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ARTICLE

Effects of Pre and Post-Rigor Marinade Injection on Some Quality Parameters of *Longissimus Dorsi* Muscles

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Abstract This study was conducted to evaluate the effects of pre and post-rigor marinade injections on some quality parameters of *Longissimus dorsi* (LD) muscles. Three marinade formulations were prepared with 2% NaCl, 2% NaCl+0.5 M lactic acid and 2% NaCl+0.5 M sodium lactate. In this study marinade uptake, pH, free water, cooking loss, drip loss and color properties were analyzed. Injection time had significant effect on marinade uptake levels of samples. Regardless of marinate formulation, marinade uptake of pre-rigor samples injected with marinade solutions were higher than post rigor samples. Injection of sodium lactate increased pH values of samples whereas lactic acid injection decreased pH. Marinade treatment and storage period had significant effect on cooking loss. At each evaluation period interaction between marinade treatment and injection time showed different effect on free water content. Storage period and marinade application had significant effect on drip loss values. Drip loss in all samples increased during the storage. During all storage days, lowest CIE L* value was found in pre-rigor samples injected with sodium lactate. Lactic acid injection caused color fade in pre-rigor and post-rigor samples. Interaction between marinade treatment and storage period was found statistically significant (p<0.05). At day 0 and 3, the lowest CIE b* values obtained pre-rigor samples injected with sodium lactate and there were no differences were found in other samples. At day 6, no significant differences were found in CIE b* values of all samples.

Keywords marination, pre-rigor, post-rigor, storage, meat quality

Introduction

Meat tenderness is one of the most important factors affecting palatability. Several factors influence meat tenderness such as ultimate pH, chilling temperature of carcasses, connective tissue and enzymatic proteolysis (Kim et al., 2013).

In order to improve meat tenderness, a number of meat tenderizing methods have

been tried as antemortem or postmortem treatments. Electrical stimulation, proteolytic enzyme application, aging, pressure cooking and marination are postmortem treatments in order to improve meat tenderness (Maiti et al., 2008).

Marination is one of the postmortem treatment that improves meat tenderness, flavor and juiciness to satisfy consumer demand (Lemos et al., 1999). Marination is based on processing of meat with acidic or alkaline solutions and modification of physical and chemical properties of meat by altering the meat pH from isoelectric point (Sheard and Tali, 2004).

When the pH of a muscle decreases, reaching the isoelectric point (pI) of approximate pH 5.3, the protein repulsion would be at the lowest point indicating the equal amounts of positive and negative charges. As the pH becomes more acidic the balance of charges is disrupted by an increase in positive charges, causing repulsion. The same process occurs with negative charges when the pH becomes more basic. As the pH of the meat is altered away from the pI, with the use of marinade solution, charges begin to free themselves causing repulsion of the meat fibers, and the free charges begin to attract water (Baczwaski and Mondigo, 2003).

Today in meat industry, various marination techniques are applied with different processing methods to improve the tenderness, water holding capacity and flavor. In marination of beef, poultry, fish and other seafood, lemon juice, vinegar, wine, yogurt, and milk are used as a marination components as well as additives such as fat, sugar, spices, salt and phosphates (Ö nenç et al., 2004; Oreskovich et al., 1992; Serdaroğlu et al., 2007).

Marination mixtures can be applied to the meat through soaking, injection or vacuum tumbling, depending on the type of meat product, and marination time changes usually between 1 to 24 h, critical point in marination procedure is the uniform dispersion of marinade ingredients into muscle (Brandt, 2003; Xargayó et al., 2001). The efffects of acidic marinades on meat texture depend on pH drop; this has been related to the combination of three mechanisms: dilution of the load-bearing material due to the swelling of myofibrils, weakening of the perimysial membrane and acceleration of the postmortem tenderization (Berge et al., 2001). The pH values obtained in the meat are generally low (between 5 and 3 depending upon the acid concentration used) thus leading to considerable swelling of fibrils.

Most of the works published on acid treatments applied to beef are on marination in acetic and citric acids (Burke and Monohan, 2003; Goli et al., 2014; Hosseini and Mehr, 2015; Ke et al., 2009; Komoltri and Pakdeechanuan, 2012; Ö nenç et al., 2004; Yusop et al., 2010). In the few works lactic acid (LA) was used (Aktaş and Kaya, 2001; Berge et al., 2001; Sawyer et al., 2008).

Alkaline marinades are generally used in meat products to enhance tenderness, water holding capacity and to improve cooking yield. One important characteristic of alkaline marinades is their ability to move meat pH away from the isoelectric range, thus increasing the proportion of negative charges on the meat proteins, and improving tenderness and water holding capacity.

Many reports have shown reductions in mechanical shear force and significant improvements in flavour, juiciness, and tenderness measured by taste panels with the injection of alkaline marinades (Ke et al., 2009; Pietrasik and Shand, 2004; Robbins et al., 2002; Vote et al., 2000). Most commonly used ingredients in alkaline marinades are phosphates and lactates. Vote et al. (2000) injected sodium tripolyphosphate, sodium lactate, sodium chloride into strip loins muscle and significantly improved tenderness and juiciness when compared to non-injected controls. Previous studies suggest that injecting beef with solutions containing salt, sodium tripolyphosphate, and sodium lactate not only improves tenderness (Papadopoulos et al., 1991b), but also enhances beef flavor (Lamkey et al., 1993; Papadopoulos et al., 1991a,b).

