sodium carbonate at 20 °C, and decomposes completely 100 °C (Skurray et al., 1986; Kang et al., 2021). Increasing the $NaHCO_3$ content of meat can facilitate the dissolving of actomyosin and myofibrillar protein, trigger the denaturation of the head domain of myosin, and promote the dissociation of actomyosin from myofibrillar protein (Chantarasuwan et al., 2011; Mohan et al., 2016; Li et al., 2021). $NaHCO_3$ is also widely used in Chinese cooking technology to improve the tenderness and water retention of livestock and poultry meat and aquatic products, in addition to masking unpleasant odours (Hsieh et al., 1980; Åsli & Mørkøre, 2012). Several previous studies reported that $NaHCO_3$ can improve the palatability and processability of PSE (Pale, Soft, Exudative) meat, sow loins and PSE-like chicken breast by increasing the pH, enhancing electrostatic repulsion, increasing water retention, yield and tenderness of muscle tissue (Kauffman et al., 1998; Woelfel & Sams, 2001; Sindelar et al., 2003). $NaHCO_3$ has also been used in chicken, pork and beef meat batters to improve their techno-functional properties and gel structures (Mohan et al., 2016; Lu et al., 2021; Kang et al., 2021). However, as far as we know, the effect of $NaHCO_3$ addition on raw and cooked marinated beef has not been investigated thus far. Hence, we investigated here the effects of $NaHCO_3$ on the colour, water holding capacity, tenderness, and water distribution/mobility of raw and cooked marinated beef, and the relationship between tenderness and water mobility.

2 Materials and methods

2.1 Raw materials and ingredients

The 72 h postmortem beef (*ectogluteus*, 2 ± 2 °C, pH 5.68 ± 0.01) derived from Simmental bull (18 month old) was purchased four times in 4 d by Henan Yisai Beef Co., Ltd.

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NaCl and $NaHCO_3$ (analytically pure) were purchased form JSC Chemical Technology Co., Ltd., China. The white pepper powder was purchased from a local market (Xinxiang, China).

2.2 Preparation of marinated beef

The visible fat and connective tissues of beef were removed, and cut into sections sized 4 cm × 4 cm× 2 cm. 20 samples were prepared by each treatment. Marinated beef samples were prepared using 1000 g beef, 15 g NaCl, 350 g ice water, 8.5 g white pepper powder. In addition, T1 added 0 g (0%) $NaHCO_3$, T2 added 2 g (0.2%) $NaHCO_3$, T3 added 4 g (0.4%) $NaHCO_3$, T4 added 6 g (0.6%) $NaHCO_3$, and T5 added 8 g (0.8%) $NaHCO_3$. The beef was marinated using the intermittent tumbling method at 2 ± 2 °C using the following procedure: 8 rpm, rolling was 20 min, stop was 10 min, a total of 60 min; vacuum degree was -0.08 MPa. After that, the beef was vacuum packaged (500 g/bag) and stored at 2 ± 2 °C for 12-16h.

2.3 pH determination

About 10 g of raw marinated beef and 40 mL of distilled water (2 ± 2 °C) were mixed uniformity by a T25 digital homogenizer (IKA Ltd., Germany; speed 15000 rpm, time 10 s) in an ice bath. The pH level of raw marinated beef was then determined using a digital pH meter (Hanna, Italy) at 4 °C. The method of the pH meter calibrated and was temperature compensation applied as follows: (1) The electrode was washed and dried using double distilled water. After that, immersed in pH 7.00 standard solution, and the instrument temperature compensation knob was placed at the solution temperature. When the indicating value was stable, adjusted the positioning knob to make the indicating value of the instrument be the pH of the standard solution. (2) The electrode was washed and dried using double distilled water. Following, immersed in pH 4.00 standard solution. After the indicating value was stable, adjusted the slope knob of the instrument, and the indicating value was the pH of the standard solution. (3) The electrode was washed and dried using double distilled water, and then immersed in pH 7.00 standard solution. If the error exceeded 0.02 units, repeated steps (1) and (2), until the correct pH was displayed in both standard solutions without the need for adjustment knobs. (4) The electrode was washed and dried using double distilled water. Following, adjusted the temperature compensation knob to the temperature of the sample solution, immersed the electrode in the sample solution, placed it still after shaking, and displayed the reading after stability.

