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Texture of Fermented Summer Sausage with Differing pH, Endpoint Temperatures, and High Pressure Processing Times

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Abstract: The objective was to evaluate the quality and texture of all-beef summer sausages produced with varying degrees of fermentation, endpoint cooking temperatures, and high pressure processing (HPP) hold times. Across 3 replications, sausages were fermented and (Process A) cooked to pH 4.6 and thermally processed to 54.4°C with smokehouse chilling, (Process B) cooked to pH 5.0 and thermally processed to 54.4°C with smokehouse chilling, (Process C) cooked to pH 5.0 and thermally processed to 54.4°C with rapid ice bath chilling, (Process D) cooked to pH 5.0 and thermally processed to 48.9°C with rapid ice bath chilling, and (Process E) cooked to pH 5.0 and thermally processed to 43.3°C with rapid ice bath chilling. After chilling, the sausages were sliced, layered, vacuum packaged, and subjected to HPP at 586 MPa for 0, 1, 150, or 300 s. Post HPP, the sausages were evaluated for objective color ($n = 9$), lipid oxidation ($n = 9$), water activity ($n = 9$), texture profile analysis (TPA; $n = 15$), sensory analysis ($n = 9$), and proximate analysis ($n = 9$). Neither process (combination of pH and endpoint temperature) nor HPP affected lipid oxidation ($P = 0.45$ and $P = 0.69$, respectively). Process A resulted in a lighter color ($P < 0.01$) compared to the other process treatments. Additionally, Process A was less red ($P < 0.01$) than all other process treatments, and Processes D and E were the reddest ($P < 0.01$). TPA and trained sensory analysis indicated that, as endpoint temperature increased, so did sample hardness ($P < 0.05$). Springiness, cohesiveness, and gumminess decreased ($P < 0.05$) as the endpoint temperature decreased. Although springiness and gumminess increased ($P < 0.05$) with longer HPP hold times, the panelists were unable to detect differences among samples with longer hold times. The use of HPP at 586 MPa for up to 300 s may be incorporated into manufacturing processes for semidry beef summer sausages with limited impacts on color and texture.

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Introduction

Consumers in the United States are seeking specialty food products and traditionally processed foods (Ilbery and Kneafsey, 1999; Guerrero et al., 2009) that historically would not meet current standards for thermal inactivation of pathogens. However, the *Escherichia coli* O157:H7 outbreak in commercially produced dry-cured salami (CDC, 1995) caused researchers and industry representatives (The Blue Ribbon Task Force of the National Cattlemen's Beef Association) to outline a course of action aimed at mitigating the *E. coli* O157:H7 risk in such products (Reed, 1995) by achieving a 5-log reduction in *E. coli* O157:H7 populations. The majority of the methods suggested focused on thermal processing (Nickelson II et al., 1996). Alternatively, The Blue Ribbon Task Force also suggested that hurdle technology could be used in leu of, or in combination with, thermal processing for the reduction of pathogens (Nickelson II et al., 1996).

High pressure processing (HPP) is a technology that can aid in the reduction of pathogenic bacteria

(Patterson et al., 1995; Cheftel and Culioli, 1997) and may be a viable option to meet the food safety performance standards requested by regulatory agencies (USDA, 2017) without requiring prior approval for use (USDA, 2012). However, inspection program personnel must verify that the hazard analysis supports the use and critical parameters of HPP (USDA, 2012). The performance standards suggest that establishments producing dry, fermented, and salt-cured products containing beef have scientific documentation demonstrating a 5D process (a process, or processes, that result in 5-log reduction under prescribed conditions for a given time or dose) for *E. coli* O157:H7 (USDA, 2017). HPP subjects the food substrate to extreme pressures (200 to 700 MPa; Campus, 2010) through forced water displacement (Cheftel and Culioli, 1997). Because pressure is created from forced water, the distribution of that pressure is isostatic, pseudo-instantaneous, and should not cause gross deformation, provided that there is not a significant amount of gas present in the food or package (Cheftel and Culioli, 1997). Although there should be no product deformation, the pressures achieved during HPP are enough to influence molecular changes and interactions, including weak hydrostatic interactions, hydrogen bonding, and hydrophobic bonds, as well as increasing protein denaturation, aggregation, and gelation (Messens et al., 1997; Campus, 2010). While the pressures created through HPP have been shown to reduce pathogens, including in dried and fermented meat products (Hugas et al., 2002; Morales et al., 2006; Omer et al., 2010; Scheinberg et al., 2014), little is known about the influence of HPP on the texture and color of fermented dry and semidry meat products containing beef. HPP has been shown to variably alter meat texture, tenderness, color, and oxidation stability dependent on rigor state, pressure setting, use of nitrate/nitrite, cooked state, and packaging type (Simonin et al., 2012). Therefore, the objective of this study was to investigate the influence of HPP in combination with total production process parameters (pH and endpoint cooking) on the texture and color of an all-beef fermented, semidry sausage product.