Vote et al. (2000) injected sodium tripolyphosphate, sodium lactate, sodium chloride into strip loins muscle and significantly improved tenderness and juiciness when compared to non-injected controls. Previous studies suggest that

injecting beef with solutions containing salt, sodium tripolyphosphate, and sodium lactate not only improves tenderness (Papadopoulos et al., 1991b), but also enhances beef flavor (Lamkey et al., 1993; Papadopoulos et al., 1991a;b).

Burke and Monahan's (2003) study has shown that acid marination increased meat tenderness. Sawyer et al. (2007) suggested that LA enhancement can reduce muscle pH and improve the cooked beef color/degree of doneness of dark cutting beef.

Although extensive research describes beneficial effects of alkaline and acidic marinates on eating quality of meat there is a lack of information about the effects of pre or postrigor marination on meat quality. Therefore, the objective of this study was to investigate the effects of pre or postrigor injection of salt/ lactic acid and salt/sodium lactate marinades solutions on quality characteristics of *Longissimus dorsi* (LD) muscles.

When the pH of a muscle decreases, reaching the isoelectric point of approximate pH 5.3, the protein repulsion would be at the lowest point indicating the equal amounts of positive and negative charges. As the pH becomes more acidic the balance of charges is disrupted by an increase in positive charges, causing repulsion. The same process occurs with negative charges when the pH becomes more basic.

Materials and Methods

Five Holstein cows (17-18 mon of age, 950-1,000 kg body weight) were slaughtered at an average carcass weight of 500-550 kg. LD muscles from left side were removed after 1 h and right side after 24 h of slaughtering. Muscles were trimmed of excess fat before marination procedure. Left sides were stored at +4°C for 24 h before the injection treatment. Right sides were used for pre-rigor injection after 1 h after the slaughter. Food-grade salt (sodium chloride), sodium lactate (Purasal S-Purac, Netherlands) and lactic acid (Merck, Germany) were used to prepare the marinade solutions. Three different marinade solutions were prepared (2% NaCl, 2% NaCl+0.5 M Lactic acid and 2% NaCl+0.5 M Sodium lactate) by using double distilled water at 20°C.

The 15 left (1 h) and 15 right (24 h) muscles were randomly allotted into six different treatment groups of sodium chloride injection at 1 h postmortem (C1) and at 24 h postmortem (C24), lactic acid+sodium chloride injection at 1 h postmortem (LA1) and at 24 h postmortem (LA24), sodium lactate+sodium chloride injection at 1 h postmortem (SL1) and at 24 h postmortem (SL24). Experimental design is given in Table 1.

The muscles were injected with marinade solutions (11% (v/w)) using a multi-needle injector by using multi needle injector (Fomaco-Danimark). The injection was performed at 3 depths (50 mL/level) with approximately 5 mm between

Table 1. Experimental design

Samples	
Marinate injection (1 h)	Marinade injection (24 h)
2% NaCl (C1)	2% NaCl (C24)
2% NaCl+0.5 M Lactic Acid (LA1)	2% NaCl+0.5 M Lactic Acid (LA24)
2% NaCl+0.5 M Sodium Lactate (SL1)	2% NaCl+0.5 M Sodium Lactate (SL24)

Free water, drip loss, cooking loss and color analyzes were conducted on days 0 (24 hour after the marination process), 3 and 6 of storage.
Sample denomination; C1, 2% NaCl injected at 1 h; LA1, 2% NaCl+0.5 M Lactic Acid injected at 1 h; SL1, 2% NaCl+0.5 M Sodium Lactate injected at 1 h; C24, 2% NaCl injected at 24 h; LA24, 2% NaCl+0.5 M Lactic Acid injected at 24 h; SL24, 2% NaCl+0.5 M Sodium Lactate injected at 24 h.

injection points. For stable distribution of marinade solutions, samples were kept at 4℃ for 24 h than placed in the polystyrene foam box were wrapped with PVC film (stretch film) and were stored at +4℃ for 6 d.

pH measurement

Marinade pH and pH of meat samples were measured before and after marination (Burke and Monahan, 2003). The pH of meat homogenates, prepared by blending 5 g of sample with 50 mL of distilled water for 1 min using a Waring blender, was measured using a pH meter (Inolab pH 720 WTW-Germany).

Marinade uptake

Following marination, excess marinade was removed by applying paper towel to the sample (whole muscle) surfaces and % marinate uptake was calculated from the weight of samples taken before and after margination (Young and Smith, 2004). Calculation for marinade uptake was as follows:

$$\%marinade\ uptake = \frac{marinated\ weight\ -\ raw\ weight}{raw\ weight} \times 100$$

Free water

Water holding capacity measurement; A filter press technique was used to determine water holding capacity (WHC) of cooked samples (Zayas and Lin, 1998). Lower values indicate better water holding capacity.

Cooking loss

Cooking loss was calculated from the weight of the slices taken before and after cooking (Hoffman et al., 2008). Samples were cut into 1 cm thick for evaluating cooking loss. Than cooked by placing in plastic bags and immersing in a water bath at 80℃ 1 h then cooled to room temperature and weighed.

Cooking loss (g/100 g)=Marinated weight–cooked weight / marinated weight×100

Drip loss

Samples were weighed and individually placed in polystyrene foam plate, packaged with PVC film (stretch film) and stored at +4℃ for 6 d. The fillets were patted dry and weighed at 3rd and 6th day of storage for drip loss determination. During the storage of meat samples, the amount of drip loss was measured according to Bloukas et al. (1997). The drip loss was calculated as a percentage of the difference between two measurements to initial weight.

