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Understanding the Impact of Oven Temperature and Relative Humidity on the Beef Cooking Process

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Abstract: The objective of this study was to evaluate the roles that cooking rate and relative humidity has on the sensory development of beef strip steaks. Thirty USDA Choice beef strip loins were collected from a commercial packing facility. Each strip loin was cut into steaks and randomly assigned to 1 of 6 cooking methods utilizing 2 oven temperatures (80°C and 204°C) and 3 levels of relative humidity [zero (ZH), mid (MH), and high (HH)]. Cooked steaks were used to evaluate internal and external color, Warner-Bratzler and slice shear force, total collagen content, protein denaturation, and trained sensory ratings. Relative humidity greatly reduced cooking rate, especially at 80°C. Steaks cooked at 80°C-ZH had the greatest ($P < 0.01$) cook loss of all treatments, and cook loss was not affected ($P > 0.05$). Steaks cooked at 80°C-ZH appeared the most ($P < 0.01$) well-done and had the darkest ($P > 0.01$) surface color. Total collagen was greatest ($P < 0.01$) in steaks cooked with ZH, regardless of oven temperature. Myosin denaturation was not affected ($P > 0.05$) by treatment. Increased ($P = 0.02$) sarcoplasmic protein denaturation was observed with ZH and MH, while increased ($P = 0.02$) actin denaturation was observed only with ZH. Oven temperature did not influence ($P > 0.05$) protein denaturation. Trained panelists rated steaks the most tender ($P < 0.01$) when cooked at 80°C and with ZH and MH. Humidity did not affect ($P > 0.05$) juiciness at 204°C; however, MH and HH produced a juicier ($P < 0.01$) steak when cooked at 80°C. Humidity hindered ($P < 0.01$) the development of beefy/brothy and brown/grilled flavors but increased ($P = 0.01$) metallic/bloody intensity. Lower oven temperatures and moderate levels of humidity could be utilized to maximize tenderness, while minimally affecting flavor development.

Keywords: beef, cooking rate, flavor, protein denaturation, sensory, tenderness
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Introduction

Tenderness is one of the most important attributes when determining consumer acceptability of beef (O'Quinn et al., 2012), which was shown to be influenced by cooking method (Yancey et al., 2011). Therefore, it is critical to establish cooking parameters that maximize palatability, without sacrificing efficiency and practicality of the cooking process. In previous tenderness studies, researchers have accredited the addition of humidity to the cooking environment as a way to improve the process of tenderization (Kolle et al., 2004; Bowers et al., 2012). Moisture has shown to be useful in the breakdown of protein and specifically the solubilization of collagen, which is especially beneficial in the cooking of tougher muscles (Cover and Smith, 1956). Collagen shrinks and denatures around 65°C, contributing to the toughening of meat during cooking; however, if held above 70°C for extended periods, denatured collagen will begin to gelatinize and increase tenderness (Purslow, 2005, Bailey and Light, 1989). For this reason, rate of cooking has also shown to play a significant role in the tenderness of cooked beef. Therefore, the objective

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of this study was to evaluate the influence of relative humidity and oven temperature on external and internal color appearance, protein denaturation, collagen content, shear force values, and sensory attributes of beef strip steaks cooked using varying oven temperatures and relative humidity levels.

Materials and Methods

Sample collection, fabrication, and treatment designation

The study was designed as a 2 × 3 factorial utilizing 2 oven temperatures (80°C and 204°C) and 3 levels of relative humidity [zero (ZH), mid (MH), and high (HH)] for a total of 6 individual cooking treatments. To maximize humidity level at each oven temperature, different percentages of relative humidity were utilized at each oven temperature because a relative humidity of 100% was unobtainable at 204°C. At 80°C, relative humidity of 0, 50, and 100% were utilized for ZH, MH, and HH treatments, respectively. Whereas, at 204°C, relative humidity of 0, 35, and 70% were utilized for ZH, MH, and HH treatments, respectively. Therefore, the addition of humidity was relative to the maximal achievable humidity level at each oven temperature. Paired steaks representing each factor combination (randomized within each strip loin) served as the experimental unit. Thirty USDA Low Choice beef strip loins were randomly selected from a commercial beef harvest facility for inclusion in this study. Following collection, all strip loins were transported under refrigeration (2°C) to the Colorado State University Meat Laboratory and stored (2°C) until being fabricated into twelve 2.54 cm steaks. Two adjoining paired steaks ($N = 180$) were randomly assigned to 1 of 6 treatments methods, so each treatment was represented within each strip loin. The first paired steak was identified as a "shear force" steak, while the second steak was identified as a "sensory" steak. All steaks were vacuum packaged (Clarity Vacuum Pouches #75001839, Koch Supplies, Kansas City, MO), aged for 14 d post mortem at 2°C, then frozen (–20°C) until analysis.

