Impact of High Pressure Processing on the Functional Aspects of Beef Muscle Injected with Salt and/or Sodium Phosphates

The Faculty of Oregon State University has made this article openly available. Please share how this access benefits you. Your story matters.

<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DOI</td>
<td>10.1111/jfpp.12155</td>
</tr>
<tr>
<td>Publisher</td>
<td>John Wiley &amp; Sons Ltd.</td>
</tr>
<tr>
<td>Version</td>
<td>Accepted Manuscript</td>
</tr>
<tr>
<td>Terms of Use</td>
<td><a href="http://cdss.library.oregonstate.edu/sa-termsofuse">http://cdss.library.oregonstate.edu/sa-termsofuse</a></td>
</tr>
</tbody>
</table>
IMPACT OF HIGH PRESSURE PROCESSING ON THE FUNCTIONAL ASPECTS OF BEEF MUSCLE INJECTED WITH SALT AND/OR SODIUM PHOSPHATES

AUSTIN C. LOWDER, CHRISTINA A. MIRELES DEWITT

Department of Food Science and Technology and the Seafood Research and Education Center, Oregon State University, Astoria, OR 97103, USA

Corresponding author:
Christina A. Mireles DeWitt
E-mail: christina.dewitt@oregonstate.edu
2001 Marine Dr. Rm 253 Astoria, OR 97103, USA
Fax: 503-325-2753
Phone: 503-325-4531
Abstract: This study aimed to determine the interactions among salt (NaCl), sodium phosphate (SP) and mild HPP in brine-injected beef. Beef strip loin segments were injected to 10% over initial weight with solutions containing water and various levels of salt (0, 2 or 4% of solution) and/or SP (0 or 4% of solution). Pieces from the loin sections were exposed to varying pressure levels (0.1, 152 or 303 MPa) and evaluated for selected quality and biochemical characteristics. Use of SP and pressure application increased pH by ~0.2 units. $L^*$ values were increased by pressure and decreased by SP. Redness ($a^*$) increased at 303 MPa. Purge increases due to pressure were mitigated by SP. Pressure application at 303 MPa reduced total and sarcoplasmic protein solubility by 24 and 32%, respectively. There were no beneficial interactions among salt or SP and HPP. However, results indicate SP may prevent yield loss due to HPP.

Keywords: High pressure processing, beef, salt, phosphate, brine injection

Practical application: This study has demonstrated that beneficial interactions between high pressure processing (HPP) and salt are not achieved in a brine-injected whole muscle product when salt levels are at or below 0.4% of final product weight. Use of sodium phosphates prevented reduced yields and alleviated some of the color change incurred by HPP at mild pressures.

INTRODUCTION

It is common practice to inject whole muscle, fresh meat cuts with a brine containing sodium chloride (salt; NaCl) and sodium phosphates (SP), as they act synergistically through several mechanisms to increase the water-binding ability of meat proteins. Salt causes depolymerization of myosin as well as a downward shift in the protein’s isoelectric point (Offer and Knight 1988). Sodium phosphates dissociate the acto-myosin bond, further increasing solubilization and relaxation of the protein structure, and increase meat pH (Offer and Knight 1988). These effects translate to a significantly heightened ability of salt/SP-injected meat to retain injected fluid throughout storage, display and cooking (McGee et al. 2003; Lawrence et al. 2004; Baublits et al. 2006a). Sodium phosphates also improve color stability (Baublits et al. 2006b) and inhibit lipid oxidation (McGee et al. 2003).
High pressure processing (HPP) is a non-thermal, non-chemical treatment, which subjects materials to very high hydrostatic pressure (100-1000 MPa). Observations in comminuted products suggest the potential for HPP to be used as a way to enhance the functionality of salt and SP, possibly allowing for usage reductions of these sodium-heavy ingredients. Low-salt (1%) beef hot dogs had similar cook losses and improved texture characteristics compared to controls (2%) when subjected to 200 MPa for 2 min (Sikes et al. 2009). Water-holding capacity and protein solubility of 0.5% salt restructured turkey rolls were increased when subjected to 50 – 200 MPa HPP (Chan et al. 2011). However, whole muscle products are very different from comminuted products in their character: instead of an amorphous protein network there is the ordered structure of myofibers and connective tissue layers. Duranton et al. (2012) noted that making inferences on the effects of HPP on whole muscle products based on results from restructured or comminuted food matrices is ill-advised. In their work it was found that 1.5 or 3% salt injection increased tenderness and water holding capacity of HPP (500 MPa; 6 min) whole muscle hams compared to no salt. Beef loin muscle injected with 1% salt and HPP treated (650 MPa; 10 min) had lower expressible moisture than raw meat without salt with or without high pressure treatment (Fernández et al. 2007). However, these salt levels are much higher than what is commonly used in brine enhanced beef (<0.5%). Additionally, sodium phosphates, commonly used concurrently with salt, have not been investigated in whole muscle HPP-treated product. This study aims to establish what, if any, interactions exist between salt, phosphates and high pressure in brine-injected beef. Common indicators of protein functionality, like protein solubility, and quality aspects, like color and purge loss, were investigated.

