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Effects of high-pressure processing on cooked color and eating qualities of dark-cutting beef

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ABSTRACT

High meat pH leads to an undercooked or an abnormal pink appearance in fully-cooked product. High-pressure processing (HPP) promotes protein denaturation. The objective was to evaluate the effects of HPP on cooked steak color and sensory attributes of dark-cutting beef. USDA Choice (mean pH = 5.5) and dark-cutting (mean pH = 6.3) strip loin sections were vacuum packaged and treated with 0 (no HPP), 300, 450, and 600 MPa of pressure for 90 s using chilled water. Steaks were randomly assigned to measure external cooked color, Warner-Bratzler shear force, and trained sensory panel. Applying 300 MPa of pressure improved ($P < 0.05$) redness of raw dark-cutting steaks compared with control. HPP treatments did not influence ($P > 0.05$) a^* and chroma of the external cooked steak color. HPP treatments also did not affect ($P > 0.05$) initial juiciness, sustained juiciness, beef flavor intensity, or overall acceptability. However, 600 MPa made dark-cutting steaks tougher and lighter ($P < 0.05$) in appearance than all other treatments. In conclusion, low (300 MPa) and moderate (450 MPa) pressure levels improved raw steak redness without affecting the eating qualities of dark-cutting cooked steaks. HPP did not minimize the undercooked appearance commonly associated with high-pH beef.

1. Introduction

Maillard reaction and myoglobin denaturation are the two important biochemical reactions determining cooked meat color (Djimsa et al., 2017; Hunt et al., 1999; King & Whyte, 2006). A study noted that 67% of consumers use color as a primary means to assess doneness (Ramanathan et al., 2017). Myoglobin is the primary protein responsible for meat color, and it can exist as oxy-, deoxy-, and metmyoglobin in fresh meat (AMSA, 2012). The thermal stability of myoglobin forms is different. For example, deoxymyoglobin is stable to heat, while oxy- and metmyoglobin forms are labile to heat (Hunt et al., 1999). Depending on the cooking temperature, the cooked color ranges from rare (pinkish red; 65 °C) to well-done (brown; 77 °C). The formation of ferrohemochrome gives purplish red, while ferrihemochorme gives brown color to cooked meat (Yoshida et al., 1965). However, various factors, such as myoglobin form before cooking and pH, influence cooked meat color (Grobbel et al., 2008; Holdstock et al., 2014; Suman et al., 2016). Greater muscle pH protects myoglobin from denaturation and imparts a pink or undercooked appearance (Moiseev & Cornforth, 1999). High-pH or dark-cutting meat cooked to the United States Department of Agriculture's (USDA) recommended temperature of 71 °C appears undercooked (Apple et al., 2011; Mancini et al., 2011). Therefore, developing post-harvest processes to minimize persistent pinking in high-pH cooked meat is critical for consumer acceptance.

Previous studies noted citric acid enhancement and high-oxygen packaging minimized the cooked pink color of dark-cutting beef (Stackhouse et al., 2016; Yang et al., 2022). High-pressure processing (HPP) is a non-thermal pasteurization technique increasingly used in the food industry (Hygreeva & Pandey, 2016; Janardhanan et al., 2022). Of the total HPP applications in the food industry, meat products account for approximately 20% (Jung & Samson, 2018). Paleness associated with the HPP application limits its use in fresh meat. More specifically, greater pressure leads to protein denaturation and causes gelling of raw meat (Bak et al., 2019; Bolumar et al., 2021). Recent studies from our laboratory noted that 300 MPa application to dark-cutting beef improved redness and reversed muscle darkening (Reesman et al., 2022). However, limited knowledge is currently available on the effects of HPP on cooked external color and palatability. The hypothesis of the study was HPP treatment will increase myoglobin denaturation and minimizes pinking in cooked dark-cutting beef. Therefore, the objective

Abbreviations: HPP, High-pressure processing; MPa, Mega pascal; WBSF, Warner-Bratzler shear force.

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of the study was to evaluate the effects of 0, 300, 450, and 600 MPa pressure on the external cooked color and palatability of dark-cutting beef.