Materials and Methods

Beef trimmings procurement and batter processing

For each of 3 replicates, 20.4 kg of beef trimmings generated from previously frozen (20 ± 4 d of age) beef chuck rolls (Institutional Meat Purchase Specifications #116A; USDA Select) were blended to target 10% fat and were ground through a 12.7-mm plate. Trimmings were then ground a second time (4.76 mm) and placed into a reverse action mixer (Model A-80, Koch, Kansas City, MO). The ground trimmings were subsequently mixed for 1 min with a typical summer sausage seasoning blend including the following: 2% salt (Mortons, Chicago, IL); 0.8% or 0% dextrose (to achieve target pH values of 4.6 or 5.0, respectively, after fermentation); 0.25% sodium nitrite (156 parts per million [ppm]); 0.13% black pepper, white pepper, and garlic powder; 0.06% ginger, coriander, and mustard; and 0.05% sodium erythorbate (539 ppm). The batter was then inoculated with 10 g of thawed *Pediococcus acidilacti* starter culture (Kerry, Rochester, MN) diluted in 236 mL of distilled water (23°C ± 2°C) and mixed for an additional 2 min. The prepared batter was then placed into a vacuum stuffer (Vemag Robot 500, Reiser, Canton, MA), stuffed into fibrous mahogany casings of 5.08 cm in diameter (11 chubs) (Visko Teepak, Kenosha, WI), and clipped. After stuffing, 5 chubs were allocated to texture profile analysis (TPA), 3 chubs were allocated for color and lipid oxidation, and 3 chubs were allocated for sensory analysis. All chubs were then hung on a smoke cart and placed in an Alkar smokehouse (Model 8770-4-12000, Lodi, WI). Sausages were allowed to ferment at 43.3°C dry bulb with 85% relative humidity until the target endpoint pH was achieved. After fermentation, the dry bulb temperature was increased to 62.8°C with a relative humidity of 85% for 30 min and was then increased again to 73.9°C with 90% relative humidity for the remainder of the cooking cycle, and the sausages were cooked to an internal temperature of 43.3°C, 48.9°C, and 54.4°C followed by ice bath chilling. Two processing treatment groups, one from pH 4.6 and one from pH 5.0, were cooked to 54.4°C and cooled using a smokehouse cold-water shower for 10 min followed by refrigerated chilling methods to simulate industrial chilling, whereby the sausages were removed from the smokehouse after the cold shower and placed in a rapid chill ready-to-eat cooler at 1°C ± 1°C. The endpoint pH and cooking parameters were arranged into 5 different total processes, as follows: fermented to pH 4.6 and thermally processed to 54.4°C with smokehouse chilling (Process A), fermented to pH 5.0 and thermally processed to 54.4°C with smokehouse chilling (Process B), fermented to pH 5.0 and thermally processed to 54.4°C with rapid ice bath chilling (Process C), fermented to pH 5.0 and thermally processed to 48.9°C with rapid ice bath chilling (Process D), and fermented to pH 5.0 and thermally processed to 43.3°C with rapid ice bath chilling (Process E). The 5 treatment

structures were evaluated as total processes that combined fermentation-level thermal processing with chilling procedures. After chilling, samples from all treatment groups were packaged and exposed to various HPP hold times at 586 MPa. HPP typically ranges from 300 to 600 MPa for meat pasteurization, dependent on the time and temperature during pressurization and the organism being targeted (Aymerich et al., 2008; Omar et al., 2010). Pressures close to 600 MPa have been shown to be the most effective against pathogenic *E. coli* (Gill and Ramaswamy, 2008; Omer et al., 2010; Simonin et al., 2012; Hygreeva and Pandey, 2016) and are commonly used for meat products in current industrial practices.

HPP

After thermal processing and chilling, the sausages destined for TPA were cut to 5-cm lengths and vacuum packaged (B-620 series; 30–50 cm^3O_2/m^2/24 h/101,325 Pa/23°C; Cryovac Sealed Air Corporation, Duncan, SC). The remaining chubs were sliced to 3.18 mm using a Hobart meat slicer (Model HS9, Hobart, Troy, OH), shingle packed, and vacuum sealed (Cryovac Sealed Air Corporation, Duncan, SC). The packages were then transported (0°C ± 2°C; 170 km) to Universal Pasteurization (Villa Rica, GA) and high pressure processed at 4°C ± 2°C and 586 MPa for 0, 1, 150, and 300 s. Samples processed for 0 s were packaged and transported with all other samples but remained in cold storage while other samples were subjected to HPP. One second was the amount of time for the HPP chamber to come up to 586 MPa and then release, which demonstrates the effects on summer sausage quality characteristics due to pressure alone. A common time under pressurization for meat products at the pressure used in the current study is between 150 and 180 s. Therefore, 150 s was selected to represent the lower end of a common time setting. The final HPP hold time (300 s) was selected to examine the impact of extended (double) time under pressurization on summer sausage quality.