METHODS AND MATERIALS

Raw materials and injection

Beef strip loins (IMPS 180; n=10) were purchased from a local processor. Loins were trimmed of all excess fat and connective tissue, cut into three segments and assigned to injection treatments. Loin segments were injected to 110% of initial weight with a solution containing 0, 2 or 4% salt (0, 0.2 or 0.4% final product weight) with or without 4% (0.4% final product weight) of a commercially available sodium phosphate blend (Brifisol® 85 Instant; BK Giulini Corp., Simi Valley, CA, USA) using a single-needle hand-operated injector (Koch, Kansas City, MO,
USA). The segments identified as 0% salt and 0% SP were injected with water targeting 110% of initial weight. Segments were then weighed and allowed to rest for 20 min after injection (equilibration period) before being cut into 2.5 cm x 2.5 cm x ~8 cm pieces, re-weighed, then vacuum packaged in 15.5 x 22 cm oxygen impermeable bags.

**Pressure treatment**

Pressurization took place in a 22-L chamber (National Forge Company, Andover, MA, USA) using a pressurization medium of soluble oil (Hydrolubric® 123-B, Houghton International, Valley Forge, PA, USA) in water (5% w/w). Packaged beef pieces were subjected to either 0.1 (atmospheric pressure), 152 or 303 MPa for 1 minute. The samples were submerged in ice-water within a nylon bag placed in the chamber during pressurization to deter temperature-induced denaturation. The pressure ramp-up rate was approximately 4 MPa/sec. Depressurization time was ~30 sec regardless of final pressure.

**Processing and sampling**

After pressurization beef pieces were either frozen for further analyses or removed from their packages, pat dry with a paper towel and reweighed to determine purge due to pressurization. Subsequently, these pieces were allowed to bloom for 30 min and used for color and pH analysis.

**pH and color**

A pH meter (pH 3210, WTW GmbH, Weilheim, Germany) equipped with a piercing probe was used to determine pH. Instrumental color was determined using a Minolta CM–600 (Konica Minolta Sensing Americas, Inc., Ramsey, NJ, USA) with a 10° observer and illuminant A calibrated with a white tile. CIE $L^*$ and $a^*$ values (CIE 1978) were recorded with the spectral component excluded. Measurements were taken perpendicular to muscle fiber direction, as if they were taken on the sliced surface of a steak.

**Purge**
Multiple variables were used to detail the fluid loss from beef loin segments and pieces. The calculations used to generate these variables are presented in Lowder et al. (2011, 2013). They are described here briefly.

\( \text{Purge}_{\text{inj}} \) represents the fluid lost during the equilibration period as a percentage of the total loin segment weight. It was calculated by taking the difference between the loin segments immediately after injection and after the 20-min rest period, dividing by the weight of the injected segments and multiplying by 100.

\( \text{Brine Loss}_{\text{inj}} \) reports the fluid lost during the equilibration period as a percentage of the total fluid injected. To calculate, the difference between loin segment weight immediately after injection and after equilibration is divided by the difference between segment weight immediately after injection and initial segment weight. The resulting value is multiplied by 100 to get a percentage.

\( \text{Purge} \) represents the fluid lost from the beef piece during pressurization. It is calculated using the following equation:

\[
\text{Purge} (\%) = \frac{(S_0 - S_f)}{S_0} \times 100,
\]

where \( S_0 \) = the weight of the beef piece at slicing and \( S_f \) = the weight of the beef piece after pressurization.

\( \text{Purge}_{\text{total}} \) represents the weight lost from injection through pressurization as a percentage of the total weight of the piece.