Drip loss=$100\times(wt_m-wt_d)/wt_m$

wt_m=Marinated weight

wt_d=Weight after dripping

Color

CIE color parameters (CIE L*, CIE a*, CIE b*) of marinated meats were measured by using Minolta 508-D

spectrocolorimeter (USA) and were performed on 0th, 3rd and 6th days of storage. Before each measurement, the apparatus was standardized against a black and white tile. Four readings were taken for each treatment.

Statistical analysis

Analysis of variance (ANOVA) was performed on the data to determine any significant difference ($p<0.05$) among or within the different marination groups using SPSS for windows; advanced statistics release 11.5. Analysis of variance of all data was conducted using the Duncan's Multiple Rang test.

Results and Discussion

pH values of marinade solutions and samples

Meat pH is an important factor affecting meat tenderness and the effect is greatly associated with water holding capacity. The effects of various marinade treatments on pH values are shown in Table 2. pH values were affected by marinade formulation. Lactic acid marinade has a low pH resulted a decrement in meat pH from 7.4 to 4.7. Lactic acid marination applied after 1 hour and 24-hour lead to decrease in pH of these samples below to isoelectric point. Previous studies have reported that the use of organic acids, including citric and lactic acids, within marinades leads to a decrease in the pH value of marinated meat (Aktaş et al., 2003; Ke et al., 2009; Serdaroğlu et al., 2007). Most of the works published on acid treatments applied to beef are on marination in acetic acid. The pH values obtained in the meat were generally low (between 5 and 3 depending upon the acid concentration used) leading to considerable swelling of the meat. Medyński et al. (2000) found that using lactic acid marinades at higher than 1% concentrations at normal pH caused to decrease in pH value of beef and pork samples to 4.25-3.90. In the few works using lactic acid like our study, it was injected pre-rigor and the final meat pH values were generally higher than those obtained with acetic acid (4.5 or more), suggesting meat swelling was limited. Claus and Sorheim (2006) found that pH value of pre-rigor muscles injected with NaCl was higher than post rigor injected muscles. Injection time (pre-rigor or post-rigor) had no effect on pH. Claus and Sorheim (2006) found that pH value of pre-rigor muscles injected with NaCl was higher than post rigor injected muscles. Fischer et al. (1982) reported that pH reduction rate in meat samples which is injected salt prior to rigor was slow. Berge et al. (2001) found that the pH values were 5.1 and 4.9 respectively, by injection of 0.5 M lactic acid into *Pectoralis profundus* muscles 1 h and 24 h after slaughter. There was no significant difference between the pH values of samples marinated with lactic acid solution after 1 (prerigor) and 24

Table 2. PH values of marinade solutions and muscles before and after margination

Sample	Marinade pH	pH-before marination	pH-after marination
C1	$7.4^{c}\pm0.04$	$6.7^{a}\pm0.10$	$5.6^{b}\pm0.02$
LA1	$2.0^{a}\pm0.15$	$6.7^{a}\pm0.08$	$4.7^{a}\pm0.30$
SL1	$6.9^{b}\pm0.00$	$6.6^{a}\pm0.07$	$5.4^{b}\pm0.06$
C24	$7.3^{c}\pm0.16$	$5.5^{b}\pm0.03$	$5.4^{b}\pm0.33$
LA24	$2.1^{a}\pm0.14$	$5.3^{b}\pm0.10$	$4.7^{a}\pm0.35$
SL24	$7.0^{b}\pm0.42$	$5.5^{b}\pm0.11$	$5.4^{b}\pm0.16$

[a-c] Means with the different letter in the same column are significantly different ($p<0.05$).
Sample denomination; C1, 2% NaCl injected at 1 h; LA1, 2% NaCl+0.5 M Lactic Acid injected at 1 h; SL1, 2% NaCl+0.5 M Sodium Lactate injected at 1 h; C24, 2% NaCl injected at 24 h; LA24, 2% NaCl+0.5 M Lactic Acid injected at 24 h; SL24, 2% NaCl+0.5 M Sodium Lactate injected at 24 h.

(postrigor) hours. Similar results have been reported by Morris et al. (1997). The investigators found that there was no significant difference between the pH values of samples injected $CaCl_2$ and lactic acid immediately after slaughter and 24 h later. Although the pH value of marinates containing lactic acid was 2.0, the pH values of LA1 and LA24 samples did not fall below pH 4.7 and it is considered that NaCl in the formulation inhibits the decreasing of pH by affecting the reactive groups of the proteins. Medyński et al. (2000) reported that 1.5% lactic acid marination in the presence of salt limited the interaction of meat proteins with lactic acid and pH did not decrease further after this time.

In SL1 and SL24 samples the pH value was found to be 5.4. Mancini et al. (2009) reported that injections of 1.5% and 2.5% lactate solution did not affect the pH value of *Longissimus lombarum* and Psoas major muscles.

Marinade uptake

Carcass part and meat type should have significant effect on marinade uptake of the meat samples (Serdaroğlu et al., 2007). Marinade uptake levels were changed between 4.6 to 9.7% (Table 3). Regardless of marinate formulation, marinade uptake of prerigor samples injected with marinade solutions were higher than postrigor samples ($p<0.05$). This may be due to the high water binding capacity of the meat prior to rigor.