Cooking procedures

The treatment combinations outlined above were achieved by setting oven temperature (dry bulb temperature) and relative humidity levels (percent moisture) in a commercial combination oven (Model SCC WE 61 E; Rational, Landsberg am Lech, Germany). Prior to cooking, frozen steaks were tempered at 2°C for 16 to 24 h. Steaks were first cross-marked on a 315°C open-hearth char broiler (2 min per side), then cooked on a perforated pan at the prescribed oven conditions to an internal temperature of 71°C. Internal steak temperature was monitored throughout the entire oven cooking process using a built in probe placed in the center of a representative steak and final peak temperature was recorded for each steak when removed from the oven (Splash-Proof Super-Fast Thermapen, ThermoWorks, Lindon, UT).

External and internal steak appearance and slice shear force measurements

Steaks designated for shear force were cooked per their respective treatments and subjected to slice shear force (SSF) procedures. Prior to cooking, each steak was individually weighed to calculate cook loss. Steaks were cooked in batches during 4 individual cooking cycles per treatment. For each cooking cycle, the time required for the entire batch to reach the target temperature was recorded. Upon removal from the oven, each cooked steak was weighed to calculate the percent cook loss. Immediately following cooking and before shear force determinations, the external and internal appearance of steaks was evaluated. A colorimeter equipped with a 6 mm measurement port, calibrated at an illuminant of D65 and operated at a 10° standard observer angle (Hunter Associates Laboratory, Reston, VA) was used to collect L^* a^* b^* measurements on the exterior and interior of each steak immediately after cooking. Three measurements of L^* a^* b^* were obtained from separate locations within or on the outer surface of the steak to gather an average for each sample. Exterior measurements were taken between char marks created by grill marking the steaks and interior measurements were taken from the most interior portion of the steak cross-section at a point 5 cm from the lateral end of the steak. Subjective measurements for degree of doneness, internal, and external steak appearance was also recorded by 2 trained individuals at the aforementioned locations. Visual degree of doneness was evaluated and recorded using a 5-point scale (1 = rare, 2 = medium rare, 3 = medium, 4 = medium well, and 5 = well done) in reference to published photographic standards (American Meat Science Association, 2012). Internal steak appearance was recorded using an 8-point scale (1 = purple, 2 = red, 3 = reddish-pink, 4 = pink, 5 = pinkish-gray, 6 = light brown, 7 = medium brown, and 8 = dark brown). External steak measurements were recorded using an 8-point scale (1 = light gray, 2 = gray, 3 = greyish-brown, 4 = light brown, 5 = brown, 6 = dark brown, 7 = brownish-black, 8 = black).

Slice shear force measurements were obtained from every steak using procedures described by Lorenzen et al. (2010). Within 5 min of recording peak internal temperature, a 1 cm × 5 cm slice was removed from the steak parallel to the muscle fibers from the lateral end and sheared perpendicular to the muscle fibers, using a universal testing machine (Instron Corp., Canton, MA) equipped with a flat, blunt-end blade (crosshead speed: 500 mm/min, load capacity: 100 kg), resulting in a single SSF measurement for each steak. All remaining portions from shear force analysis were saved and frozen (–20°C) for collagen analysis.