Proximate analysis

Samples from different HPP hold times were not different ($P > 0.05$) from each other for proximate analysis, therefore HPP hold time was composited by process treatment within each replicate to determine moisture and crude protein for the determination of the moisture-to-protein ratio (MPR). Total lipids were determined from the raw meat block. All analyses were performed in duplicate with a coefficient of variation less than 10.

Moisture was determined using disposable aluminum pans that were dried at 100°C in a forced-air oven (Fisher Scientific, Pittsburg, PA) overnight and equilibrated for 10 min in a desiccator. Pans were weighed, and 2.0 ± 0.1 g of homogenized sample was dried in duplicate at 100°C for 18 h (Soderberg, 1991). Samples were removed from the oven and allowed to cool for 10 min in the desiccator. Percent moisture was calculated as follows:

$$\%\,\text{moisture} = [1 - (\text{dry sample weight} \div \text{wet sample weight})] \times 100\%$$

Crude protein was determined using a Nitrogen autoanalyzer (Leco FP-528 Nitrogen analyzer, Leco Company, St Joseph, MI) for the determination of N content (0.1 ± 0.05 g) and was expressed as percent crude protein (N content × 6.25). Total lipid content of the raw meat block was analyzed using wet tissue lipid extraction as outlined by Folch et al. (1957). Additionally, water activity was measured using an Aqualab water activity meter (Aqualab 4TE, Pullman, WA) immediately upon returning from HPP. Sausage pH was measured immediately after the fermentation step and was performed using a 1:10 dilution method in deionized water with an Oakton pH meter (Vernon Hills, IL; Koniecko, 1979).

Lipid oxidation

Lipid oxidation was preformed using the rapid, wet method of thiobarbituric acid reactive species following the methods of Sinnhuber and Yu (1958) and Buege and Aust (1978) and modified according to Zipser and Watts (1962) and Shahidi et al. (1985) to account for the addition of sodium nitrite. Lipid oxidation was expressed as milligrams of malonaldehyde (MDA) per kilogram of meat.

Objective color

Subsequent to HPP treatment, product was transported to the Meat Science and Technology Center (Athens, GA) under refrigeration, and vacuum-packaged slices were removed from the package and stacked 5 slices thick, making 3 stacks. Objective color was preformed using a Hunter-Lab MiniScan EZ (Hunter Associates Laboratory, Reston, VA) with illuminant A and a 10° viewing angle with a 32-mm aperture. Prior to use, the colorimeter was standardized with white, black, and saturated red tiles. Commission Internationale de l'Eclairage (CIE) L* (lightness),

a* (redness), and b* (yellowness) were measured in triplicate and averaged. Cure color fading values were calculated using the reflectance at isosbestic wavelength ratios of R_{570}:R_{650} (AMSA, 2012).

Sensory

Trained sensory analysis was approved and conducted under Institutional Review Board No. STUDY00005493. An 8-member trained panel (AMSA, 2015) was used to evaluate the organoleptic properties. Samples were removed from the vacuum package, and 6 slices were cut into fourths and served on coded serving plates for consistent mastication orientation. Each panelist received 3 slices of each sample. A maximum of 16 samples were served each day across 2 sessions, with 3 h between the start of each session. Sliced quarters were served with a glass of distilled water and salt-free soda crackers for panelists to cleanse their palates between samples. Panelists sampled and recorded traits in a dark room with positive air flow and illuminated with red lighting to mask color. Once plated, samples were given to all panelists at the same time through a breadbasket with individual walls separating each panelist.

Slices were evaluated on the textural descriptors firmness, cohesiveness, springiness, and gumminess using a 15-cm line scale with anchors at 0, 7.5, and 15 (0 indicates the least intense and 15 is the most intense). The lines were anchored on both ends using various food products as reference points for the 0- and 15-cm points. The center of each line scale was anchored at 7.5 cm with a commercially available all-beef summer sausage. The extremity anchors for hardness, springiness, and cohesiveness were bologna, Now and Later candies, and SweeTARTS candies, respectively, for 0 cm and beef jerky, marshmallows, and Now and Later candies, respectively, for 15 cm. The benchmarks for gumminess were SweeTARTS candies for 0 cm and refrigerated gummy bears for 15 cm. The panelists were from a standing trained beef sensory panel. Panelists were further screened across 4 training sessions for their ability to identify and calibrate themselves to the standard anchors. After panelist screening and calibration, 2 additional sessions directed toward the measurement of various commercial meat products were included to ensure that panelists were accurately identifying each attribute consistently.