The lowest marinade uptake was found in LA24 samples (pH 4.8) with the lowest pH value. The highest marinade uptake was obtained in samples prerigor injection of lactic acid marinade. Likewise, Ö nenç et al. (2004) have indicated that 0.5% citric acid marination did not cause significant weight gain in cattle. Burke and Monahan (2003) reported that marinating cattle with 0.05 M citric acid solution caused significant increase in sample weight.

Increasing lactic acid concentration from 1% to 2% resulted significant increment in marinade uptake (Sawyer et al., 2008). There was no significant difference in marine uptake between acidic marinate or basic marinate.

Expressible moisture

The sensory and technological properties of meat products depend on the ability of the muscle tissue to bind and retain water and gel formation capacity. All of these properties vary in relation to the changes that occur after slaughtering and the materials applied to the meat during technological processing (Medyński et al., 2000). In this study, water holding capacity was calculated as expressible moisture.

Changes in free water content of samples are seen in Table 4. At each evaluation period interaction between marinade

Table 3. Marinade uptake of muscles marinated after 1 and 24-hour postmortem time

Sample[1)]	Marinade uptake (%)
C1	6.0^{b}±0.88
LA1	9.7^{c}±0.30
SL1	9.2^{c}±0.26
C24	5.5^{ab}±0.33
LA24	4.6^{a}±0.07
SL24	5.3^{ab}±0.21

[a-c] Means with the different letter in the same column are significantly different ($p<0.05$).
[1)] Sample denomination; C1, 2% NaCl injected at 1 h; LA1, 2% NaCl+0.5 M Lactic Acid injected at 1 h; SL1, 2% NaCl+0.5 M Sodium Lactate injected at 1 h; C24, 2% NaCl injected at 24 h; LA24, 2% NaCl+0.5 M Lactic Acid injected at 24 h; SL24, 2% NaCl+0.5 M Sodium Lactate injected at 24 h.

Tablo 4. Free water changes during storage of marinated samples

Sample[1)]	Day 0	3rd day	6th day
C1	44.21^{dy}±1.12	53.80^{ez}±1.27	55.10^{ez}±1.70
LA1	42.10^{bx}±0.90	43.15^{cy}±0.89	42.92^{cy}±1.06
SL1	43.26^{cy}±0.88	44.07^{dy}±0.95	43.22^{cy}±1.05
C24	41.12^{bx}±1.14	41.91^{bx}±0.75	39.72^{ax}±0.35
LA24	41.60^{bx}±1.17	43.85^{cy}±0.98	42.48^{bx}±0.47
SL24	46.54^{dz}±0.96	44.33^{dy}±1.13	43.43^{cy}±0.79

[a-c] Means with the different letter in the same column are significantly different (p<0.05).
[x-z] Means with the different letter in the same row are significantly different (p<0.05).
[1)] Sample denomination; C1, 2% NaCl injected at 1 h; LA1, 2% NaCl+0.5 M Lactic Acid injected at 1 h; SL1, 2% NaCl+0.5 M Sodium Lactate injected at 1 h; C24, 2% NaCl injected at 24 h; LA24, 2% NaCl+0.5 M Lactic Acid injected at 24 h; SL24, 2% NaCl+0.5 M Sodium Lactate injected at 24 h.

treatment and injection time showed different effect on free water content. At day 0, the highest free water (lowest WHC) was obtained in post-rigor samples injected with sodium lactate however on the other storage days no differences were obtained in free water content of lactic acid and sodium lactate injected samples. On the 3rd and 6th d of storage, the highest free water contents were recorded in C1 samples, 53.8% and 55.1%, respectively. Post rigor meat has decreased spacing between filaments and decreased protein functionality; therefore, less free water was retained. The difference in the free water contents of the samples in these study is due to the difference in the pH values of the samples. Since the pH values of the SL24 samples having the highest free water content on day 0 were close to the isoelectric point (pH 5.36), these samples were found to have the lowest water retention capacity. During the storage period decrement in free water was recorded in all samples except SL24 samples. In general, as the pH of meat approaches to isoelectric point (pH 5.0–5.1), the net charge and hence the number of water molecules which is combine with them decreases.

In many studies, it was found that an increase in water holding capacity of meat marinated with 1.5% lactic acid had been due to low pH value (Rao et al., 1989). In these studies, it has been reported that the effect of acid on the tissues at the pH values below the isoelectric point of meat proteins was dependent on the type of muscle tissue as well as the final acidity value. The pH value between 4-4.5 caused the swelling of the white muscle fibers, as opposed to the red muscle fibers and collagen surrounding the perimysium and the epimysium (Rao et al., 1989).

Cooking loss

Marinade treatment and storage period had significant effect on cooking loss (p<0.05). The lowest cooking loss (34.4) was obtained in pre-rigor samples injected with lactic acid and the highest value (37.8) was obtained in pre-rigor samples injected with 2% NaCl (C1) at the beginning of storage. The highest cooking losses were found in C1 and C24 samples at all storage periods. Similar to our results Omojola (2007) presented that marinade injection time after slaughter has effect on cooking losses.

Wheeler et al. (1992) found that cooking losses were higher in post rigor samples injected with $CaCl_2$ than prerigor samples. In contrast to these results, Choi et al. (1984) found that a 10% increase in cooked yield in roughly ground bovine *Triceps brachii* muscles treated with 3% NaCl before rigor. Claus and Sorheim (2006) reported that the cooking efficiency increased by 6% in *Semimembranosus* muscles injected with salt before rigor.