Trained sensory analysis

Due to limited oven capacity to accommodate 6 cooking treatments, all sensory steaks were cooked in advanced and reheated on the day of analysis. Steaks were cooked following the same cooking protocol as mentioned above. Immediately following cooking, each steak was placed in a vacuum bag, chilled in an ice water bath for 5 to 15 min, vacuum packaged, and stored at 2 to 4°C for 16 to 48 h prior to analysis. To ensure steaks were not becoming excessively oxidized and warmed over during the storage and reheating process, panelists were trained to evaluate oxidized flavor notes to assess during sensory evaluation. On the day of sensory analysis, steaks were reheated in a circulating water bath set at 57.5°C for 30 min. Once removed from the water bath, steaks were trimmed of all external fat and connective tissue, sized into 1-cm cubes, and served to trained panelists. All panelists were trained to evaluated initial tenderness, sustained tenderness, overall tenderness, juiciness, beefy/brothy, browned/grilled, buttery/fat, burnt, bloody/metallic, livery, and oxidized flavors adapted from Adhikari et al. (2011). Each panelist (n = 7 to 8 per session) received 2 to 3 cubes and evaluated each sample for the aforementioned sensory characteristics using a 10 cm structured line scale verbally anchored at both ends (0 = very tough, very dry, not present; 10 = very tender, very juicy, very intense). Two samples per treatment were served each panel for a total of 12 samples per panel. Two panels were conducted per day: 1 in the morning and 1 in the afternoon. Panelists were provided with unsalted saltine crackers, apple juice, and water to cleanse their palate between each sample. All remaining cubes were vacuum packaged and stored at –20°C for protein denaturation analysis.

Protein denaturation

Denaturation of major skeletal muscle proteins (myosin, sarcoplasmic proteins/collagen, and actin) was evaluated by differential scanning calorimetry (DSC; TA Instruments DSC Q20, Albuquerque, NM). When analyzed via DSC, meat samples produce 3 very distinct denaturation peaks based on denaturation temperature for the aforementioned protein groups, allowing for differentiation in protein groups when analyzing results (Findlay et al., 1986). Denaturation was assessed from remaining cooked sample used for trained sensory analysis. Five strip loins were randomly selected to be analyzed for protein denaturation, with each of the 6 cooking treatments being evaluated per strip loin. An aliquot of 4 to 10 mg was extracted from the center most portion of each cooked cube and sealed in a DSC pan. An empty pan was used as a reference. The sample and reference pans were heated from 25°C to 100°C at a heating rate of 5°C/minute. The peak temperature and denaturation enthalpy (Δ_H) were determined from the DSC curve that was obtained from each run. Each sample was extracted and analyzed separately in triplicate. The weight of each sample was used to calculate the change in energy (measured in Joules; J) per g of sample required to denature remaining intact protein. A greater Δ_H (J/g) is indicative of a greater amount of intact (undenatured) protein remaining in the sample after the cooking process.

Collagen

Retained samples from the shear force analyses were composited for the determination of total collagen content. Five (n = 5), 6 steak composites from each treatment were homogenized in liquid nitrogen for collagen analysis. Homogenates were prepared and hydroxyproline content was determined according to the method described by Switzer (1991) using a spectrophotometer. Collagen content was calculated by multiplying the hydroxyproline content by a factor of 7.52 (Cross et al., 1973).

Statistical analysis

Data were analyzed using the procedures of SAS (Version 9.4; SAS Inst. Inc., Cary, NC). The experiment was designed as a 2 by 3 factorial with oven temperature and added humidity as the fixed effects. Main effect and interaction comparisons were tested for significance using PROC GLIMMIX with $\alpha = 0.05$ and the denominator degree of freedom was calculated by the Kenward-Roger method. For trained sensory analysis, the scores of each panelist were averaged, resulting in one value per sample and panel number was included in the model as a random variable. Peak cooking temperature of each steak was initially included as a covariate in each model but was removed from final models due to a lack of significance.

Results and Discussion

Cooking rate and cook loss

The time required to cook beef strip steaks to 71°C for each of the 6 treatments is presented in Table 1. At 80°C, MH and HH decreased cooking time by 93.25 and 107.75 min, respectively, compared to steaks cooked with ZH. Cooking times were shorter when relative humidity was added at 204°C; however, it was to a much lower extent. At 204°C, MH and HH decreased cooking time by 3.75 and 7.00 min, respectively, compared to steaks cooked with ZH. Evaluating various beef roasts, Jeremiah and Gibson (2003) produced similar results showing very noticeable decreases in cooking time when added moisture was included in the cooking process. Water has a much greater specific heat capacity than air, thus, adding moisture to the cooking environment significantly increased the efficiency of heat transfer from the environment to the steak to decrease cooking time. These results are in agreement with previous studies reporting an increase in cooking rate when humidity is added to the cooking environment (Laakkonen et al., 1970; Vittadini et al., 2005). Additionally, cooking times for 80°C-HH and 204°C-ZH steaks were essentially equal (17.53 vs. 17.00 min, respectively), which allowed for the inadvertent comparison of the 2 treatments to assess the influence of humidity when cooking rate is kept similar. Percent cook loss was influenced by an oven temperature by relative humidity interaction (Table 2). Steaks cooked at 80°C-ZH showed the greatest ($P < 0.01$) loss of moisture during cooking of all treatments. Relative humidity had no ($P > 0.05$) impact on cook loss when steaks were cooked at 204°C; nevertheless, cook loss at 204°C was still greater ($P < 0.01$) than both 80°C-MH and 80°C-HH. These results are in agreement with those found by Belk et al. (1993) who showed that increasing oven temperature, adding humidity, and ultimately increasing cooking rate resulted in a decrease in cooking yields. King et al. (2003) concluded rapid cooking rates cause excessive myofibrillar shortening, resulting in decreased cooking yields. Therefore, increases in cooking yield through the addition of humidity may only be achievable if a slower cooking rate is maintained by a lower oven temperature.