2. Materials and methods

2.1. Experimental design

The current research had four levels of pressure treatments. A loin length is not enough to allocate all four HPP treatments. Hence, an incomplete block design was used (Mancini et al., 2009) to determine the effects of high-pressure processing on cooked dark-cutting beef quality. Normal-pH (n = 8) and dark-cutting (n = 12) strip loins (*longissimus lumborum*) were purchased 2 d postmortem from a USDA-inspected slaughter facility in Nebraska. The loins were transported to the University of Nebraska-Lincoln Loeffel Meat Laboratory and aged for 5 additional days. Normal-pH loins with no high-pressure processing application were used as a control. Following aging, each dark-cutting loin was cut into three equal sections and randomly assigned to 0, 300, 450, and 600 MPa of pressure treatment resulting in eight replications (12 loins × 3 = 36 sections; from 36 sections, 32 sections that had uniform pH and color were selected for the present study; 32 sections ÷ 4 treatments = 8 replications). Each section was vacuum packaged (Flair Flexible Packaging Corporation; 12 × 14 cm^2 pouches; 5 mil thickness) for HPP application.

2.2. High-pressure processing

The approach reported in previously published research was used in the application of HPP (Sun et al., 2017, 2019). A commercial HPP unit located at the Food Processing Center at the University of Nebraska Lincoln was utilized to apply pressure on dark-cutting strip loin sections (Hiperbaric 55, Hiperbaric USA, Miami, FL; 55 L vessel; 200 mm diameter inside the vessel; throughput of 270 kg/h) with chilled water (12–16 °C) as the pressurizing medium. Vacuum packaged loin sections were placed in bins packed with ice so that the fluid temperature was lowered to 8 °C. All sections were processed and held for 90 s at the designated pressure level. The pressurization rate of the HPP unit was between 1 and 1.5 min. After high-pressure treatment, all strip loin sections were transported on ice to the Robert M. Kerr Food and Agricultural Products Center at Oklahoma State University (Stillwater, OK) for meat quality studies.

2.3. Allocation of steaks for raw and cooked quality analysis

After HPP, the strip loin sections were stored in the dark at 2 °C for 48 h. Following storage, each section was cut into four 1.9-cm-thick steaks. The first steak was used for raw color and pH measurements, the second steak was used for instrumental shear force, the third steak was used for taste panel, and the fourth steak was used for cooked external color analysis. The steaks assigned for instrumental tenderness, external cooked color, and taste panel were frozen for four weeks in a −18 °C freezer until analysis.

2.4. Raw color and pH measurements

Steaks assigned for raw color analysis were placed in Styrofoam® trays and overwrapped with PVC (15,500–16,275 cm^3 O_2/m^2 /24 h at 23 °C, E-Z Wrap Crystal Clear Polyvinyl Chloride Wrapping Film; Koch Supplies; Kansas City, MO), and bloomed at 2 °C for 1 h. Overwrapping steaks limit moisture loss during bloom (AMSA, 2012). The instrumental color was measured using a HunterLab 4500 L MiniScan EZ Spectrophotometer (2.5 cm aperture, illuminant A, and 10̊ standard observer angle; HunterLab Associates, Reston, VA). The HunterLab MiniScan spectrophotometer readings provide the Commission International de l'éclairage L^*, a^*, and b^* values and reflectance from 400 to 700 nm. The surface of each steak was read three times, and the surface color was characterized by the Commission International de l'éclairage L^*, a^*, and b^* values and reflectance from 400 to 700 nm.

The initial pH of dark-cutting strip loins and USDA Choice strip loins were measured at the University of Nebraska-Lincoln using a pH instrument probe (Handheld HI 99163; probe FC232; Hanna Instruments, Smithfield, RI) at three different locations of each strip loin (Supplemental Fig. 1). At Oklahoma State University, the pH was measured by blending 5 g of the sample with 50 mL of distilled water. Once blended, samples were placed in an incubator for 10 min (VWR Forced Air General Incubator, 5.4 ft^3; VWR, Radnor, PA) until sample temperature reached 25 ± 0.5 °C. pH is influenced by temperature. Hence, all samples were incubated to reach a temperature of 25 ± 0.5 °C. Three pH measurements were taken using a tabletop pH probe (OrionStar A111 pH meter; Thermo Scientific, Waltham, MA).

2.5. Cooked color analysis

Frozen steaks were thawed at 4 °C for 24 h. Steaks were cooked in a Rational oven (hot air oven with air circulation; Model SCC WE 102 G, Rational AG, Landsberg am Lech, Germany). Steak temperature was monitored in the cooking process using an oven core temperature probe (Model SCC WE 61 E; Rational, Landberg am Lech, Germany) placed in the geometric center of one centrally located steak. Steaks were removed from the oven after achieving an internal temperature of 71 °C. The average cooking time was 10 min. The temperature of the oven was set to 204.4 °C with 0% humidity and default air circulation speed. The external steak color was measured at three locations described in Section 2.4.