Storage period had also significant effect on cooking loss of samples (p<0.05). However, each marination treatment had different effects during storage period. Cooking losses were not different on storage days in postrigor samples injected with 2% NaCl solution, while cooking losses were decreased in other sample groups in the later days of storage.

Wenham and Locker (1976) observed an increase in cooked yield when the pH was decreased from 4.4 to 4.1 by lactic acid or acetic acid marination of beef. It has been showed that applying different marinade techniques effected cooking losses of the samples. Medyński et al. (2000) noted that increasing the lactic acid concentration above 0.5% in meat reduced the heat treatment losses and increased water retention capacity. Researchers suggested that the effect of lactic acid on water holding capacity was greater than that of sodium chloride.

Cooking losses were not different in samples injected with 2% NaCl before and after rigor in each period of storage. Wheeler et al. (1993) found that cooking losses of post rigor *Longissimus* muscles injected with 10%(w/w) $CaCl_2$ were higher than control samples.

Many studies have showed that moisture loss decreased during cooking due to the pH drop in beef meat (Aktaş and Kaya, 2001; Aktaş et al., 2003; Gault, 1984; 1985; Ö nenç et al., 2004).

Drip loss

The amount of drip loss during storage of fresh meat is closely related to the pH value and ionic strength of meat system, when pH increased, the amount of drip loss reduced, and the amount of drip loss is lowest at pH 6.4 (Hamm and Deatherage, 1960).

Drip loss of samples are seen in Table 5. Drip loss of samples during the storage changed between 1.6 to 7.9%. Storage period and marinade application had significant effect on drip loss values (p<0.05). No differences were recorded on the first day of storage. At day 6, the highest drip loss was found in control samples and the lowest drip loss was found in samples injected with sodium lactate.

On the 3rd day of storage, highest amount of drip was observed in pre-rigor samples injected with sodium lactate and lowest amount of drip was observed in pre and postrigor of samples injected with NaCl. It was observed that drip loss in all

Table 5. Cooking loss and drip loss of marinated samples during storage

	Cooking loss of marinated samples			Drip loss of marinated samples		
Sample[1)]	Day 0	3rd day	6th day	Day 0	3rd day	6th day
C1	37.80^{dx}±0.00	36.40^{cy}±0.88	36.12^{dy}±0.80	2.25^{ax}±0.34	5.01^{dy}±0.79	7.79^{ez}±0.81
LA1	34.40^{ax}±0.10	34.90^{bx}±0.29	29.42^{ay}±0.26	2.43^{ax}±0.90	5.81^{dy}±0.56	7.40^{ez}±0.68
SL1	35.31^{bx}±0.90	35.10^{bx}±0.95	32.82^{by}±0.81	1.87^{ax}±0.36	5.68^{dy}±0.60	7.60^{ez}±0.73
C24	36.82^{cx}±1.14	36.11^{cx}±0.71	35.90^{dx}±0.35	2.27^{ax}±0.82	4.14^{cxy}±1.01	5.83^{dy}±0.93
LA24	35.90^{bx}±0.17	34.62^{by}±0.98	34.40^{cy}±0.47	2.23^{ax}±0.16	4.20^{cxy}±0.33	5.73^{dy}±0.31
SL24	34.84^{bx}±0.69	33.91^{ay}±0.78	33.50^{by}±0.74	1.90^{ax}±0.13^{a}	3.18^{by}±0.38^{b}	4.59^{cxy}±0.37

[a-d] Means with the different letter in the same column are significantly different (p<0.05).
[x-z] Means with the different letter in the same row are significantly different (p<0.05).
[1)] Sample denomination; C1, 2% NaCl injected at 1 h; LA1, 2% NaCl+0.5 M Lactic Acid injected at 1 h; SL1, 2% NaCl+0.5 M Sodium Lactate injected at 1 h; C24, 2% NaCl injected at 24 h; LA24, 2% NaCl+0.5 M Lactic Acid injected at 24 h; SL24, 2% NaCl+0.5 M Sodium Lactate injected at 24 h.

samples increased during the storage.

Lawrence et al. (2003) investigated the effect of calcium chloride, calcium lactate in *Longissimus* muscle of cattle and they found that the amount of drip loss in samples marinated with calcium chloride and calcium lactate was higher than the control samples during 5 days of storage.

Amount of drip loss in fresh meat during storage period is closely related with pH and ionic power of meat system. Water binding capacity of muscle is lowest at pH 5.4 and this point is isoelectric point of actomyosin. Drip loss decrease when pH increase, drip loss is lowest at pH 5.4.

Color values of marinated cooked samples

Color values of samples could be seen in Table 6, 7, and 8. The results show that significant differences were obtained in color parameters depending on marinate formulation. During storage period no significant change were observed in CIE L* values of C1, LA1, SL24 samples.