**Protein solubility**

Sarcoplasmic (water-soluble) and total (salt- and water-soluble) protein solubility was determined using the Bradford (1976) method with premixed reagents (Bio-Rad Laboratories, Hercules, CA, USA). For sarcoplasmic, two g of sample were homogenized (Polytron PT10-35, Kinematica, Inc., Bohemia, NY) at 10,000 rpm for 30 s in 10 volumes of a low ionic strength buffer (30 mM sodium phosphate, pH 7.4) then incubated on a rocker on ice for 2 h. Samples were kept on an ice bath or under refrigeration immediately before and after homogenization. After centrifugation at 5000 x \( g \) and 4 °C for 20 min, supernatant was decanted, reacted with Bradford reagent and read on a spectrophotometer (Shimadzu UV-2400, Shimadzu Scientific Instruments, Inc, Columbia, MD) at 595 nm. Total solubility used the same procedures with a high ionic strength buffer (0.6 M KCl, 50 mM sodium phosphate, pH 7.4). Myofibrillar solubility was estimated by subtracting the water-soluble fraction from the total fraction for a given sample. Protein solubility was reported as mg/g sample.
Total and reactive sulfhydryls (SH)

Total and reactive sulfhydryl groups were determined in the presence and absence of urea by a modification of the procedures described by Hamada et al. (1994). Samples (1 mg protein/ml) were retained from the protein solubility test. Adjusted sample (0.5 mL) was mixed with 2 mL 8M urea in 0.2 M Tris (pH 7.0) and 50 μL of 10 mM 5,5’-dithiobis(2-nitrobenzoic acid) (DTNB) with 0.1 M sodium phosphate and 0.2 mM ethylenediaminetetraacetic acid (EDTA) (pH 7.2) and incubated in a 40 °C water bath for 15 min. Reacted samples were measured on a spectrophotometer (UV 2401, Shimadzu Corporation, Kyoto, Japan) at 412 nm. Total SH content was determined as μMol/mg protein using a molar extinction coefficient of 14,150 M⁻¹ cm⁻¹ (Riddles et al. 1979). The adjusted protein sample was incubated at 5 °C for 1 hr without urea to determine reactive SH content.

Experimental design and statistical analysis

The experiment was arranged as a split plot with the whole plot being a 3 x 2 factorial (3 salt levels; 2 SP levels) in a balanced incomplete block design with loin as the block. The whole plot was replicated 5 times and each treatment appeared in a block twice with any other given treatment. The split plot factor was pressure level (0.1, 152, 303 MPa) with a replication of 30.

Data were analyzed in PROC GLIMMIX of SAS Version 9.2 with block (loin) defined as a random variable. The whole plot error term was defined as block x salt level x phosphates level. Significance was pre-determined at α = 0.05. Treatment effects were subjected to analysis of variance (ANOVA) and, where applicable, means were separated using t-tests. In order to protect experiment-wise error while maintaining power, mean separations within two-way interactions were performed only across certain levels of the other main effect. The L* data, due to a non-normal distribution, were transformed using the procedure of Box and Cox (1964) as implemented by SAS for ANOVA and mean comparisons. Because of a three-way interaction, the L* data were sliced by SP level and subjected to two-way ANOVA. Figures and reported means for L* are based on the reverse-transformed geometric means; standard errors are approximations from those means.

RESULTS AND DISCUSSION
Brine retention in loins

Brine was injected into meat until initial weight was increased 10%. However, a significant amount of brine can be lost after injection (equilibration). Following the equilibration period, product weight was only 5.3 to 7.7% above initial weight. The fluid loss as a percentage of product weight ($Purge_{inj}$) and total fluid injected ($Brine Loss_{inj}$) is reported in Table 1.

Curiously, $Purge_{inj}$ was not significantly affected ($P > 0.05$) by either salt or SP, though it was numerically reduced by the presence of each (Table 1). $Brine Loss_{inj}$ was reduced ($P < 0.05$) by 15.13 or 16.38% by using 4% salt or SP, respectively, in the brine. Fluid retention during the rest period was lower than that seen in previous studies using similar ingredients and raw materials (Lowder et al. 2011, 2013). Fluid loss may have been encouraged by segmenting the loins, which increased surface area relative to internal area of the muscle, or the use of a hand-operated, as opposed to automated, pump injection system.