2.6. Trained sensory panel

Sensory panelists were trained using the beef flavor lexicon (Adhikari et al., 2011). The descriptive sensory panel was approved by the Institutional Review Board. A total of six trained panelists (n = 6) evaluated cooked samples (Miller et al., 2019). Each panelist tasted all five treatments. Ten samples were tested in each session. There were four sessions to taste 40 samples by each panelist. Therefore, six panelists tasted 240 samples. The same panelists tasted all samples during four sessions. The cooking of steaks is described in Section 2.5. Samples were cut into 1 cm × 1 cm × 1.9 cm pieces and placed into sample cups. Each sample cup contained two pieces. Sample cups were placed into a warming cabinet during sensory evaluation to maintain a temperature of 50 °C. Samples were evaluated under red lighting. Panelists cleansed their palettes between samples with deionized water and salt-free crackers. Panelists used an 8-point hedonic scale (Adhikari et al., 2011; Denzer et al., 2020) to evaluate initial juiciness (1 = extremely dry, 8 = extremely juicy), sustained juiciness (1 = extremely dry, 8 = extremely juicy), tenderness (1 = extremely tough, 8 = extremely tender), beef flavor intensity (1 = extremely dull, 8 = extremely beefy), and overall acceptability (1 = extremely dislike, 8 = extremely like).

2.7. Warner-Bratzler shear force

Steaks were thawed for 24 h at 4 °C before cooking (details of cooking in Section 2.5). Steaks were cooled for 18 h at 4 °C prior to shearing. Six cores were taken from each steak (1.27 cm in diameter) parallel to the muscle fiber orientation. The Instron Universal Testing Machine (Model 66 5943; Instron Corporation; Norwood, MA) with Bluehill 3 software was used to evaluate the maximum load (Newton) of each core. The crosshead speed was 200 mm min^{-1}.

2.8. Statistical analysis

An incomplete block design was used to evaluate the effects of HPP pressure levels (0, 300, 450, and 600 MPa) on cooked color and eating

quality (n = 8 replications). The pressure levels were considered as a fixed effect. Panelists considered a random effect for the sensory data. The sensory session day had no effect; hence not included in the model. The least squares means were determined using the PROC GLIMMIX procedure, separated using the PDIFF options of SAS (SAS, 2022; SAS 9.4; SAS Inst.; Cary, NC), and considered significance at $P < 0.05$.

3. Results

3.1. pH and raw color

Applying 450 and 600 MPa of pressure for 90 s using chilled water increased pH compared with control dark-cutting steaks and dark-cutting steaks treated with 300 MPa (Table 1). As expected, dark-cutting steaks had greater pH and lower lightness and redness than normal-pH steaks. The HPP increased lightness and redness of dark-cutting steaks. The reflectance spectra indicated dark-cutting steaks had lower reflectance from 400 nm to 700 nm (Fig. 1). Steaks treated with 300 MPa had similar spectral characteristics compared to normal-pH steaks between 400 nm and 590 nm. Steaks applied with 450 and 600 MPa had greater reflectance than 300 MPa and control dark-cutting steaks. The HPP decreased absorbance at 525 nm (isobestic form for all three myoglobin forms). Lower absorbance at 525 nm indicates lower myoglobin concentration and myoglobin denaturation (Fig. 2; dark-cutter control > dark-cutter 300 > dark-cutter 450 = dark-cutter 600 MPa; $P < 0.05$). The HPP increased metmyoglobin content on surface (dark-cutter control < dark-cutter 300 < dark-cutter 450 < dark-cutter 600 MPa; $P < 0.05$).

Table 1
Effect of high-pressure processing[1] on raw color and pH of beef longissimus steaks.

Sample	Pressure levels	L^* values	a^* values	pH
Normal-pH	0	42.2^{e}	32.4^{d}	5.5^{c}
Dark-cutter	0	34.6^{d}	23.2^{c}	6.5^{b}
Dark-cutter	300 MPa	41.2^{c}	27.4^{b}	6.5^{b}
Dark-cutter	450 MPa	50.2^{b}	28.4^{a}	6.7^{a}
Dark-cutter	600 MPa	51.8^{a}	29.4^{a}	6.6^{a}
	SEM[2]	0.6	0.55	0.05

[a-c] Least squares means with different letters are significantly different ($P < 0.05$; n = 8).
[1] HPP was achieved by using chilled water as a pressuring medium for 90 s.
[2] SEM = standard error of the mean.

Table 2
Effect of high-pressure processing[1] on cooked color of external surface of steaks.