CIE L* values have affected differently from marination treatment regardless of storage period ($p<0.05$). At day 0, the lowest CIE L* value (41.8) was found in prerigor samples injected with sodium lactate, the highest CIE L* value (46.3) was found in postrigor samples injected with lactic acid. Lactic acid injection caused color fade in pre-rigor and post rigor

Table 6. CIE L* values of marinated, cooked samples

Sample[1)]	Day 0	3rd day	6th day
C1	$42.0^{bx}\pm0.54$	$43.0^{bx}\pm0.23$	$42.4^{bx}\pm0.59$
LA1	$45.5^{dx}\pm0.66$	$45.9^{dx}\pm0.28$	$46.2^{dx}\pm0.17$
SL1	$41.8^{ax}\pm0.80$	$39.6^{ay}\pm0.52$	$40.6^{ay}\pm0.52$
C24	$44.4^{dx}\pm0.31$	$48.3^{ey}\pm0.34$	$48.0^{ey}\pm0.21$
LA24	$46.3^{dx}\pm0.37$	$44.9^{cy}\pm0.47$	$46.1^{cx}\pm0.71$
SL24	$43.3^{cx}\pm0.33$	$44.5^{cx}\pm0.61$	$44.8^{cx}\pm0.18$

[a-e] Means with the different letter in columns are significantly different ($p<0.05$).
[x-z] Means with the different letter in rows are significantly different ($p<0.05$).
[1)] Sample denomination; C1, 2% NaCl injected at 1 h; LA1, 2% NaCl+0.5 M Lactic Acid injected at 1 h; SL1, 2% NaCl+0.5 M Sodium Lactate injected at 1 h; C24, 2% NaCl injected at 24 h; LA24, 2% NaCl+0.5 M Lactic Acid injected at 24 h; SL24, 2% NaCl+0.5 M Sodium Lactate injected at 24 h.

Table 7. CIE a* values of cooked samples marinated after 1 and 24 hour postmortem time

Sample[1)]	Day 0	3rd day	6th day
C1	$6.4^{cy}\pm0.19$	$6.1^{cxy}\pm0.28$	$6.2^{cy}\pm0.21$
LA1	$4.9^{ay}\pm0.13$	$4.8^{axy}\pm0.07$	$4.4^{ay}\pm0.11$
SL1	$5.8^{cy}\pm0.13$	$5.8^{cxy}\pm0.31$	$5.9^{cy}\pm0.23$
C24	$6.4^{cx}\pm0.33$	$6.0^{cxy}\pm0.31$	$5.1^{cx}\pm0.10$
TL24	$5.9^{by}\pm0.02$	$5.1^{bx}\pm0.49$	$4.6^{bx}\pm0.61$
TSL24	$5.6^{cy}\pm0.57$	$5.9^{cxy}\pm0.25$	$6.1^{cx}\pm0.33$

[a-c] Means with the different letter in the same column are significantly different ($p<0.05$).
[x-y] Means with the different letter in the same row are significantly different ($p< 0.05$).
[1)] Sample denomination; C1, 2% NaCl injected at 1 h; LA1, 2% NaCl+0.5 M Lactic Acid injected at 1 h; SL1, 2% NaCl+0.5 M Sodium Lactate injected at 1 h; C24, 2% NaCl injected at 24 h; LA24, 2% NaCl+0.5 M Lactic Acid injected at 24 h; SL24, 2% NaCl+0.5 M Sodium Lactate injected at 24 h.

Table 8. CIE b* values of cooked samples marinated after 1 and 24 hour postmortem time

Sample[1)]	Day 0	3rd day	6th day
C1	14.3^{by}±0.13	14.8^{by}±0.15	13.5^{ax}±0.68
LA1	14.8^{by}±0.25	14.4^{by}±0.40	13.7^{ax}±0.01
SL1	13.5^{ay}±0.25	13.7^{ay}±0.39	13.1^{ax}±0.61
C24	15.2^{by}±0.35	14.7^{by}±0.42	13.9^{ax}±0.42
TL24	15.1^{by}±0.48	14.4^{by}±0.48	13.7^{ax}±0.63
TSL24	14.9^{by}±0.26	14.6^{by}±0.12	13.6^{ax}±0.30

[a-c] Means with the different letters in the same column are significantly different (p<0.05).
[x-y] Means with the different letters in the same row are significantly different (p<0.05).
[1)] Sample denomination; C1, 2% NaCl injected at 1 h; LA1, 2% NaCl+0.5 M Lactic Acid injected at 1 h; SL1, 2% NaCl+0.5 M Sodium Lactate injected at 1 h; C24, 2% NaCl injected at 24 h; LA24, 2% NaCl+0.5 M Lactic Acid injected at 24 h; SL24, 2% NaCl+0.5 M Sodium Lactate injected at 24 h.

samples. In Table 6, lactic acid treatments increased CIE L* values of meats. This result can be related to denaturation of myoglobin by lactic acid and due to decreased pH. Aktaş and Kaya (2001) observed that CIE L* value decreased when lactic acid concentration increased from 0 to 1.5% in cooked beef steak samples. Sawyer et al. (2008) investigated the effect of lactic acid concentration and salt in dark meat and they found that CIE L* value of marinated cooked samples decreased when lactic acid concentration increased.

During all storage days, lowest CIE L* value was found in prerigor samples injected with sodium lactate. Sodium lactate marinade treatment has led to a darker color in samples. The interaction of storage and marinade treatment was found statistically important (p<0.05). It was observed that marinade treatment had different effect on CIE L* values of samples on different days of storage. During storage period, CIE L* values of samples injected with sodium lactate decreased, CIE L* values of samples injected with NaCl increased while CIE L* values of other samples did not change.

Arganosa and Marriott (1989) reported that CIE L* value was higher in cooked samples marinated with lactic acid. At day 6, the highest CIE L* value was found in C24, LA1, LA24 samples.

Marinade formulation effected CIE a* values of samples (p<0.05). It was found that in all storage days CIE a* values of samples injected with lactic acid marinade solutions were lower than other samples regardless of injection time. Lactic acid treatment resulted in reduction of samples.