TPA

Chilled samples (4°C) were removed from the package, and a hand-held coring device was used to extract a core of 1.27 cm (diameter) by 1.27 cm (length) from the geometric center of each sausage chub. Each core was centered on the platform of a TA-XT Texture Analyzer (Texture Technologies Corp., Hamilton, MA) and compressed to 50% of its original height by a 75-mm compression probe and a 25-kg load cell with a crosshead speed of 3.33 mm/s and a trigger force of 5 g. A 2-cycle sequence was used with a 5-s pause between compressions to allow for sample recovery. The TPA values were obtained from the graphed force-time curve output by Exponent Connect (Texture Technologies Corp., Hamilton, MA) for hardness, cohesiveness, springiness, gumminess, and chewiness.

Statistical analysis

Data were analyzed using "Proc Mixed" of SAS (version 9.3, SAS Institute Inc., Cary, NC) as a randomized split-plot design, in which total process batch (pH and cooking temperature combination) was the whole plot and chub within process treatment batch was the sub-plot. HPP times were included as fixed effects, and replication was included as a blocking factor. Chub within process batch was considered the experimental unit, and slice(s) or core was considered the observational unit. Means were separated using the "LSmeans pdiff" option for main effects and the interaction of process treatment by HPP hold time. Means were considered different at $\alpha = 0.05$.

Results and Discussion

Proximate analysis

Descriptive data for the sausage treatments are presented in Table 1. The percent fat in the raw meat block was not different between fermentation endpoints or replicates ($P = 0.17$ and $P = 0.32$, respectively). As expected, due to target endpoint pH and dextrose in the formulation, differences between fermentation endpoint pH for the treatments were achieved ($P < 0.01$). There were no differences for the MPR attributed to process treatment or HPP ($P = 0.68$, $P = 0.63$, respectively). HPP times did not affect the water activity ($P = 0.60$) of the product. Both process treatments cooked to 54.4°C and traditionally chilled (Processes A and B) had similar ($P = 0.51$) water activities. However, Processes B, C, and D were also similar to each other ($P \geq 0.06$), with Processes C and D having lower ($P \leq 0.05$) water activity than Process A.

Table 1. Least square means for proximate analysis parameters of all-beef summer sausage fermented and cooked to varying degrees of doneness

			Water activity by cook temperature				Moisture:protein by cook temperature			
Target pH	pH	Fat %	54.4°C T[1]	54.4°C	48.9°C	43.3°C	54.4°C T[1]	54.4°C	48.9°C	43.3°C
4.6	4.60[b]	8.4	0.96[c]	—	—	—	3.0	—	—	—
5.0	5.03[a]	11.3	0.96[bc]	0.97[b]	0.97[b]	0.97[a]	3.0	3.0	3.1	3.1
SEM	0.02	1.39	0.001	0.001	0.001	0.001	0.07	0.07	0.07	0.07

[1]Indicates traditional smokehouse and cooler chilling methods. All remaining samples were chilled using rapid ice water chilling.

[abc]Means within a heading with different superscripts differ ($P < 0.05$).

Process E had a higher ($P \leq 0.01$) water activity than all other processes. Although there were statistical differences among processes for water activity, all processes were between 0.96 and 0.97, with minimal variation among replicates.

All treatments met US Department of Agriculture-Food Safety and Inspection Service requirements for a summer sausage product with pH 5.0 or less and an MPR of 3.1 or less (USDA, 2011). Similar to the differences in the water activity reported in the current project, Porto-Fett et al. (2010) described the water activity of fermented, cooked, and HPP semidry fermented meat, with differences of 0.06 as subtle. The small magnitude of differences in water activity combined with similar product MPR would not be expected to affect overall summer sausage quality.