2.4 Cooking yield

After stored overnight at 2 ± 2 °C, 12 samples of raw marinated beef were cooked using a water bath kettle (HH-42, Changzhou Guohua Electric Appliance Co., Ltd., China) at 85 ± 2 °C for 25 min until the core temperature was 72 °C. Following, the cooked beef was cooled using running water. After that, the lost water and fat from the marinated beef was wiped away. Then, the cooking yield was calculated according to the formula:

Cooking yield % = Weight of cooked marinated beef/Weight of raw marinated beef ×100%.

2.5 Colour measurement

A CR-400 Colorimeter (Minolta Camera Co, Japan) with a pulse xenon lamp (the aperture is a diameter of 11 mm) was used to determine the center colour of raw marinated beef at the 10° observer angle, and it was calibrated with a standard white colorimeter using the illuminant D65. The fresh slice from each raw marinated beef was measured at most 1 min.

2.6 Shear force measurement

The cooked marinated beef was left the laboratory at room temperature for 2 h after 2 ± 2 °C stored overnight. Then, the cooked marinated beef was cut into 4 cm × 1 cm × 1 cm slices along the direction of the muscle fibers. The shear force (N) was measured using a muscle tenderness meter (C-LM4, College of Engineering, Northeast Agricultural University, China).

2.7 Low-field nuclear magnetic resonance (LF-NMR) measurements

The raw and cooked marinated beef were cut into about 2 g cubes and placed in Ziplock bags, and the marinated beef were left at a 32 °C thermostat (P series, Guangdong Hongzhan Technology Co., Ltd., China) for 30 min. LF-NMR relaxation measurements were performed by using a Niumag NMR analyzer (NMI20-040 V-1, China). During the process of measurement, a resonance frequency of 22.6 MHz at 32 °C was operated, the value of τ (the time between 90° and 180° pulse) was 200 μs, the number of collected echoes was 5000, repeat the scan 32 times with a repetition interval of 6.5 s to get 12000 echoes. The data were analyzed using the equipped software.

2.8 Statistical analysis

The experiment was repeated four times at different occasions, using different samples (raw and cooked marinated beef). Data were analyzed by the linear mixed models (LMM) procedure (SPSS v.18.0), considering the treatments (marinated beef with 0%, 0.2%, 0.4%, 0.6%, and 0.8% $NaHCO_3$) as a fixed effect and the replicates as a random effect. The pH, cooking yield, colour, and shear force data were analysed in a similar fashion. LF-NMR date of raw and cooked marinated beef were included in the random term for the evaluation of the initial relaxation time and peak ratio, and the NMR data time as a fixed term along with the interaction with treatment. Approximate F-ratio tests for each fixed effect were conducted and critical value for a statistically important effect taken at $P < 0.05$. Non-significant terms were excluded from models using stepwise backward elimination.

3 Results and discussion

3.1 pH

The pH level is a major indicator of beef quality, as it directly affects palatability, tenderness, water retention, and shelf life. Figure 1 shows the effect of $NaHCO_3$ addition on pH of marinated beef. As expected, the pH of raw marinated beef was significantly increased ($P < 0.05$) from 5.68 to 6.57 with increasing $NaHCO_3$. This is because $NaHCO_3$ is a strong alkali

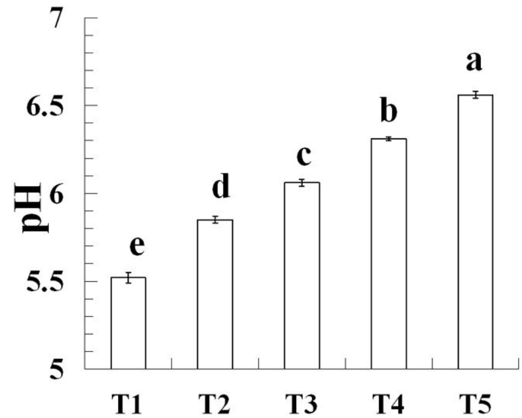

Figure 1. pH of raw marinated beef with various amounts of added $NaHCO_3$. Each value represents the mean ± SE, n = 4. [a-e] Different parameter superscripts indicate significant differences ($P < 0.05$).