Interaction between marinade treatment and storage period was found statistically significant (p<0.05), during storage period CIE a* values of all samples did not change except postrigor samples injected with lactic acid. Similar results were obtained by Arganosa and Marriott (1989) and Aktaş and Kaya (2001). They found that lactic acid marinade solutions caused a reduction in CIE a* values of samples. Sawyer et al. (2008) investigated the effects of lactic acid concentration and NaCl in dark meat and they found that when lactic acid concentration increased CIE a* values of marinated cooked meat decreased. Decrease in CIE a* values of samples is due to pigment loss during storage period. CIE a* values of samples injected with sodium lactate were not changed during storage period.

At day 0 and 3, the lowest CIE b* values obtained prerigor samples injected with sodium lactate and there were no differences were found in other samples. At day 6 no significant differences were found in CIE b* values of all samples.

Interaction between marinade treatment and storage was found statistically important (p<0.05). No difference has been found on the CIE b* values of samples at day 6. At 6th day of storage CIE b* values of all samples were found lower than the other days.

Aktaş and Kaya (2001) observed that CIE b* values of cooked beef steak samples decreased when lactic acid concentration

increased from 0 to 1.5%. Sawyer et al. (2008) indicated that CIE b* values of cooked dark slices of beef samples decreased when lactic acid concentration increased from 1% to 2%.

Conclusion

Pre-rigor marinade injection resulted higher marinade absorption and lower cooking losses and higher water holding capacity. Marination with sodium lactate or lactic acid solution can be used successfully to enhance water holding capacity of LD muscles. Pre-rigor and post rigor lactic acid marinade injection tenderized LD muscles. During all storage days, lowest CIE L* and CIE b* values were found in pre-rigor samples injected with sodium lactate. Sodium lactate marination resulted darker color in samples

References

Aktaş N, Kaya, M. 2001. The influence of marinating with weak organic acids and salts on the intramuscular connective tissue and sensory properties of beef. Eur Food Res Technol 213:88-94.

Aktaş N, Aksu Mİ, Kaya M. 2003. The influence of marination with different salt concentrations on tenderness, water holding capacity and bound water content of beef. Turk J Vet Anim Sci 27:1207-1211.

Arganosa GC, Marriott NG. 1989. Organic acids as tenderisers of collogen in restructured beef. J Food Sci 54:1173-1176.

Baczwaski M, Mondigo R. 2003. Ingredient opportunities for case-ready beef. Nebraska Beef Cattle Report.

Berge P, Ertbjerg P, Larsen LM, Astruc T, Vignon X, Møller AJ. 2001. Tenderization of beef by lactic acid ınjected at different times post mortem. Meat Sci 57:347-357.

Bloukas JG, Paneras ED, Fournitzis GC. 1997. Effect of replacing pork backfat with olive oil on processing and quality characteristics of fermented sausages. Meat Sci 45:133-144.

Brandt L. 2003. Marinades “Meat” challenges, Prepared Foods. Available from: https://www.preparedfoods.com/articles/104029-marinades-meat-challenges. Accessed Dec 15. 2017.

Burke RM, Monahan FJ. 2003. The tenderization of shin beef using a citrus juice marinade. Meat Sci 63:161-168.

Choi YI, Kastner CL, Dikeman ME, Hunt MC, Kropf DH. 1984. Effects of electrical stimulation and hot boning on functional characteristics of preblended beef muscle in model systems. J Food Sci 49:867-869.

Claus JR, Sørheim O. 2006. Preserving pre-rigor meat functionality for beef patty production. Meat Sci 73:287-294.

Fischer C, Honikel KO, Hamm R. 1982. Influence of sodium chloride on biochemical changes, water holding capacity and sarcomere length of freshly slaughtered beef muscle. Z Lebensm Unters Forsch 174:447-452.

Gault NFS. 1984. The influence of acetic acid concentration on the efficiency of marinading as a process for tenderizing beef. Proceedings of the 30th European Meeting of Meat Research Workers. pp 184-185.

Gault NFS. 1985. The relationship between water-holding capacity and cooked meat tenderness in some beef muscles as influenced by acidic conditions below the ultimate pH. Meat Sci 15:15-30.

Goli T, Ricci J, Bohuon P, Marchesseau S, Collignan A. 2014. Influence of sodium chloride and pH during acidic marination on water retention and mechanical properties of turkey breast meat. Meat Sci 96:1133-1140.

Hamm R, Deatherage FE. 1960. Changes in hydration, solubility and changes of muscle proteins during heating of meat. J Food Res 25:587-610.

Hoffman LC, Muller M, Vermaak A. 2008. Sensory and preference testing of selected beef muscles infused with a phosphate

and lactate blend. Meat Sci 80:1055-1060.

Hosseini SE, Mehr AE. 2015. The effect of meat marinating with citric acid and lactic acid on some physicochemical and electrophoretic pattern of beef burger. Iran J Vet Med 9:103-108.

Ke S, Huang Y, Decker EA, Hultin HO. 2009. Impact of citric acid on the tenderness, microstructure and oxidative stability of beef muscle. Meat Sci 82:113-118.

Kim HW, Choi YS, Choi JH, Kim HY, Lee MA, Hwang KE, Song DH, Lim YB, Kim CJ. 2013. Tenderization effect of soy sauce on beef *M. biceps femoris*. Food Chem 139:597-603.

Komoltri P, Pakdeechanuan P. 2012. Effects of marinating ingredients on physicochemical, microstructural and sensory properties of golek chicken. Int Food Res J 19:1449-1455.