pH and color

A pressure level*SP interaction was observed ($P = 0.013$) for pH (Fig. 1). As expected, phosphates increased ($P < 0.05$) pH regardless of pressure treatment. In addition, pressure treatment at 152 MPa further increased ($P = 0.014$) the pH of samples with SP but not those without it. Pressure at 303 MPa increased pH of samples not treated with SP. Both SP and pressure treatment as low as 200 MPa have been shown to raise the pH of muscle foods by 0.1 - 0.2 units (Lawrence et al. 2004; Ma and Ledward 2004). The two effects are seen here to be additive, with SP not only increasing the final pH of 303 MPa pressurized meat, but reducing the pressure needed to cause the increase to, at most, 152 MPa. The changes in pH seen here are similar to those seen by other researchers (Lawrence et al. 2004; Ma and Ledward 2004) even though the values of the non-pressurized meat are lower than those frequently observed (Lowder et al. 2011; Parsons et al. 2011). Increases in meat pH due to pressure have been attributed to increased ionization, which may sequester free hydrogen ions, and protein denaturation, which can bury acidic side groups (Macfarlane et al. 1980; Ma and Ledward 2004).

The $L^*$ (lightness) values are shown visually in Fig. 2. Data were sliced by salt level and analyzed using the SP and pressure variables to explain the three-way interaction. This, unfortunately, limits the inferences that can be made on the impact of salt level. When salt was absent from the brine, SP inclusion reduced ($P < 0.01$) lightness at the 0.1 and 152 MPa pressure
levels, but not at 303 MPa ($P = 0.98$). Sodium phosphates reduced ($P < 0.017$) lightness at all pressure levels at 2% salt but had no significant effect ($P > 0.05$) at 4% salt.

In addition to increasing water-binding ability, SP increases the pH of meat which increases mitochondrial oxygen consumption rate, causing competition with myoglobin and resulting in darker muscle appearance (Faustman and Cassens 1990). Absent salt, 152 MPa decreased ($P = 0.021$) lightness of beef without SP but did not affect ($P = 0.28$) beef with SP. Lightness was decreased ($P < 0.05$) by 152 MPa regardless of SP presence at 2% salt, but at 4% salt it was the SP treated beef that was darker ($P < 0.01$). At 303 MPa, all beef was significantly lighter ($P < 0.05$) than atmospheric pressure or 152 MPa except the salt and phosphate free treatment which was almost significantly higher ($P = 0.052$). Previous studies (Carlez et al. 1993; Hong et al. 2005) on minced beef and pork loin found numerical but non-significant increases in $L^*$ values upon pressurization at 150 MPa, whereas the current data show a minor (1 – 4 units) decrease at 152 MPa. Higher pressures are more commonly examined and the current study is in agreement with the majority of the literature. At pressures in the range of 200 – 400 MPa with as little as 15-s dwell time a major (5–15 units) increase in lightness is frequently observed in beef and pork (Carlez et al. 1995; Cheftel and Culioli 1997; Hong et al. 2005; Souza et al. 2011). The increase in lightness, believed to be caused by globin denaturation or protein coagulation, is often cited as a negative effect of HPP on fresh beef and, in this case, the darkening effect of SP at 2% salt should be considered a benefit (Carlez et al. 1995).

Incorporation of SP without salt increased ($P = 0.005$) redness by 2.3 units, but had no effect ($P > 0.515$) on redness with salt at 2 or 4% of the brine (Table 2). Salt inclusion increased redness at 4% without SP, but had no significant effect ($P > 0.13$) when SP was also present. Increasing salt level is not typically associated with an increase in $a^*$ values, as salt is pro-oxidative and has been shown to contribute to myoglobin oxidation (Lawrence et al. 2004; Baublits et al. 2006a). The pressure*SP interaction (Fig. 3) shows an increase ($P < 0.001$) in redness upon pressurization to 303 MPa by 2 units over non-pressurized for both 0 and 4% SP. An increase of redness ($P = 0.044$) at 303 MPa by SP was also observed. Much like salt, the observed increases of $a^*$ due to SP use are curious and not common in the literature, though it is known to increase color stability over time by acting as an antioxidant (Baublits et al. 2006a). It should be noted that color measurements were taken within several hours of injection and it is unlikely there was sufficient time for oxidation to develop in the salt-treated samples. The
increase in redness by HPP at 303 MPa is supported by other work. Hong et al. (2005) noticed an increase in redness of pork *longissimus dorsi* at 200 MPa and Jung et al. (2003) observed increased redness between 130 and 350 MPa in beef *biceps femoris*. The mechanism of this redness increase is not understood, but often attributed to the activation of enzyme systems with metmyoglobin reducing activity (MRA; Jung et al. 2003). The observation by Cheah and Ledward (1997) that this phenomenon is more apparent in the *longissimus dorsi*, which is considered color stable with a surplus of MRA species, than in the *psoas major*, which lacks in color stability, lends credence to this idea (Joseph et al. 2012).