Sample	Pressure levels	L^* values	a^* values	b^* values	Chroma	Hue
Normal-pH	0	35.1^{b}	15.4^{b}	18.2	23.9^{b}	49.7^{a}
Dark-cutter	0	36.7^{b}	18.9^{a}	20.0	27.6^{a}	46.7^{b}
Dark-cutter	300 MPa	35.0^{b}	20.2^{a}	20.4	28.8^{a}	45.0^{bc}
Dark-cutter	450 MPa	36.5^{b}	20.3^{a}	19.8	28.4^{a}	44.1^{c}
Dark-cutter	600 MPa	40.0^{a}	19.0^{a}	20.2	27.8^{a}	46.5^{b}
	SEM[2]	0.9	0.5	0.7	0.8	0.7

[a-c] Least squares means with different letters are significantly different ($P < 0.05$; n = 8).
[1] HPP was achieved by using chilled water as a pressuring medium for 90 s.
[2] SEM = standard error of the mean.

3.2. Instrumental cooked color

There was a significant pressure level effect on L^* values, a^* values, chroma, and hue for the external surface of cooked steaks ($P < 0.05$; Table 2). The cooked steaks that applied with a pressure of 600 MPa had greater L^* values ($P < 0.05$) than all other steaks. L^* values of cooked steaks treated at 300 and 450 MPa were not different ($P > 0.05$) from both control steaks. The normal-pH control steaks exhibited lower ($P < 0.05$) a^* values than HPP-treated steaks after cooking. There were no differences ($P > 0.05$) in redness among cooked dark-cutting control steaks and steaks treated with the HPP. There was no HPP level effect ($P > 0.05$) for b^* values of cooked steaks. Normal control steaks had the lowest ($P < 0.05$) chroma and the least red intensity of all steaks after cooking. There was no difference ($P > 0.05$) in red intensity among HPP-treated steaks and dark-cutting control cooked steaks. The hue of normal-pH control cooked steaks was the highest ($P < 0.05$) than other treatments. Higher hue values in cooked steaks indicate a more well-done cooked color. Steaks treated at 300 and 600 MPa were statistically similar ($P > 0.05$) to dark-cutting control, while a pressure level of 450 MPa had less ($P < 0.05$) hue than dark-cutting control steaks.

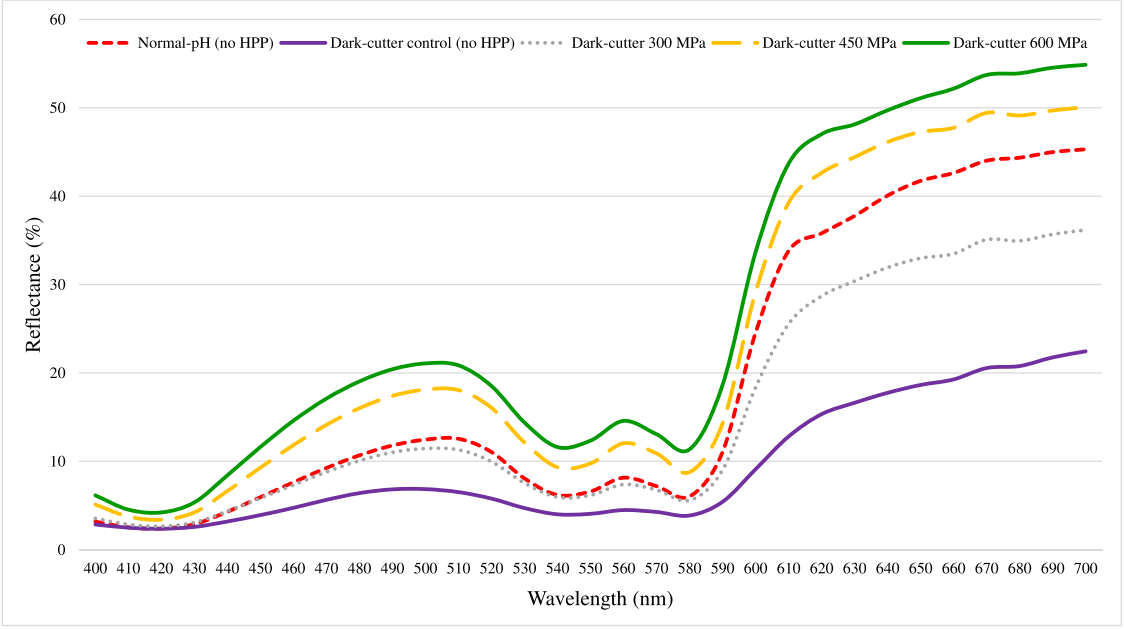

Fig. 1. Effects of high pressure processing for 90 s using chilled water on reflectance spectral characteristics of raw beef longissimus steaks.