Lamkey JM, Dunlavy KA, Dolezal HG. 1993. Changes in the palatability of beef chuck muscles with the addition of sodium lactate and soy protein isolate. J Muscle Foods 4:193-206.

Lawrence TE, Dikeman ME, Hunt MC, Kastner CL, Johnson DE. 2003. Effects of calcium salts on beef *longissimus* quality. Meat Sci 64:299-308.

Lemos ALSC, Nunes DRM, Viana AG. 1999. Optimization of the still-marinating of chicken parts. Meat Sci 52:227-234.

Maiti AK, Ahlawat SS, Sharma DP, Khanna N. 2008. Application of natural tenderisers in meat - A review. Agricultural Reviews 29:226-230.

Mancini RA, Suman SP, Konda MKR, Ramanathan R. 2009. Effect of carbon monoxide packaging and lactate enhancement on the color stability of beef steaks stored at 1℃ for 9 days. Meat Sci 81:71-76.

Medyński A, Pospiech E, Kniat R. 2000. Effect of various concentrations of lctic acid and sodium chloride on selected physicochemical meat traits. Meat Sci 55:285-290.

Morris CA, Theis RL, Miller RK, Acuff GR, Savell JW. 1997. Improving the flavor of calcium chloride and lactic acid injected mature beef top round steaks. Meat Sci 45:531-537.

Omojola AB. 2007. Effects of calcium chloride ($CaCl_2$) injection at different times post-mortem on meat of spent layers. Bulgarian Journal of Agricultural Sci 13:131-139.

Ö nenç A, Serdaroğlu M, Abdraimov K. 2004. Effect of various additives to marinating baths on some properties of cattle meat. Eur Food Res Technol 218:114-117.

Oreskovich DC, Bechtel PJ, McKeith FK, Novakofski J, Basgall EJ. 1992. Marinade pH affects textural properties of beef. J Food Sci 57:305-311.

Papadopoulos LS, Miller RK, Acuff GR, Lucia LM, Vanderzant C, Cross HR. 1991a. Consumer and trained sensory comparisons of cooked beef top rounds treated with sodium lactate. J Food Sci 56:1141-1146.

Papadopoulos LS, Miller RK, Ringer LJ, Cross HR. 1991b. Sodium lactate effect on sensory characteristics, cooked meat color and chemical composition. J Food Sci 56:621-626.

Pietrasik Z, Shand PJ. 2004. Effect of blade tenderization and tumbling time on the processing characteristics and tenderness of ınjected cooked roast beef. Meat Sci 66:871-879.

Rao M, Gault NFS, Kennedy S. 1989. Variations in waterholding capacity due to changes in the fibre diameter, sarcomere length and connective tissue morphology of some beef muscles under acidic conditions below the ultimate pH. Meat Sci 26:19-37.

Robbins K, Jensen J, Ryan KJ, Homco-Ryan C, McKeith FK, Brewer MS. 2002. Enhancement effects on sensory and retail display characteristics of beef rounds. J Muscle Foods 13:279-288.

Sawyer JT, Apple JK, Johnson ZB. 2007. The impact of acidic marination concentration and sodium chloride on sensory and ınstrumental color characteristics of dark-cutting beef. Arkansas Animal Science Department Report. pp 92-95.

Sawyer JT, Apple JK, Johnson ZB. 2008. The impact of lactic acid concentration and sodium chloride on pH, water-holding capacity and cooked color of injection-enhanced dark-cutting beef. Meat Sci 79:317-325.

Serdaroğlu M, Abdraimov K, Ö enenç A. 2007. The effects of marinating with citric acid solutions and grapefruit juice on cooking and eating quality of turkey breast. J Muscle Foods 18:162-172.

Sheard PR, Tali A. 2004 Injection of salt, tripolyphosphate and bicarbonate marinade solutions to improve the yield and tenderness of cooked pork loin. Meat Sci 68:305-311.

Xargayó M, Lagares J, Fernández E, Ruiz D, Borell D. 2001. Marination of fresh meat by means of spray effect: Influence of spray injection on the quality of marinated products. Fleischwirstschaft 81:181-190.

Vote DJ, Platter WJ, Tatum JD, Schmidt GR, Belk KE, Smith GC, Speer NC. 2000. Injection of beef strip loins with solutions containing sodium tripolyphosphate, sodium lactate, and sodium chloride to enhance palatability. J Anim Sci 78:952-957.

Wenham LM, Locker RH. 1976. The effect of marinading on beef. J Sci Food Agr 27:1079-1084.

Wheeler TL, Crouse JD, Koohmaraie M. 1992. The effect of postmortem time of injection and freezing on the effectiveness of calcium chloride for improving beef tenderness. J Anim Sci 70:3451-3457.

Wheeler TL, Koohmaraie M, Lansdell JL, Siragusa GR, Miller MF. 1993. The effects of post mortem injection time, inject level and concentration of calcium chloride on beef quality trait. J Anim Sci 71:2965-2974.

Young LL, Smith DP. 2004. Moisture retention by water- and air-chilled chicken broilers during processing and cutup operations. Poultry Sci 83:119-122.

Yusop SM, Osullivan MG, Kerry JF, Kerry JP. 2010. Effect of marinating time and low pH on marinade performance and sensory acceptability of poultry meat. Meat Sci 85:657-663.

Zayas JF, Lin CS. 1998. Quality characteristics of frankfurters containing corn germ protein. J Food Sci 53:1587-1591.