**Purge**

*Purge*, the fluid loss during packaging and pressurization, increased ($P = 0.003$) in non-SP treated beef by 0.80% when exposed to 152 MPa but was only numerically greater ($P = 0.279$) when exposed to 303 MPa (Fig. 4). In the beef with SP, *Purge* values ranged from 2.94 to 3.17%, but were unaffected ($P = 0.725$) by HPP and were 1.35 – 2.31% lower ($P < 0.001$) than their non-SP counterparts. The loss of fluid from time of injection through pressurization, *Purge*$_{total}$, produces a pattern of fluid loss that is exactly the same as that seen for *Purge* (Fig. 5); 152 MPa, but not 303 MPa increased ($P = 0.033$) fluid loss from 0% SP meat while having no effect ($P = 0.487$) on SP meat. The salt*SP interaction showed a synergistic cooperation, with at least 2% salt reducing ($P = 0.035$) *Purge*$_{total}$ of SP beef by an additional 1.5 – 2.5% over that without salt. The cooperative effects of salt and SP on fluid retention properties of muscle foods are well documented and understood (Offer and Knight 1988; Lawrence et al. 2004; Lowder et al. 2013); observations of these actions here are expected. Pressurization has been previously documented as negatively affecting fluid retention variables in whole muscle meat. 200 MPa of pressure (5 min) reduced WHC of beef *semitendinosus* steaks (Kim et al. 2007). Hong et al. (2005) and Marcos et al. (2010) investigated pressurization on pork loin muscle. The former noted reduced WHC at 150 – 200 MPa when exposed for long periods of time (15 – 60 min) while the latter observed increased expressible moisture at 400 MPa, but not 200 MPa. Pork *biceps femoris* was reduced in water holding capacity (WHC) upon pressurization to 500 MPa for 6 min (Duranton et al. 2012). Observations of cross-sectional microstructure through electron microscopy revealed contracted myofibril structure and increased space in extracellular channels, which are known to reduce water holding capacity by allowing diffusion of water out.
of myofibrils (Kim et al. 2007; Liu et al. 2010; Duranton et al. 2012). Reduction in protein solubility, which is correlated with water binding characteristics, was also reported concurrently with rises in fluid loss in cases where it was investigated (Joo et al. 1999; Kim et al. 2007; Marcos et al. 2010); it is likely that the two phenomena are related. Duranton et al. (2012) and Fernandez et al. (2007) showed that salt injection of pork and beef, respectively, prevented the detrimental effects of pressurization on fluid retention. These effects were not seen in the present work, most likely because the salt level (0.4% final target) was much lower than the other studies (1.5 and 1% final target, respectively). Use of SP in this study, however, which was targeted (0.4%) near the legal limit of 0.5% final weight, was able to negate the water loss induced by HPP.

**Protein solubility and sulfhydryls**

Protein solubility was only affected (\( P < 0.002 \)) by pressure level (Table 3). In all cases, solubility was decreased when HPP was applied at 303 but not 152 MPa. No tested factor influenced reactive or total sulfhydryls (SH) or the reactive/total SH ratio. Pressure level showed a tendency to increase (\( P = 0.078 \)) reactive SH content, but, curiously, the reactive/total SH ratio did not seem to be influenced by this (\( P = 0.520 \)). Varying observations on protein solubility of HPP meats have been reported. Lee et al. (2007) reported decreased solubility of beef semitendinosus in 0.6 M KCl at pressures of 400 MPa or greater; using low ionic strength buffer (0.1 M KCl); however, solubilized greater amounts of protein at 200 MPa. Solubility of beef biceps femoris myofibrils was increased by pressurization at 300 – 600 MPa while in 0.1 M KCl buffer (Jung et al. 2000), while that of chicken breast myofibrils was increased at 100 – 300 MPa in a similar solution (Iwasaki et al. 2006). Marcos et al. (2010) noted stepwise decreases in solubility of sarcoplasmic protein fractions (extracted under very low ionic strength) when subjected to 200 and 400 MPa for 20 min. Total protein extraction (0.55 M KI) from minced chicken breast containing 0 or 2.5% salt was decreased when 400 or 600 MPa pressure was applied when compared to 200 MPa, but this decrease was almost completely counteracted when 0.3% sodium tripolyphosphate and 1% salt were used (Omana et al. 2011). The same study reported decreased solubility of the sarcoplasmic fraction regardless of included non-meat ingredients. Decreases in solubility, regardless of fraction (myofibrillar/sarcoplasmic) are associated with protein denaturation and aggregation, both of which reduce functionality of
proteins important to meat quality (Joo et al. 1999). Denaturation of proteins, specifically a folded to unfolded transition, with exposure of hydrophobic side groups, is expected when proteins are subjected to high hydrostatic pressure (Mozhaev et al. 1996). Observations of pressurized myofibrillar suspensions support this assertion (Chapleau et al. 2002, 2003). The cited studies characterized pressure-induced changes to myofibrillar proteins, including a maximum three-fold increase in surface hydrophobicity, indicative of denaturation, and formation of protein aggregates. Greater exposure of sulfhydryl groups due to unfolding may encourage this aggregation, as the ratio of reactive to total SH groups has been seen to increase upon pressurization in myofibrillar suspensions (Chapleau et al. 2003) and in model meat systems (Chan et al. 2011; Omana et al. 2011). While reactive SH group exposure showed some amenability to pressure application in the current work, truly significant effects on SH characteristics may have been difficult to discern from analysis of total extracted protein as opposed to a more pure fraction. The overall lack of influence of salt and SP on solubility suggests that, at the tested levels, they were unable to significantly alter how hydrostatic pressure affects muscle protein. However, the fact still remains that SP use was able to completely counteract the purge increase due to pressurization. Given the evidence from this study, we assert that the additive pH increase from combined SP/pressure treatment played a primary role in that phenomenon.