Lipid oxidation

There was not a process-by-HPP interaction ($P = 0.46$) for lipid oxidation. Furthermore, neither process nor HPP hold time impacted lipid oxidation ($P = 0.07$, $P = 0.88$ respectively). Due to the lack of differences for lipid oxidation, data are not presented in tabular form; however, samples ranged from 0.36 ± 0.06 to 0.60 ± 0.06 mg MDA/kg sausage, with an average of 0.47 mg MDA/kg sausage. Previous research has shown that HPP can have a negative effect on lipid oxidation and lipid stability of meat and meat products. The effect of HPP on lipid oxidation has been reported to be dependent on pressure setting, temperature during HPP, lipid amount and saturation index, product packaging, and whether the meat product was further processed (ready-to-eat, cooked, cured, dried) or fresh (Campus, 2010; Simonin et al., 2012; Hygreeva and Pandey, 2016). HPP can have a negative effect on the lipid stability of fresh meat samples, including beef, pork, and chicken (Cheah and Ledward, 1996; Ma et al., 2007; McArdle et al., 2010) both immediately after HPP and continuing through post-processing storage. According to the previously mentioned studies, the HPP parameters included temperatures in excess of 20°C, which was approximately 16°C above those used in the current study. Maintaining product in vacuum packaging or modified atmosphere packaging after HPP and at lower temperatures has been suggested to decrease the impact of HPP on lipid oxidation. Sun et al. (2017) reported no difference in lipid oxidation when vacuum-packaged beef steaks were subjected to HPP at 450 and 600 MPa for up to 15 min. Utama et al. (2017) found that vacuum-packaged beef steaks subjected to HPP at 600 MPa had greater lipid oxidation than steaks exposed to HPP at lower pressures (0.1, 200, and 400 MPa) and that lipid oxidation potential increased out to 6 d post processing. Contrary to the current research, Banerjee et al. (2017) reported differences in lipid oxidation between untreated mutton patties and patties processed at 200 and 400 MPa. Beltran et al. (2004) reported that minced poultry thigh samples subjected to pressurization under elevated temperatures had greater lipid oxidation than non-pressurized samples that were heated and refrigerated in aerobic conditions after 6 d of shelf life. However, there was no difference in lipid oxidation between pressurized and non-pressurized samples on d 1, indicating similar findings as the present study. In a follow-up study, Beltran et al. (2004) reported that when raw minced poultry thighs were pressurized at 500 MPa (−10°C to 50°C) for 30 or 60 min, there was no difference in lipid oxidation between the 30- and 60-min samples or after 1 or 9 d of anaerobic storage (4°C) but that cooked samples exhibited greater oxidation than uncooked samples. In the current study, the use of vacuum packaging plus the addition of nitrite in the formulation would prevent lipid oxidation during thermal processing, HPP, and further storage (Freybler et al., 1993).

Objective color analysis

There was not a process-by-HPP time interaction ($P \geq 0.08$) for any objective color measure (L*, a*, b*, and R_{570}:R_{650} for cured color fading); therefore,

Table 2. Least square means for objective color scores for all-beef summer sausage cooked to varying degrees of doneness

Process[1]	L	a*	b*	Fade[2]
Process A	53.21[a]	23.83[c]	14.58[b]	0.28[a]
Process B	52.24[b]	24.28[b]	14.57[b]	0.27[b]
Process C	52.43[b]	24.27[b]	14.56[b]	0.27[b]
Process D	51.96[b]	24.62[a]	14.89[a]	0.27[b]
Process E	52.12[b]	24.54[a]	14.92[a]	0.27[b]
Standard error	0.24	0.08	0.04	0.002

[1]Process A: pH 4.6 at 54.4°C with traditional smokehouse chilling; Process B: pH 5.0 at 54.4°C with traditional smokehouse chilling; Process C: pH 5.0 at 54.4°C with rapid ice bath chilling; Process D: pH 5.0 at 48.9°C with rapid ice bath chilling; Process E: pH 5.0 at 43.3°C with rapid ice bath chilling.

[2]Values determined by the following equation using isosbestic wavelengths: fade = 570 nm/650 nm (AMSA, 2012).

[abc]Means within a column with different superscripts differ ($P < 0.05$).

Table 3. Least square means for objective color scores for all-beef summer sausage high pressure processed at 586 MPa for varying hold times

High pressure hold time, s	L*	a*	b*	Fade[1]
0	52.13	24.56[a]	14.84[a]	0.27[b]
1	52.27	24.38[ab]	14.71[b]	0.27[ab]
150	52.48	24.24[bc]	14.67[b]	0.27[ab]
300	52.69	24.05[c]	14.60[b]	0.28[a]
Standard error	0.22	0.07	0.04	0.002

[1]Values determined by the following equation using isosbestic wavelengths: fade = 570 nm/650 nm (AMSA, 2012).

[abc]Means within a column with different superscripts differ ($P < 0.05$).

the main effects of process and HPP time are shown in Tables 2 and 3, respectively. For L* values, Process A was lighter ($P < 0.05$) than all other treatment processes, which were similar to each other ($P \geq 0.17$). HPP time did not impact sausage lightness ($P = 0.29$). Measurements of a* showed that Processes D and E, while similar to each other ($P = 0.47$), were more red ($P < 0.05$) than all other treatments. Treatments cooked to pH 5.0 and 54.4°C (Processes B and C), regardless of chilling, were similar in redness ($P = 0.97$) but were more red ($P < 0.01$) than Process A. HPP times indicated that, as time at 586 MPa increased, redness decreased ($P < 0.05$). However, the difference between 0 and 300 s was only 0.56 units.