Table 1. Interaction means for the length of time required to cook beef strip steaks to 71°C and cook loss using 2 oven temperatures and 3 levels of humidity

Treatment	Cook time, min	Cook loss, %
80°C		
Zero Humidity	125.29[a]	33.03[a]
Mid Humidity	32.03[b]	21.37[c]
High Humidity	17.53[c]	21.91[c]
204°C		
Zero Humidity	17.00[c]	24.56[b]
Mid Humidity	13.53[c]	24.41[b]
High Humidity	10.60[c]	24.64[b]
SEM[1]	2.48	0.71
P– Value	< 0.01	< 0.01

[a-c]Means in the same column lacking a common superscript differ ($P < 0.05$).

[1]Standard error (largest) of the least squares mean.

Cooked steak color

Instrumental and visual assessment of external and internal color of cooked strip steaks are presented in Table 2. All color measurements were affected by an interaction of the main effects. For both oven temperatures, external L^* values increased ($P < 0.01$) with increasing relative humidity levels, which is indicative of a lighter surface color. Additionally, 80°C-ZH steaks had the darkest external color ($P < 0.01$) of all treatments as determined by L^* values. When steaks were cooked at 204°C, a^* values, which are indicative of a redder color, decreased ($P < 0.01$) as relative humidity increased. However, when cooked at 80°C, a^* values were the lowest ($P < 0.01$) when humidity was absent from the cooking environment. Similarly, Isleroglu et al. (2014) reported higher L^* and lower a^* values from chicken breasts cooked using a steam-assisted hybrid oven. Visual assessment of external color produced similar results as instrumental color values. Trained panelists found 80°C-ZH steaks had the darkest external color ($P < 0.01$) of all treatments. At 80°C, external surface color became lighter ($P < 0.01$) as relative humidity increased. Similarly, external color of 204°C-ZH steaks were darker ($P < 0.01$) than both 204°C-MH and 204°C-HH steaks; however, no visual color differences ($P > 0.05$) were found between 204°C-MH and 204°C-HH samples. These results indicate that added moisture inhibited surface browning during cooking.

Internal L^* values were greatest ($P < 0.01$) from 80°C-ZH steaks compared to all other treatments. No additional differences ($P > 0.05$) in internal L^* values were observed among any other treatments. Steaks cooked at 80°C-ZH produced the lowest ($P < 0.01$) a^* values of all treatments. Based off instrumental color values, 80°C-ZH steaks had the appearance of being the most well done, regardless of all treatments being cooked to the same internal temperature (71°C). This is also reflected in trained panelist ratings for doneness and internal color. Steaks cooked at 80°C-ZH appeared to be the most ($P < 0.01$) well done, as well as, the brownest ($P < 0.01$) internally of all treatments. No oth-

Table 2. External and internal color (CIE *L**, *a**, and *b**) and trained personnel (n = 2) visual assessment of doneness, external color, and internal color of beef strip steaks cooked to 71°C using 2 oven temperatures and 3 levels of humidity