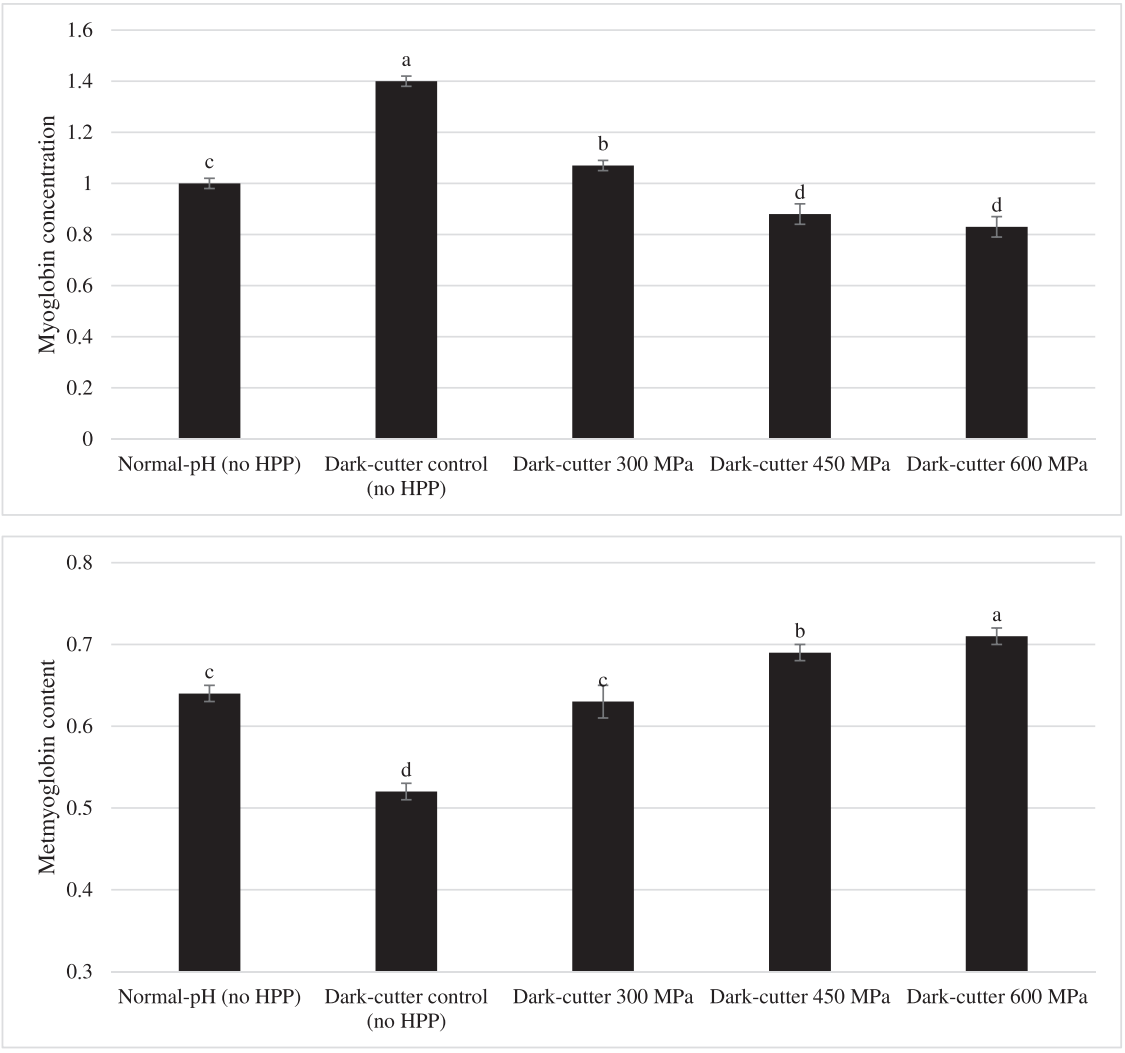

Fig. 2. Effects of high-pressure processing for 90 s using chilled water on total myoglobin concentration and metmyoglobin level[1].
[1]Myoglobin concentration was determined as absorbance at 525 nm. Metmyoglobin was determined as absorbance at 503 nm (wavelength maxima of metmyoglobin; metmyoglobin calculated as absorbance 503 nm ÷ 525 nm). Standard error bars are indicated. Reflectance values were converted to absorbance by log transformation (absorbance = −1 ÷ [log(1/R)], where R is reflectance. Least square means within a parameter with different letters (a-d) are different ($P < 0.05$).