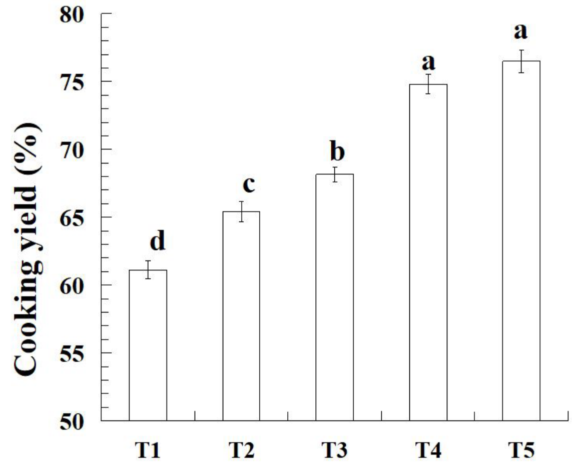

Figure 2. Cooking yield of marinated beef with various amounts of added $NaHCO_3$. Each value represents the mean ± SE, n = 4. [a-d] Different parameter superscripts indicate significant differences ($P < 0.05$).

weak acid salt, which produces hydroxide ions (OH^-) and carbonic acid (H_2CO_3) in aqueous solutions (Li et al., 2021). Thus, when used in marinated beef, $NaHCO_3$ increases the pH level. Similar findings were previously reported by Zhu et al. (2018), where the authors used $NaHCO_3$ to replace sodium chloride, resulting in significant increases in the pH of chicken breast meat batter. Petracci et al. (2014) also found that the pH of marinated chicken breast meat was increased with increasing the levels of $NaHCO_3$.

3.2 Cooking yield

Figure 2 shows the effect of $NaHCO_3$ addition on cooking yield of marinated beef. The cooking yield of marinated beef with $NaHCO_3$ was significantly increased compared to that of T1. The pH of raw marinated beef was found to be very different ($P < 0.05$) from the isoelectric point of myofibrillar proteins upon $NaHCO_3$ addition. This could increase the net negative charge of proteins, and lead to swelling and dissolving of beef muscle fibers, prompting more water to be immobilized during marination (Offer & Knight, 1988). Kang et al. (2021) previously found that partial replacement of NaCl by $NaHCO_3$ significantly increased the salt-soluble protein concentration of raw pork batters. Mohan et al. (2016) also reported that ground beef with $NaHCO_3$ or $KHCO_3$ improved the water holding capacity during the heating process. As for the other samples, the cooking yield was significantly increased ($P < 0.05$) with increasing $NaHCO_3$, except for T5. $NaHCO_3$ is known to cause generation of carbon dioxide (CO_2) during the heating process. If excessive amounts of $NaHCO_3$ are added, large amounts of produced carbon dioxide may disrupt the beef structure (Petracci et al., 2013; Kang et al., 2021). This may explain why similar cooking yields for T4 and T5 were obtained.

3.3 Colour

The changes in colour of raw marinated beef with various amounts of added $NaHCO_3$ are shown in Table 1. The L^* and b^* values of raw marinated beef with $NaHCO_3$ were significantly decreased ($P < 0.05$) compared to that of T1. Specifically, the levels of these metrics significantly decreased with increasing $NaHCO_3$ addition from 0.2% to 0.4%, whereas the addition of $NaHCO_3$ at levels between 0.4% to 0.8% did not lead to significant differences. On the other hand, the a^* value showed an overall decreasing trend with $NaHCO_3$ addition, yet without any significant differences between the samples.

Table 1. Color (L^*, a^* and b^* values) of raw marinated beef with various amounts of added $NaHCO_3$.

Sample	L^*	a^*	b^*
T1	47.15 ± 0.72[a]	9.58 ± 0.32[a]	12.06 ± 0.35[a]
T2	46.16 ± 0.41[b]	9.36 ± 0.16[a]	10.73 ± 0.31[b]
T3	44.78 ± 0.38[c]	9.29 ± 0.22[a]	9.67 ± 0.32[bc]
T4	43.59 ± 0.42[cd]	9.21 ± 0.19[a]	9.41 ± 0.22[c]
T5	42.81 ± 0.37[d]	9.01 ± 0.21[a]	9.03 ± 0.16[c]

Each value represents the mean ± SE, n = 4. [a-d]Different parameter superscripts indicate significant differences ($P < 0.05$).

Several studies have reported effects of $NaHCO_3$ on colour of meat and sea food. Kaewthong et al. (2021) studied the effect of plant juices and $NaHCO_3$ on the quality of marinated goat meat, and showed that L^*, a^* and b^* values were decreased with increasing concentrations of $NaHCO_3$, indicating that the marinating solution containing $NaHCO_3$ caused the marinated goat meat to obtain a dark-brown colour. Petracci et al. (2014) found that the L^*, a^* and b^* values of raw chicken breast meat following marination were not significantly affected by increasing levels of $NaHCO_3$. Mohan et al. (2016) found that the L^* value of ground meat products were not significantly affected by $NaHCO_3$ addition due to added modified food or potato starch content of these products. However, the L^* values of salted Atlantic cod were decreased upon $NaHCO_3$ addition (Åsli & Mørkøre, 2012). The differences were due to the different materials and processing method. Here, the beef samples included more myoglobin than goat meat, chicken meat, and Atlantic cod, and thus the stability of myoglobin was higher when the pH was increased (Lu et al., 2021). Hence, the addition of $NaHCO_3$ led to a darker coloured beef product.