CONCLUSIONS

In the current study, no evidence of interactions between high hydrostatic pressure and the ingredients salt or sodium phosphates were seen. It is likely that levels in this study, while appropriate for a similar commercial product, where too low to elicit any changes due to pressure. Additionally, the highly ordered character of intact muscle prevents the degree of ingredient-protein interaction achievable in comminuted and restructured products. However, SP addition was able to lessen the whitening effect to some degree and completely counteract the purge losses incurred upon pressurization. Since protein solubility and SH content were not affected and salt was unable to achieve the same result, the additive SP/pressure induced pH increase is implicated in both cases rather than retention of protein functionality. This assertion is not definitive, however, as only basic protein characterization was carried out in this study.
Current results suggest SP may play a role in producing acceptable fresh HPP-treated whole muscle beef, but further experimentation at higher pressures with longer dwell times is needed to confirm this. Independent of pressure application, the ability of salt and SP to retain fluid in whole muscle injected beef seen here further supports the body of work already done on the subject.

ACKNOWLEDGEMENT

This project was funded by Oregon State University and the Coastal Oregon Marine Experiment Station’s Seafood and Research Education Center, Astoria, OR.

REFERENCES


from beef strip loins and steaks injected with salt and phosphate with or without a

MACFARLANE, J.J., MCKENZIE, I.J., and TURNER, R.H. 1980. Pressure treatment of meat:

MA, H.J., and LEDWARD, D.A. 2004. High pressure/thermal treatment effects on the texture of

MARCOS, B., KERRY, J.P., and MULLEN, A.M. 2010. High pressure induced changes on

of sodium chloride, sodium tripolyphosphate, and sodium lactate improves Warner-
Bratzler shear and sensory characteristics of pre-cooked inside round roasts. Meat Sci.,
64, 273-277.

MOZHAEV, V.V., HEREMANS, K., FRANK, J., MASSON, P., and BALNY, C. 1996. High
pressure effects on protein structure and function. Proteins: Struct., Funct., Genet., 24,
81-91.

Lawrie (Ed.), Developments in Meat Science – 4, Chapters 3-4 (pp. 63 – 243). London:
Elsevier Applied Science.


Retail display evaluation of steaks from Select beef strip loins injected with a brine


TABLE 1. MAIN EFFECT LS MEANS FOR PURGE\textsubscript{INJ} AND BRINE LOSS\textsubscript{INJ} OF LOIN SEGMENTS INJECTED TO 10% OVER INITIAL WEIGHT WITH VARYING LEVELS OF SALT AND/OR SODIUM PHOSPHATES (SP)