In support of raw color, cooked 600 MPa steaks had more reflectance values than other treatments. Increased redness of high-pH steaks was also confirmed with greater reflectance between 590 nm to 630 nm (Fig. 3).

3.3. Warner-Bratzler shear force (WBSF)

There was a pressure level effect ($P < 0.05$) on Warner-Bratzler shear force (WBSF) values (Table 3). The WBSF measures the tenderness of a sample by using physical force (AMSA, 2016). High WBSF measurements indicate more force is required to cut through the sample. Therefore, lower values represent a more tender sample. Steaks treated at 600 MPa had the highest ($P < 0.05$) WBSF values than other treatments. Dark-cutting control and normal-pH control steaks had the lowest ($P < 0.05$) WBSF values; however, the 450 MPa treated steaks were not different ($P > 0.05$) from the controls (Table 3).

Table 3
Effect of high-pressure processing[1] on Warner-Bratzler shear force values.

Sample	Pressure levels	WBSF (N)	SEM[2]
Normal-pH	0	26.6[c]	1.9
Dark-cutter	0	24.7[c]	1.9
Dark-cutter	300 MPa	33.0[b]	1.9
Dark-cutter	450 MPa	29.2[bc]	1.9
Dark-cutter	600 MPa	48.2[a]	1.9

[a-c] Least squares means with different letters are significantly different ($P < 0.05$; $n = 8$).
[1] High pressure processing (HPP) treatments for 90 s using chilled water included normal-pH USDA Choice and dark-cutting loin sections. Samples that were not HPP-treated (i.e., 0 MPa) were used as a control.
[2] SEM = standard error of the mean.

3.4. Sensory analysis

Of all attributes evaluated by panelists, only tenderness was significantly affected by pressure level ($P < 0.05$). Similar to WBSF results, 600 MPa treatment had the lowest ($P < 0.05$) tenderness scores (Table 4). Steaks treated at 300 and 450 MPa were statistically similar ($P > 0.05$) to normal-pH control steaks. There were no differences ($P > 0.05$) in beefy flavor, overall acceptability, initial juiciness, and sustained juiciness amoung different treatments.