3.4 Shear force

Shear force is an important measure of beef tenderness. The smaller the shear force, the better the tenderness. The change in shear force of cooked marinated beef with different $NaHCO_3$ is shown in Figure 3. Accordingly, the shear force was significantly decreased ($P < 0.05$) with increasing $NaHCO_3$ amounts, except for T5. T4 and T5 yielded the highest shear force at similar levels. This is because $NaHCO_3$ can lead to the formation of disordered collagen tissue between muscle cells, and decrease in toughness of beef (Zou et al., 2019). In addition, $NaHCO_3$ added samples yielded high pH and ionic strength levels, which caused increased solubilisation of salt-soluble proteins, and decreased the hardness of muscle fibers (Saleem et al., 2015). Hence, myofibril fragmentation index was effectively increased upon $NaHCO_3$ addition, and reduced the shear force (Xiong et al., 2020; Zou et al., 2019). A similar study was shown by Xiong et al. (2020), who found that used the $NaHCO_3$ assisted curing of chicken breast meat has a lower shear force and larger myofibril fragmentation index (8.01 N and 56.82) than that of traditional wetting curing (6.99 N and 61.65). Lee et al. (2015) previously studied the effect of $KHCO_3$, $NaHCO_3$, potassium lactate, and salt injections on functional properties of whole chicken breast, and found that the shear force values were lower at 0.5% level for both $KHCO_3$ and $NaHCO_3$ compared with those of potassium lactate and salt.

3.5 LF-NMR measurements

Spin-spin relaxation time (T_2) measured by LF-NMR can reflect the distribution and mobility of water in marinated meat (Åsli et al., 2016). The T_2 of raw and cooked marinated beef meat with different $NaHCO_3$ are shown in Figure 4, Table 2 and 3. The peaks of T_{2b}, T_{21}, and T_{22} correspond to 0–10, 10–100, and 100–1000 ms, and represent bound water, immobile water and free water in the samples, respectively (Petracci et al., 2014; Kang et al., 2016).

LF-NMR measurements of raw marinated beef

Figure 4 and Table 2 show the changes in initial relaxation time and the peak ratio of raw marinated beef with various amounts of added $NaHCO_3$. The initial relaxation time of T_{2b}, T_{21}, and T_{22}, and the peak ratio of P_{22} were significantly decreased, whereas the peak ratio of P_{21} was significantly increased ($P < 0.05$) upon $NaHCO_3$ addition. On the other hand, the peak ratio of P_{2b} was not significantly affected. These results indicate that the water was tightly connected to the meat matrix, and the water mobility was reduced when $NaHCO_3$ was added (Kang et al., 2021). Several studies have previously reported that the addition of $NaHCO_3$ could shorten the relaxation time of cured pork and chicken meat compared to marination with NaCl (Bertram et al., 2008; Petracci et al., 2014; Xiong et al., 2020). With increasing

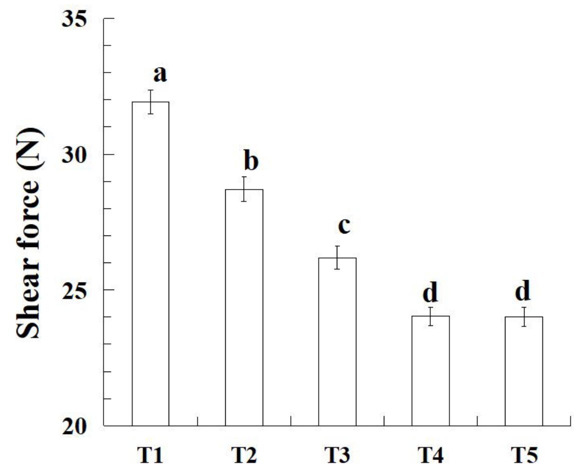

Figure 3. Shear force of cooked marinated beef with various amounts of added $NaHCO_3$. Each value represents the mean ± SE, n = 4. [a-d] Different parameter superscripts indicate significant differences ($P < 0.05$).