<table>
<thead>
<tr>
<th>Salt (%)\textsuperscript{c}</th>
<th>Purge\textsubscript{inj}</th>
<th>SEM\textsuperscript{d}</th>
<th>Brine Loss\textsubscript{inj}</th>
<th>SEM\textsuperscript{d}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>4.66</td>
<td>0.31</td>
<td>66.67\textsuperscript{a}</td>
<td>3.75</td>
</tr>
<tr>
<td>2</td>
<td>3.55</td>
<td>0.31</td>
<td>56.59\textsuperscript{ab}</td>
<td>3.92</td>
</tr>
<tr>
<td>4</td>
<td>3.77</td>
<td>0.27</td>
<td>51.54\textsuperscript{b}</td>
<td>3.45</td>
</tr>
<tr>
<td>SP (%)\textsuperscript{c}</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>4.19</td>
<td>0.25</td>
<td>66.46\textsuperscript{a}</td>
<td>3.19</td>
</tr>
<tr>
<td>4</td>
<td>3.79</td>
<td>0.23</td>
<td>50.08\textsuperscript{b}</td>
<td>2.87</td>
</tr>
</tbody>
</table>

\textsuperscript{a,b}Means within a column and main effect with differing superscripts are significantly different (P < 0.05)
\textsuperscript{c}As a percentage of the brine
\textsuperscript{d}Standard error of the mean
TABLE 2. REDNESS (A* VALUES) OF BEEF PIECES FROM LOINS INJECTED TO 10% OVER INITIAL WEIGHT WITH VARYING LEVELS OF SALT AND/OR SODIUM PHOSPHATES (SP) AND SUBJECTED TO HIGH PRESSURE PROCESSING AT 0.1, 152 OR 303 MPA AS AFFECTED BY SALT/SP LEVELS

<table>
<thead>
<tr>
<th>SP (%)</th>
<th>0</th>
<th>2</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>20.72 ± 0.63</td>
<td>22.23 ± 0.61</td>
<td>22.46 ± 0.56</td>
</tr>
<tr>
<td>4</td>
<td>23.07 ± 0.56</td>
<td>22.02 ± 0.61</td>
<td>22.01 ± 0.56</td>
</tr>
</tbody>
</table>

*Means (± standard error of the mean) within a row with differing superscripts are significantly different (*P* < 0.05)

*As a percentage of the brine

*P* value of the comparison of SP levels at a given salt level
TABLE 3. SARCOPLASMIC, MYOFIBRILLAR AND TOTAL PROTEIN SOLUBILITY AND REACTIVE, TOTAL AND REACTIVE/TOTAL SULFHYDRYL (SH) RATIO OF BEEF PIECES FROM LOINS INJECTED TO 10% OVER INITIAL WEIGHT WITH VARYING LEVELS OF SALT AND/OR SODIUM PHOSPHATES (SP) AS AFFECTED BY APPLIED HIGH PRESSURE PROCESSING (HPP)

<table>
<thead>
<tr>
<th>Pressure (MPa)</th>
<th>Sarcoplasmic Solubility&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Myofibrillar Solubility&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Total Solubility&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Reactive SH&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Total SH&lt;sup&gt;d&lt;/sup&gt;</th>
<th>Reactive/Total SH Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>1.64&lt;sup&gt;a&lt;/sup&gt; ± 0.07</td>
<td>1.64&lt;sup&gt;a&lt;/sup&gt; ± 0.11</td>
<td>3.28&lt;sup&gt;a&lt;/sup&gt; ± 0.15</td>
<td>106 ± 4.7</td>
<td>150 ± 6.6</td>
<td>0.74 ± 0.03</td>
</tr>
<tr>
<td>152</td>
<td>1.58&lt;sup&gt;a&lt;/sup&gt; ± 0.07</td>
<td>1.69&lt;sup&gt;b&lt;/sup&gt; ± 0.11</td>
<td>3.26&lt;sup&gt;a&lt;/sup&gt; ± 0.15</td>
<td>113 ± 4.7</td>
<td>155 ± 6.3</td>
<td>0.76 ± 0.03</td>
</tr>
<tr>
<td>303</td>
<td>1.37&lt;sup&gt;a&lt;/sup&gt; ± 0.07</td>
<td>1.11&lt;sup&gt;b&lt;/sup&gt; ± 0.12</td>
<td>2.48&lt;sup&gt;b&lt;/sup&gt; ± 0.15</td>
<td>120 ± 4.6</td>
<td>156 ± 6.7</td>
<td>0.77 ± 0.03</td>
</tr>
</tbody>
</table>

<sup>a,b</sup>Means within a column with differing superscripts are significantly different (P < 0.05)

<sup>c</sup>Protein solubility means are expressed as mg protein/g sample ± standard error of the mean