The treatments cooked to a lower degree of doneness (Processes D and E) were similar to each other ($P = 0.64$) and were more yellow ($P < 0.01$) than the other processes, which were similar ($P \geq 0.77$) to each other. Samples processed under HPP for any amount of time, while similar to each other ($P \geq 0.06$), had lower b* values than the non-HPP controls ($P < 0.05$). Cured color fade (R_{570}:R_{650}) was greater ($P < 0.01$) in the sausages from Process A than all others, which were similar to each other ($P \geq 0.06$). Furthermore, sausages subjected to HPP for 300 s had a more faded color ($P < 0.01$) than sausages that were not subjected to HPP. Sausages that underwent HPP for 1 or 150 s were similar ($P \geq 0.18$) to those that were exposed to HPP for 0 and 300 s, respectively. Although there were differences regarding cured color fading, it is important to note that the greatest magnitude of difference was 0.01 units and likely not discernable to the naked eye.

It is likely that the majority of the overall color differences are due to the manufacturing process (pH and endpoint temperature) rather than the effects of HPP, as indicated by the differences found for L* between the processes but not the HPP times. Additionally, for a*, there was a greater magnitude of difference objectively observed as a result of process compared to the slight differences noted as a result of HPP. HPP can influence redness (indicated by its main effect of a*), but the difference is minimal and likely undetectable in subjective observation. Banerjee et al. (2017) found no difference between pressurized and non-pressurized mutton patties for the color parameters L*, a*, and b*, further substantiating the impact of cooking treatments over HPP on color parameters. Beltran et al. (2004) reported changes in the redness of minced chicken thighs; when pressure (500 MPa) was applied, the sample redness decreased. In addition, the authors reported a decrease in yellowness, although the decrease in yellowness was less remarkable than the decrease in redness. Although differences were unable to be detected in a* values with magnitudes greater than the current study (1.4 to 3.4 units), it is also important to note the elevated temperatures (5°C to 50°C) of the environment in which their chicken patties were processed compared to those of the current study (Beltran et al., 2004). As previously mentioned, the current study included sodium nitrite, heating, and acidification producing nitrosylhemochrome, which is a stable color under vacuum (AMSA, 2012). The present study also confirms that nitrosylhemochrome is stable through the HPP in cured and vacuum-packaged products that are subjected to pressures up to 586 MPa.

Sensory analysis

An interaction for process by HPP time ($P \geq 0.58$) was not observed for any of the texture attributes evaluated by the trained sensory panelists. The panelists

Table 4. Least square means for the sensory analysis of all-beef summer sausage cooked and fermented to varying degrees of doneness

Process[1]	Firmness[2]	Springiness[2]	Cohesiveness[2]	Gumminess[2]
Process A	8.4[a]	8.0[a]	8.6[a]	8.5[a]
Process B	7.8[b]	7.7[ab]	8.1[b]	7.9[b]
Process C	7.7[bc]	7.6[bc]	8.1[b]	7.9[bc]
Process D	7.4[cd]	7.5[bc]	7.9[bc]	7.5[cd]
Process E	7.1[d]	7.2[c]	7.8[c]	7.3[d]
Standard error	0.1	0.1	0.1	0.1

[1]Process A: pH 4.6 at 54.4°C with traditional smokehouse chilling; Process B: pH 5.0 at 54.4°C with traditional smokehouse chilling; Process C: pH 5.0 at 54.4°C with rapid ice bath chilling; Process D: pH 5.0 at 48.9°C with rapid ice bath chilling; Process E: pH 5.0 at 43.3°C with rapid ice bath chilling.

[2]Firmness, springiness, cohesiveness, and gumminess were measured on a 15-cm line scale with anchors at 0, 7.5, and 15 cm indicating least intensity, average intensity, and greatest intensity, respectively.

[abc]Means within a column with different superscripts differ ($P < 0.05$).

were able to distinguish process effects for firmness ($P < 0.01$), springiness ($P < 0.01$), cohesiveness ($P < 0.01$), and gumminess ($P < 0.01$; Table 4). As expected, there was a stepwise increase in the firmness and gumminess detected by panelists as temperature and fermentation intensity increased. Process A was the firmest and gummiest ($P < 0.01$) product compared to all other processing treatments. The sausages fermented to pH 5.0 and cooked to 54.4°C, regardless of chilling method, were similar to each other in firmness and gumminess ($P = 0.40$). However, only the rapidly chilled samples were similar to the treatments cooked to 48.9°C ($P = 0.15$). Processes D and E were also similar to each other ($P = 0.08$), but Process E was less firm and gummy than Process C ($P < 0.01$).