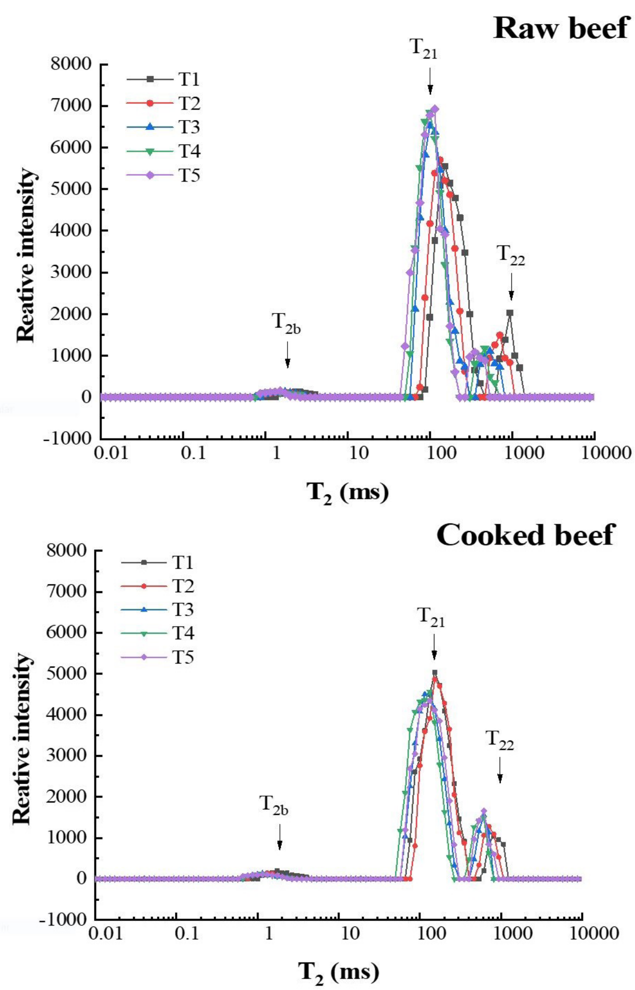

Figure 4. The changes in LF-NMR relaxation times and peak ratio of raw and cooked marinated beef with various amounts of added $NaHCO_3$.

Table 2. The initial relaxation time (ms) and the peak ratio (%) of raw marinated beef with various amounts of added $NaHCO_3$.

Sample	Initial relaxation time (ms)			Peak ration (%)		
	T_{2b}	T_{21}	T_{22}	P_{2b}	P_{21}	P_{22}
T1	1.41 ± 0.07^a	85.52 ± 1.82^a	679.38 ± 15.14^a	2.04 ± 0.06^a	86.18 ± 0.44^c	11.87 ± 0.18^a
T2	1.02 ± 0.06^b	78.91 ± 2.02^b	551.78 ± 16.86^b	2.07 ± 0.05^a	89.26 ± 0.48^b	9.05 ± 0.16^b
T3	0.96 ± 0.06^b	70.23 ± 1.76^c	412.81 ± 14.72^c	1.96 ± 0.06^a	92.65 ± 0.51^a	5.58 ± 0.18^c
T4	0.87 ± 0.09^b	61.74 ± 1.56^d	348.17 ± 15.79^d	1.94 ± 0.07^a	92.25 ± 0.47^a	5.23 ± 0.15^c
T5	0.85 ± 0.095^b	53.49 ± 1.55^e	280.17 ± 15.14^e	1.97 ± 0.05^a	93.57 ± 0.45^a	4.72 ± 0.17^c

Each value represents the mean ± SE, n = 4. $^{a-e}$Different parameter superscripts indicate significant differences ($P < 0.05$).

Table 3. The initial relaxation time (ms) and the peak ratio (%) of cooked marinated beef with various amounts of added $NaHCO_3$.

Sample	Initial relaxation time (ms)			Peak ration (%)		
	T_{2b}	T_{21}	T_{22}	P_{2b}	P_{21}	P_{22}
T1	1.18 ± 0.04^a	77.53 ± 1.65^a	607.58 ± 14.36^a	3.27 ± 0.08^a	91.53 ± 0.48^a	6.26 ± 0.13^e
T2	0.85 ± 0.05^b	71.09 ± 1.64^b	512.87 ± 13.17^b	2.80 ± 0.06^b	88.07 ± 0.45^b	9.37 ± 0.12^d
T3	0.81 ± 0.05^b	62.87 ± 1.64^c	433.69 ± 13.74^c	2.58 ± 0.07^c	86.15 ± 0.49^c	11.26 ± 0.14^c
T4	0.76 ± 0.04^b	59.07 ± 1.54^c	427.05 ± 12.84^c	2.21 ± 0.06^d	85.42 ± 0.51^c	12.84 ± 0.11^b
T5	0.70 ± 0.05^b	63.49 ± 1.71^c	446.74 ± 14.26^c	1.76 ± 0.07^e	83.90 ± 0.48^{cd}	14.27 ± 0.13^a

Each value represents the mean ± SE, n = 4. $^{a-e}$Different parameter superscripts indicate significant differences ($P < 0.05$).