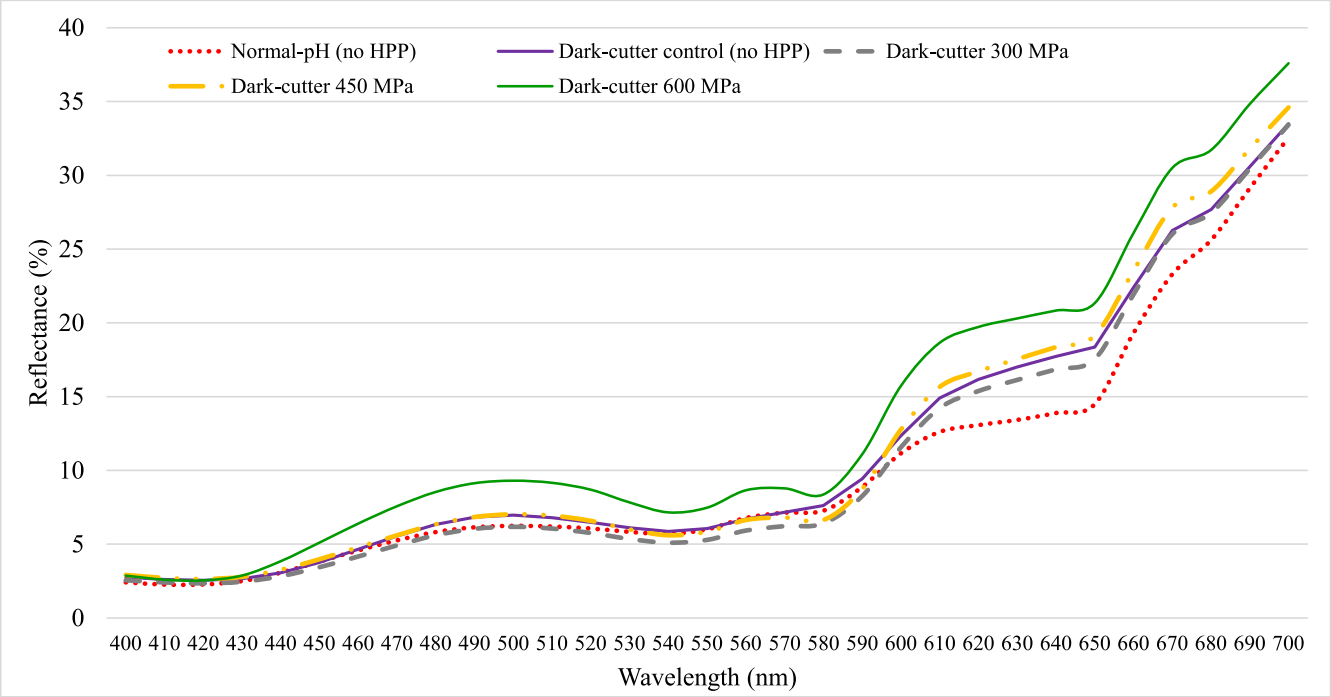

Fig. 3. Effects of high-pressure processing for 90 s using chilled water on reflectance spectral characteristics of cooked external surface of beef longissimus steaks.

Table 4
Effect of HPP[1] on trained taste panelists' scores[2] of steaks.

Sample	Pressure levels	Initial juiciness	Sustainable juiciness	Tenderness	Beef flavor	Overall acceptability
Normal pH	0	6.3	6.1	5.7[ab]	6.5	5.7
Dark-cutter	0	5.5	5.2	6.5[a]	6.5	6.1
Dark-cutter	300 MPa	5.2	5.0	5.8[a]	6.1	5.7
Dark-cutter	450 MPa	5.9	5.6	6.2[a]	6.8	6.1
Dark-cutter	600 MPa	5.7	5.5	4.9[b]	6.8	5.3
	SEM[3]	0.3	0.3	0.3	0.2	0.3

[ab] Least squares means with different letters are significantly different ($P < 0.05$).
[1] High pressure processing (HPP) treatments for 90 s using chilled water included normal-pH USDA Choice and dark-cutting loin sections. Samples that were not HPP-treated (i.e., 0 MPa) were used as a control.
[2] Trained panelists used an 8-point scale (1 = extremely dry, 8 = extremely juicy) for initial and sustainable juiciness. For tenderness, beef flavor, and overall, trained panelists used a 8-point scale (1 = extremely tough, 8 = extremely tender; 1 = extremely dull, 8 = extremely beefy, 1 = extremely dislike, 8 = extremely like).
[3] SEM = standard error of the mean.

4. Discussion

4.1. Raw and cooked color

Improving redness of dark-cutting beef has economic benefits. Hence, various approaches such as enhancement, modified atmospheric packaging, and nitrite-embedded packaging have been used to improve redness of dark-cutting beef (Denzer et al., 2022; Mitacek et al., 2018; Ramanathan et al., 2018; Wills et al., 2017; Zhang et al., 2018). Dark-cutting beef is characterized by lower postmortem glycogen content (Kiyimba et al., 2021). Hence, lower lactic acid is formed during glycolysis, resulting in greater than normal postmortem muscle pH. High pH increases oxygen consumption and leads to a lack of shrinkage of muscle bundles. Both conditions can decrease light reflectance and darker beef (English et al., 2016b; Hughes et al., 2017; Ramanathan et al., 2020). In the current research, the HPP at 300 MPa improved redness of dark-cutting beef with less metmyoglobin than other pressure levels. Although previous studies determined the effects of HPP on normal-pH and processed meat (Bak et al., 2019; Sun et al., 2019), limited knowledge is available on the application of high-pressure processing on high-pH beef. Previous research from our laboratory also noted low-pressure levels improved redness without affecting paleness (Reesman et al., 2022). Low-pressure levels can increase myoglobin oxygenation (Bak et al., 2019). Previous studies observed that dark-cutting beef has less myoglobin oxygenation and a lack of muscle shrinkage (Ramanathan et al., 2022). Hence, improved redness can be attributed to increased oxygen diffusion and oxygenation of myoglobin. However, previous studies reported higher pressure levels lead to myoglobin denaturation (Bak et al., 2019), which was also observed in the current study. Previous studies also noted greater metmyoglobin formation at greater high-pressure processing (Bak et al., 2019; Jung et al., 2003).