Panelists also noted a stepwise increase in springiness as fermentation and cooking intensity increased (Table 4). Processes A and B were similar to each other ($P = 0.09$). However, Process A was springier than Processes C, D, and E ($P < 0.05$). Process B was similar to Processes C and D ($P \geq 0.31$) but was springer than Process E ($P < 0.01$). Finally, Processes C, D, and E were all similar to each other ($P \geq 0.05$). The sausages fermented to pH 4.6 and cooked to 54.4°C (Process A) were rated the most cohesive ($P < 0.01$), followed by the treatments fermented to pH 5.0 and cooked to 54.4°C and 48.9°C, regardless of chilling method (Processes B, C, and D, respectively), which were similar to each other ($P \geq 0.20$). The sausages fermented to pH 5.0 and cooked to 43.3°C (Process E) were the least cohesive but were similar ($P > 0.39$) to the sausages from Process D. The trained panelists were unable to detect a difference in texture attributes in the sausages exposed to different HPP times ($P \geq 0.46$; Table 5).

Table 5. Least square means for the sensory analysis of all-beef summer sausage high pressure processed at 586 MPa for varying hold times

High pressure hold time, s	Firmness	Springiness	Cohesiveness	Gumminess
0	7.6	7.6	8.0	7.7
1	7.6	7.5	8.1	7.7
150	7.7	7.7	8.1	7.9
300	7.8	7.6	8.2	8.0
Standard error	0.1	0.1	0.1	0.1

Firmness, springiness, cohesiveness, and gumminess were measured on a 15-cm line scale with anchors at 0, 7.5, and 15 cm indicating least intensity, average intensity, and greatest intensity, respectively.

Others have shown that increased temperatures were associated with a firmer and less tender product (Mathevon et al., 1995; Pohlman et al., 1997). Other attributes evaluated by the panelists in the current study showed similar results to that of firmness, in which an increased cooking intensity led to increased springiness, cohesiveness, and gumminess. Additionally, Marcos et al. (2007) reported that trained sensory panelists, when evaluating the hardness and gumminess of low-acid fermented sausages, were unable to distinguish differences between pressurized and unpressurized fermented sausages. Mor-Mur and Yuste (2003) performed triangle tests comparing pressurized fermented sausages to heat-treated fermented sausages, finding that, in all cases, panelists preferred the pressurized samples over the heat-treated samples, describing them as less grainy and more uniform in texture. Although the literature is limited at present, the inability of trained sensory panelists to discern textural differences among HPP processing times should give processors confidence that the use of HPP would not affect sensorial perceptions.

TPA

Similar to the trained sensory analysis, there was not a process-by-HPP time interaction ($P = 0.47$) for TPA. The main effects for TPA due to cooking treatment and HPP time are presented in Tables 6 and 7, respectively. The differences among processes for hardness of the sausages when measured by TPA followed a trend similar to that of the sensory firmness. Process A was harder ($P < 0.01$) than the other processes. Processes C and D were similar ($P = 0.47$) in hardness; however, only Process C was similar to

Table 6. Least square means for the instrumental texture analysis of all-beef summer sausage cooked and fermented to varying degrees of doneness

Process[1]	Hardness (N)	Springiness (%)	Cohesiveness	Gumminess	Chewiness
Process A	66.3[a]	63.5[ab]	0.324[a]	21.1[a]	1,340[a]
Process B	55.4[b]	65.0[a]	0.292[b]	16.1[b]	1,053[b]
Process C	54.0[bc]	63.8[ab]	0.286[b]	15.4[bc]	986[bc]
Process D	50.9[cd]	62.7[b]	0.286[b]	14.4[cd]	907[cd]
Process E	48.2[d]	60.2[c]	0.296[b]	14.1[d]	854[d]
Standard error	1.6	0.6	0.006	0.4	30

[1]Process A: pH 4.6 at 54.4°C with traditional smokehouse chilling; Process B: pH 5.0 at 54.4°C with traditional smokehouse chilling; Process C: pH 5.0 at 54.4°C with rapid ice bath chilling; Process D: pH 5.0 at 48.9°C with rapid ice bath chilling; Process E: pH 5.0 at 43.3°C with rapid ice bath chilling.

[abc]Means within a column with different superscripts differ ($P < 0.05$).

Table 7. Least square means for the instrumental texture analysis of all-beef summer sausage high pressure processed at 586 MPa for various hold times

High pressure hold time, s	Hardness (N)	Springiness (%)	Cohesiveness	Gumminess	Chewiness
0	55.7	62.9[ab]	0.296	16.4[ab]	1,040[a]
1	52.5	61.8[b]	0.293	15.3[c]	949[b]
150	54.9	63.4[a]	0.295	16.1[bc]	1,025[a]
300	56.8	64.0[a]	0.302	17.1[a]	1,098[a]
Standard error	1.5	0.5	0.013	0.4	27

[abc]Means within a column with different superscripts differ ($P < 0.05$).