$NaHCO_3$, the initial relaxation time of T_{2b} was not significant different ($P > 0.05$), T_{21} and T_{22} were significantly decreased ($P < 0.05$); the peak ratio of P_{21} and P_{22} were significantly increased, but T3, T4 and T5 were not significant different ($P > 0.05$). The results indicated that the immobile water and free water were tied closely in the beef meat, and water mobility was reduced with increasing $NaHCO_3$. The reason is possible that the pH, ionic strength and electrostatic repulsion between the proteins were increased with increasing $NaHCO_3$, leading to the beef myofibrillar protein shifted away from the isoelectric point and promoted it dissolution, thereby increased spacing between filaments (Alvarado & Sams, 2003; Li et al., 2021). On the other hand, more collagen tissue was destroyed with increasing $NaHCO_3$, and more water can be held in the raw marinated beef (Sultana et al., 2009).

NMR measurements of cooked marinated beef

Figure 4 and Table 3 show the changes in initial relaxation time and the peak ratio of cooked marinated beef with various amounts of added $NaHCO_3$. The initial relaxation time of T_{2b}, T_{21}, and T_{22}, and the peak ratio of P_{2b} and P_{21} were significantly decreased ($P < 0.05$), whereas the peak ratio of P_{22} was significantly increased upon $NaHCO_3$ addition. This also indicates that water was tightly connected to the meat matrix, and the water mobility was increased when $NaHCO_3$ was added (Bertram et al., 2008). This result contrasts with that obtained for raw marinated beef (Table 2), yet consistent with cooking yield results of raw beef (Figure 2). Since the marinated beef with $NaHCO_3$ returned a higher cooking yield than that of T1, the peak ratio of P_{2b} of marinated beef with $NaHCO_3$ was also lower. Carbon dioxide production due to the addition of $NaHCO_3$ may cause formation of air bubbles in the marinated beef during heating process, and result in disruption of the structure of cooked marinated beef (Zhu et al., 2018). For this reason, the initial relaxation times of T_{21} and T_{22}, and the peak ratio of P_{21} were significantly decreased ($P < 0.05$) upon $NaHCO_3$ addition as well, yet T3, T4, and T5 were not significantly affected. The peak ratio of P_{22} was also significantly increased, implying the water mobility was increased when excessive $NaHCO_3$ was added.

4 Conclusion

In the study, we showed that $NaHCO_3$ addition significantly affected the colour, tenderness, and water holding capacity of marinated beef. The addition of $NaHCO_3$ significantly increased the pH and cooking yield, and significantly decreased the shear force, L^* and b^* values, and the initial relaxation time of T_{2b}, T_{21} and T_{22} of marinated beef. $NaHCO_3$ also caused significant increases in the pH and cooking yield, whereas shear force and initial relaxation times of T_{2b}, T_{21}, and T_{22} were significantly decreased, except for the cooking yield and shear force of sample with 0.8% $NaHCO_3$ content. The water mobility of raw marinated beef was reduced with increasing $NaHCO_3$ content, whereas that of cooked marinated beef was increased. Overall, $NaHCO_3$ addition could lead the water to form a tight connection to the beef matrix, and thereby improve the tenderness and cooking yield of marinated beef.

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References

Alvarado, C. Z., & Sams, A. (2003). Injection marination strategies for remediation of pale, exudative broiler breast meat. *Poultry*

Science, 82(8), 1332-1336. http://dx.doi.org/10.1093/ps/82.8.1332. PMid:12943306.

Åsli, M., & Mørkøre, T. (2012). Brines added sodium bicarbonate improve liquid retention and sensory attributes of lightly salted Atlantic cod. *Lebensmittel-Wissenschaft + Technologie*, 46(1), 196-202. http://dx.doi.org/10.1016/j.lwt.2011.10.007.

Åsli, M., Ofstad, R., Böcker, U., Jessen, F., Einen, O., & Mørkøre, T. (2016). Effect of sodium bicarbonate and varying concentrations of sodium chloride in brine on the liquid retention of fish (*pollachius virens* l.) muscle. *Journal of the Science of Food and Agriculture*, 96(4), 1252-1259. http://dx.doi.org/10.1002/jsfa.7213. PMid:25869532.