<sup>d</sup>Sulfhydryl means are expressed as μMol SH/mg protein ± standard error of the mean

<sup>e</sup>P value for the main effect of pressure level
FIG. 1. PRESSURE X SODIUM PHOSPHATE (SP) INTERACTION PH VALUES FOR BEEF FROM STRIP LOINS INJECTED TO 110% OF INITIAL WEIGHT WITH SOLUTIONS CONTAINING SALT (0, 2 OR 4% OF SOLUTION) AND/OR SP (0 OR 4% OF SOLUTION) AND EXPOSED TO HIGH PRESSURE (0.1, 152 OR 303 MPa; 1 MIN AT AMBIENT TEMPERATURE). DATA POINTS WITH DIFFERING LETTERS WITHIN AN SP LEVEL ARE SIGNIFICANTLY DIFFERENT ($P < 0.05$); AN '*' DENOTES A SIGNIFICANT DIFFERENCE ($P < 0.05$) BETWEEN SP LEVELS AT THAT PRESSURE.
FIG. 2. \( L^\ast \) (LIGHTNESS) VALUES OF BEEF FROM STRIP LOINS INJECTED TO 110% OF INITIAL WEIGHT WITH SOLUTIONS CONTAINING SALT AT (a) 0, (b) 2 OR (c) 4% OF SOLUTION AND/OR SP (0 OR 4% OF SOLUTION) AND EXPOSED TO HIGH PRESSURE (0.1, 152 OR 303 MPA; 1 MIN AT AMBIENT TEMPERATURE). DATA POINTS WITH DIFFERING LETTERS WITHIN AN SP LEVEL ARE SIGNIFICANTLY DIFFERENT (P < 0.05); AN **"" DENOTES A SIGNIFICANT DIFFERENCE BETWEEN SP LEVELS AT THAT PRESSURE.
FIG. 3. PRESSURE X SODIUM PHOSPHATE (SP) INTERACTION FOR \( a^* \) (REDNESS) VALUES OF BEEF FROM STRIP LOINS INJECTED TO 110% OF INITIAL WEIGHT WITH SOLUTIONS CONTAINING SALT (0, 2 OR 4% OF SOLUTION) AND/OR SP (0 OR 4% OF SOLUTION) AND EXPOSED TO HIGH PRESSURE (0.1, 152 OR 303 MPa; 1 MIN AT AMBIENT TEMPERATURE). DATA POINTS WITH DIFFERING LETTERS WITHIN AN SP LEVEL ARE SIGNIFICANTLY DIFFERENT \((P < 0.05)\); AN ‘*’ DENOTES A SIGNIFICANT DIFFERENCE \((P < 0.05)\) BETWEEN SP LEVELS AT THAT PRESSURE.
FIG. 4. PRESSURE X SODIUM PHOSPHATE (SP) INTERACTION FOR PURGE VALUES OF BEEF FROM STRIP LOINS INJECTED TO 110% OF INITIAL WEIGHT WITH SOLUTIONS CONTAINING SALT (0, 2 OR 4% OF SOLUTION) AND/OR SP (0 OR 4% OF SOLUTION) AND EXPOSED TO HIGH PRESSURE (0.1, 152 OR 303 MPa; 1 MIN AT AMBIENT TEMPERATURE). DATA POINTS WITH DIFFERING LETTERS WITHIN AN SP LEVEL ARE SIGNIFICANTLY DIFFERENT (P < 0.05); AN ‘*’ DENOTES A SIGNIFICANT DIFFERENCE (P < 0.05) BETWEEN SP LEVELS AT THAT PRESSURE.
FIG. 5. (A) PRESSURE X SODIUM PHOSPHATE (SP) AND (B) SALT X SP INTERACTIONS FOR PURGE\textsubscript{TOTAL} VALUES OF BEEF FROM STRIP LOINS INJECTED TO 110% OF INITIAL WEIGHT WITH SOLUTIONS CONTAINING SALT (0, 2 OR 4% OF SOLUTION) AND/OR SP (0 OR 4% OF SOLUTION) AND EXPOSED TO HIGH PRESSURE (0.1, 152 OR 303 MPA; 1 MIN AT AMBIENT TEMPERATURE). DATA POINTS WITH DIFFERING LETTERS WITHIN AN SP
LEVEL ARE SIGNIFICANTLY DIFFERENT (P < 0.05); AN ‘*’ DENOTES A SIGNIFICANT DIFFERENCE BETWEEN SP (A) OR SALT (B) LEVELS AT THAT PRESSURE.