Myoglobin denaturation is influenced by myoglobin form and pH (Djimsa et al., 2017; Suman et al., 2016). Hunt et al. (1999) reported deoxymyoglobin to be more heat stable than metmyoglobin at higher pH levels when it was cooked at 70 °C. Dark-cutting beef has a greater amount of deoxymyoglobin than normal pH beef (English et al., 2016b; Hughes et al., 2017; McKeith et al., 2016). Hence, pink color was noted in cooked high-pH beef than cooked normal-pH steaks. Sawyer et al. (2008) also reported a^* values of dark-cutting steaks are greater than those of normal-pH steaks. Normal-pH con-

trol cooked steaks illustrated lower chroma and higher ($P < 0.05$) hue than dark-cutting control steaks (Sawyer et al., 2008). There is limited research examining dark-cutting strip steaks' external cooked surface color after HPP treatment. Previous studies have evaluated HPP of meat and sous vide cooking. Utilizing sous vide cooking, Janardhanan et al. (2022) examined different pressure levels and concluded no difference in a^* values between pressure levels of cooked ground veal patties. Frenzel (2015) noted no difference in b^* values of cooked normal-pH steaks and high-pressure processing treated steaks. Sun et al. (2019) reported increased L^* in the HPP-treated sous vide cooked steaks. However, similar a^* values were reported between HPP treated sous vide cooked steaks and non-HPP-treated steaks (Sun et al., 2019).

Previous studies utilized lowering muscle pH or increasing oxymyoglobin levels as an intervention to minimize cooked pink color in dark-cutting beef (Sawyer et al., 2009; Yang et al., 2022). In this research, we speculated that HPP-induced increased myoglobin denaturation and metmyoglobin formation might limit cooked pink color in high-pH beef. Interestingly, the HPP treatment for 90 s had no effect on the cooked external color. The mechanistic basis for redness in HPP-treated and cooked dark-cutting steaks is not clear.

4.2. Tenderness and taste panel

Past research by Apple et al. (2011) supports the current study as it noted no difference in shear values between control dark-cutting steaks and normal-pH steaks. Holdstock et al. (2014) noted no differences in tenderness between dark-cutting steaks and normal-pH steaks when it was evaluated by a taste panel. No differences in initial and sustained juiciness were reported between dark-cutting and normal-pH sensory analysis (Holdstock et al., 2014; Wulf et al., 2002). Conversely, Wulf et al. (2002) reported more tenderness in dark-cutting steaks compared with normal-pH steaks. Sun and Holley (2010) noted that lower pressures (<200 MPa) could tenderize pre-rigor meat; however, the HPP treatments of post-rigor meat must be used with a combination of higher temperatures to enhance tenderness. In the current study, there were no differences between tenderness between dark-cutting control and 300 MPa. In support, Jung et al. (2000) concluded that a pressure level of 300 MPa did not improve tenderness. In this study, steaks treated at 600 MPa had higher WBSF values than other treatments. In support, Sun et al. (2017) demonstrated that increasing pressure levels to 600 MPa led to slightly tougher values than treatment at 450 MPa. Sun et al. (2019) reported similar WBSF values for 450 MPa and 600 MPa treated steaks, but consumer panelists liked the tenderness of 450 MPa than 600 MPa steaks within the same cooking time. High-pressure application (600 MPa) induces cross-linking of myofibrillar protein (Bolumar et al., 2021). In addition, depending on the pressure level, proteins will be either soluble or insoluble. Hence, high pressure in combination with cooking can enhance cross-linking and gelation (Bak et al., 2019; Lepetit, 2007). Therefore, steaks treated with 600 MPa had the greatest shear force value than other treatments. When comparing HPP-treated steaks to normal-pH steaks, Frenzel et al. (2015) reported no significant beef flavor and juiciness differences. Previous research noted HPP increased lipid and protein oxidation, which can influence palatability. Therefore, greater pH in dark-cutting beef might have minimized its impact on eating qualities. In support, lipid oxidation in dark-cutting beef was lower than normal-pH (English et al., 2016a; Wills et al., 2017). To our knowledge, current research is the first to compare the effects of pressure levels and cooking on dark-cutting beef tenderness and color. Lower pressure has minimal impact on microbial quality; hence microbial quality was not assessed in the current research.

5. Conclusion

Improving the appearance and value of dark-cutting beef benefits producers and the meat industry. Although previous studies assessed the effects of HPP on normal-pH meat, limited information is available on its application in high-pH meat. The current research demonstrated that applying 300 MPa for 90 s using chilled water can improve redness and extend shelf-life of dark-cutting beef. HPP at 600 MPa increased metmyoglobin level and toughness of steaks. In summary, HPP at 300 MPa for 90 s can improve redness of dark-cutting beef without affecting eating qualities.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Ethical statement

Meat was purchased from a USDA inspected slaughterhouse.

The trained sensory panel was approved by the Oklahoma State University Institutional Review Board (Protocol Number: AG -18-34).

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.afres.2022.100260.

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