Bertram, H. C., Meyer, R. L., Wu, Z. Y., Zhou, X. F., & Andersen, H. J. (2008). Water distribution and microstructure in enhanced pork. *Journal of Agricultural and Food Chemistry*, 56(16), 7201-7207. http://dx.doi.org/10.1021/jf8007426. PMid:18642839.

Chantarasuwan, C., Benjakul, S., & Visessanguan, W. (2011). The effects of sodium bicarbonate on conformational changes of natural actomyosin from Pacific white shrimp (*Litopenaeus vannamei*). *Food Chemistry*, 129(4), 1636-1643. http://dx.doi.org/10.1016/j.foodchem.2011.06.023.

Hsieh, Y. P. C., Cornforth, D. P., Pearson, A. M., & Hooper, G. R. (1980). Ultrastructural changes in pre- and post-rigor beef muscle caused by conventional and microwave cookery. *Meat Science*, 4(4), 299-311. http://dx.doi.org/10.1016/0309-1740(80)90029-7. PMid:22055771.

Isiuku, B. O., & Enyoh, C. E. (2020). Pollution and health risks assessment of nitrate and phosphate concentrations in water bodies in South Eastern, Nigeria. *Environmental Advances*, 2, 100018. http://dx.doi.org/10.1016/j.envadv.2020.100018.

Kaewthong, P., Wattanachant, C., & Wattanachant, S. (2021). Improving the quality of barbecued culled-dairy-goat meat by marination with plant juices and sodium bicarbonate. *Journal of Food Science and Technology*, 58(1), 333-342. http://dx.doi.org/10.1007/s13197-020-04546-8. PMid:33505077.

Kang, Z., Li, B., Ma, H., & Chen, F. (2016). Effect of different processing methods and salt content on the physicochemical and rheological properties of meat batters. *International Journal of Food Properties*, 19(7), 1604-1615. http://dx.doi.org/10.1080/10942912.2015.1105819.

Kang, Z., Zhang, X., Li, K., Li, Y., Lu, F., Ma, H., Song, Z., Zhao, S., & Zhu, M. (2021). Effects of sodium bicarbonate on gel properties, water distribution and mobility of low-salt pork batters. *Lebensmittel-Wissenschaft + Technologie*, 139, 110567. http://dx.doi.org/10.1016/j.lwt.2020.110567.

Kauffman, R. G., Van Laack, R. L., Russell, R. L., Pospiech, E., Cornelius, C. A., Suckow, C. E., & Greaser, M. L. (1998). Can pale, soft, exudative pork be prevented by postmortem sodium bicarbonate injection? *Journal of Animal Science*, 76(12), 3010-3015. http://dx.doi.org/10.2527/1998.76123010x. PMid:9928605.

Lee, N., Sharma, V., Brown, N., & Mohan, A. (2015). Functional properties of bicarbonates and lactic acid on chicken breast retail display properties and cooked meat quality. *Poultry Science*, 94(2), 302-310. http://dx.doi.org/10.3382/ps/peu063. PMid:25589078.

Leng, L., Zhang, W., Li, H., Bogush, A. A., Stegemann, J. A. & Huang, H. (2021). The impact of the particle size of meat and bone meal (MBM) incineration ash on phosphate precipitation and phosphorus recovery. *Journal of Environmental Chemical Engineering*, 9(3), 105247. http://dx.doi.org/10.1016/j.jece.2021.105247.

Li, Y. P., Zhang, X. H., Lu, F., & Kang, Z. L. (2021). Effect of sodium bicarbonate and sodium chloride on aggregation and conformation of pork myofibrillar protein. *Food Chemistry*, 350(8), 129233. http://dx.doi.org/10.1016/j.foodchem.2021.129233. PMid:33592363.

Lu, F., Kang, Z. L., Wei, L. P., & Li, Y. P. (2021). Effect of sodium bicarbonate on gel properties and protein conformation of phosphorus-free chicken meat batters. *Arabian Journal of Chemistry*, 14(2), 102969. http://dx.doi.org/10.1016/j.arabjc.2020.102969.

Madhusankha, G., & Thilakarathna, R. (2021). Meat tenderization mechanism and the impact of plant exogenous proteases: a review. *Arabian Journal of Chemistry*, 14(2), 102967. http://dx.doi.org/10.1016/j.arabjc.2020.102967.

Mohan, A., Jaico, T., Kerr, W. L., & Singh, R. K. (2016). Functional properties of bicarbonates on physicochemical attributes of ground beef. *Lebensmittel-Wissenschaft + Technologie*, 70, 333-341. http://dx.doi.org/10.1016/j.lwt.2016.02.053.