Process D ($P = 0.13$). Additionally, Processes D and E were similar ($P = 0.17$), even though Process E was less hard ($P < 0.01$) than C. Similar to sensory analysis, hardness as measured by TPA was not impacted by HPP time ($P = 0.10$).

The sample recovery in height after the first compression and before the second compression is an indication of springiness. The treatments cooked to 54.4°C, regardless of pH or cooling method (Processes A, B, and C), were similar to each other ($P \geq 0.08$) and springier ($P < 0.01$) than Process E sausages. Unlike sensory analysis, HPP hold time did influence springiness ($P < 0.05$). Hold times of 300, 150, and 0 s were similar to each other ($P \geq 0.19$), whereas samples held for 300 and 150 s were springier ($P < 0.01$) than those held for 1 s. There was no difference ($P = 0.09$) in sample springiness for hold times between 0 and 1 s.

The sausages from Process A were more cohesive ($P < 0.01$) than the others, and all other processes were similar to each other ($P \geq 0.18$). Cohesiveness was not affected by HPP time ($P = 0.62$), again following the same trend as that recorded from sensory analysis. Gumminess, a product's hardness as it relates to its ability to stay together, was influenced by both cooking treatment and HPP hold time ($P < 0.01$). The sausages fermented to pH 4.6 (Process A) were the gummiest ($P < 0.01$), while the products fermented to 5.0 and cooked to 54.4°C, regardless of cooling method (Processes B and C), were similar to each other ($P = 0.20$) but gummier ($P < 0.05$) than the sausages cooked to 43.3°C (Process E). Processes C and D were similar ($P = 0.10$), with only Process D being similar to E ($P = 0.55$). HPP hold times of 300 and 0 s were similar for gumminess ($P = 0.17$). The treatments receiving 150 s of hold time during HPP were less gummy ($P < 0.05$) than those receiving 300 s of hold time, even though 150 s of hold time was similar ($P > 0.06$) to both 0 and 1 s.

Process and HPP hold time influenced chewiness ($P < 0.01$) and followed a similar trend for process as gumminess. Process A was the chewiest ($P < 0.01$), and Processes D and E were similar to each other ($P = 0.14$) and less chewy ($P < 0.05$) than the other treatments. Furthermore, Processes B and C were similar to each other ($P = 0.06$). Treatments receiving 300-s HPP were chewier ($P < 0.05$) than the other treatments. Sausages subjected to HPP for 0 and 150 s were similar ($P = 0.68$) in chewiness and were chewier ($P < 0.05$) than samples processed for 1 s.

Hardness results were in agreement with sensory panelist observations of hardness/firmness, springiness, cohesiveness, and gumminess. Instrumental texture analysis also agreed with sensory panelist evaluations in regard to HPP hold times for hardness and cohesiveness. Mor-Mur and Yuste (2003) reported no difference

for hardness or springiness when unprocessed cooked sausages were compared to ones subjected to HPP at 500 MPa for 300 s. Their findings were attributed to the industrial cooking process causing gelation within the sausage, as well as subsequent pressure processing having only the ability to induce exudation, minorly impacting texture. Pressurization parameters used by Mor-Mur and Yuste (2003) included temperatures of 65°C, well above the heating parameters used in the current study, which could have increased protein gelation and subsequent hardening during the pressurization process. Marcos et al. (2007) reported an increase in cohesiveness, chewiness, and springiness during the pressurization of low-acid fermented sausages. Their parameters included HPP temperatures (17°C) above those used during their ripening process, which could have increased the ultimate temperature of the sausage. As noted in this study by the difference between Processes C, D, and E, the ultimate temperature endpoint does have an effect on sausage texture. Although few manuscripts exist describing the texture of low-acid fermented sausages subjected to HPP, data show that, while HPP might have an effect on sausage texture, the main force exerting control over texture is product ultimate temperature.

Conclusions

Summer sausage products that received less rigorous fermentation and thermal processing were less firm, springy, cohesive, and gummy than summer sausage products fermented and cooked to industry-validated endpoints (pH 4.6 and thermally processed to 54.4°C). The use of HPP at 586 MPa for up to 300 s did not influence the ability of trained sensory panelists to differentiate among the products even though there were slight differences for springiness, gumminess, and chewiness with evaluation by objective TPA. Although there were some differences in objective color attributed to cooking treatment and HPP hold times, the differences were minimal, and it is questionable whether they would be subjectively differentiated. HPP at 586 MPa for up to 300 s may be incorporated into a food safety plan without impacting sensory and texture attributes.

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