Offer, G., & Knight, P. (1988). The structural basis of water-holding in meat. Part 2: drip losses. In R. A. Lawrie (Ed.), *Developments in meat science* (Vol. 4, pp. 173-243). London: Elsevier Applied Science.

Petracci, M., Bianchi, M., Mudalal, S., & Cavani, C. (2013). Functional ingredients for poultry meat products. *Trends in Food Science & Technology*, 33(1), 27-39. http://dx.doi.org/10.1016/j.tifs.2013.06.004.

Petracci, M., Laghi, L., Rimini, S., Rocculi, P., Capozzi, F., & Cavani, C. (2014). Chicken breast meat marinated with increasing levels of sodium bicarbonate. *Journal of Poultry Science*, 51(2), 206-212. http://dx.doi.org/10.2141/jpsa.0130079.

Pinton, M. B., Santos, B., Lorenzo, J. M., Cichoski, A. J., & Campagnol, P. (2020). Green technologies as a strategy to reduce nacl and phosphate in meat products: an overview. *Current Opinion in Food Science*, 40, 1-5.

Saito, H., Araki, Y., Katsuno, H., & Nakada, T. (2021). Phase transition of amorphous calcium phosphate to calcium hydrogen phosphate dihydrate in simulated body fluid. *Journal of Crystal Growth*, 553, 125937. http://dx.doi.org/10.1016/j.jcrysgro.2020.125937.

Saleem, R., Hasnain, A. U., & Ahmad, R. (2015). Changes in some biochemical indices of stability of broiler chicken actomyosin at different levels of sodium bicarbonate in presence and absence of sodium chloride. *International Journal of Food Properties*, 18(6), 1373-1384. http://dx.doi.org/10.1080/10942912.2014.917661.

Sindelar, J. J., Prochaska, F., Britt, J., Smith, G. L., Miller, R. K., Templeman, R., & Osburn, W. N. (2003). Strategies to eliminate atypical flavours and aromas in sow loins. I. Optimization of sodium tripolyphosphate, sodium bicarbonate, and injection level. *Meat Science*, 65(4), 1211-1222. http://dx.doi.org/10.1016/S0309-1740(03)00027-5. PMid:22063763.

Skurray, G. R., Perkes, J. M., & Duff, J. (1986). Effect of marinading with wine, sodium bicarbonate or soysauce on the thiamin content of beef. *Journal of Food Science*, 51(4), 10591060. http://dx.doi.org/10.1111/j.1365-2621.1986.tb11231.x.

Sultana, A., Huque, K., & Amanullah, S. (2009). Development of tasty marinating kit for tenderization and preservation of beef chuck. *The Bangladesh Veterinarian*, 26(1), 23-30. http://dx.doi.org/10.3329/bvet.v26i1.4628.

Wachirasiri, K., Wanlapa, S., Uttapap, D., Puttanlek, C., & Rungsardthong, V. (2016). Changing in processing yield and physical properties of frozen white shrimp (*penaeus vannamei*) treated with lysine and sodium bicarbonate. *International Journal of Food Science & Technology*, 52(3), 763-771. http://dx.doi.org/10.1111/ijfs.13333.

Woelfel, R. L., & Sams, A. R. (2001). Marination performance of pale broiler breast meat. *Poultry Science*, 80(10), 1519-1522. http://dx.doi.org/10.1093/ps/80.10.1519. PMid:11599713.

Xiong, G., Fu, X., Pan, D., Qi, J., Xu, X., & Jiang, X. (2020). Influence of ultrasound-assisted sodium bicarbonate marination on the curing efficiency of chicken breast meat. *Ultrasonics Sonochemistry*, 60, 104808. http://dx.doi.org/10.1016/j.ultsonch.2019.104808. PMid:31568999.

Zhu, D., Kang, Z., Ma, H., Xu, X., & Zhou, G. (2018). Effect of sodium chloride or sodium bicarbonate in the chicken batters: A physico-chemical and raman spectroscopy study. *Food Hydrocolloids*, 83, 222-228. http://dx.doi.org/10.1016/j.foodhyd.2018.05.014.

Zou, Y., Shi, H., Xu, P., Jiang, D., Zhang, X., Xu, W., & Wang, D. (2019). Combined effect of ultrasound and sodium bicarbonate marination on chicken breast tenderness and its molecular mechanism. *Ultrasonics Sonochemistry*, 59, 104735. http://dx.doi.org/10.1016/j.ultsonch.2019.104735. PMid:31442769.