	80°C			204°C				*P*–value		
Color Measurement	Zero humidity	Mid humidity	High humidity	Zero humidity	Mid humidity	High humidity	SEM[1]	Oven temp	Relative humidity	OT × RH
External Color										
*L**	24.30^{d}	36.83^{b}	41.90^{a}	33.13^{c}	37.30^{b}	41.66^{a}	0.85	< 0.01	< 0.01	< 0.01
*a**	9.38^{e}	13.04^{cd}	11.85^{d}	16.89^{a}	15.14^{b}	13.18^{c}	0.47	< 0.01	< 0.01	< 0.01
*b**	9.81^{c}	18.96^{b}	18.18^{b}	24.12^{a}	22.79^{a}	20.19^{b}	0.80	0.43	< 0.01	< 0.01
Internal Color										
*L**	54.69^{a}	49.01^{b}	49.37^{b}	48.52^{b}	49.08^{b}	48.86^{b}	0.64	< 0.01	< 0.01	< 0.01
*a**	11.80^{c}	18.65^{ab}	16.18^{b}	18.66^{ab}	17.36^{ab}	19.77^{a}	1.31	< 0.01	0.04	< 0.01
*b**	16.59^{c}	18.89^{a}	17.14^{bc}	18.73^{a}	17.74^{b}	16.67^{c}	0.34	0.54	< 0.01	< 0.01
Visual Assessment										
Doneness[2]	4.81^{a}	3.26^{b}	3.33^{b}	3.27^{b}	3.18^{b}	3.28^{b}	0.09	< 0.01	< 0.01	< 0.01
External Color[3]	7.13^{a}	5.11^{bc}	4.68^{d}	5.41^{b}	4.90^{cd}	4.60^{d}	0.11	< 0.01	< 0.01	< 0.01
Internal Color[4]	6.78^{a}	5.05^{c}	5.50^{b}	5.27^{bc}	5.46^{b}	5.45^{b}	0.09	< 0.01	< 0.01	< 0.01

[a-e]Means in the same row lacking a common superscript differ (P < 0.05).

[1]Standard error (largest) of the least squares means.

[2]Doneness: 1 = rare, 2 = medium rare, 3 = medium, 4 = medium well, 5 = well done.

[3]External Color: 1 = light gray, 2 = gray, 3 = greyish-brown, 4 = light brown, 5 = brown, 6 = dark brown, 7 = brownish-black, 8 = black.

[4]Internal Color: 1 = purple, 2 = red, 3 = reddish-pink, 4 = pink, 5 = pinkish-gray, 6 = light brown, 7 = medium brown, and 8 = dark brown.

er treatment (P > 0.05) differed in the visual assessment of doneness and appeared to be cooked to a medium degree of doneness. Assessing subjective and objective measurements for both external and internal cooked surfaces, it is evident that cooking parameters had a significant influence on the appearance of cooked steaks.

Protein denaturation

Table 3 shows the change in enthalpy (Δ_H; J/g) and peak temperatures required to denature remaining intact myosin, sarcoplasmic proteins and collagen, and actin. Previously published literature has determined denaturation temperatures for myosin, sarcoplasmic proteins and collagen, and actin to be 55.5°C, 66.8°C, and 80.9°C, respectively (Findlay et al., 1986). In the current study, similar denaturation temperatures were recorded for myosin (56.6°C), sarcoplasmic proteins and collagen (65.4°C), and actin (80.5°C). Because denaturation samples were extracted from the inner-most portion of steak cross-sections and each steak was cooked to the sample end-point temperature, it is speculated that an increase in protein denaturation would indicate a slower transfer of heat from the surface to the interior, facilitating prolonged exposure to denaturation temperatures. Differences in Δ_H for each protein appear to be related to cooking rate and exposure time to heat, which was influenced by relative humidity level. No differences (P = 0.86) in Δ_H were observed for myosin, regardless of relative humidity. The low Δ_H for myosin indicates that nearly all myosin was denatured during the initial cooking process and would not be expected to contribute to tenderness differences. Myosin shrinks on denaturation and is responsible for the initial toughening phase of meat during cooking (McCormick, 1999). Most sarcoplasmic proteins and collagen were denatured during cooking with ZH and MH; however, greater (P = 0.02) amounts remained intact in steaks cooked with HH. Thus, it seems that the reduction in cooking time of HH steaks did not allow for adequate exposure of sarcoplasmic proteins and collagen to the required denaturation tem-

Table 3. Change in enthalpy[1] required to denature remaining intact myosin, sarcoplasmic protein, and actin of beef strip steaks cooked to 71°C using three levels of humidity

Relative humidity level	Myosin, J/g	Sarcoplasmic protein and collagen, J/g	Actin, J/g
Zero Humidity	0.047	0.034^{b}	0.307^{a}
Mid Humidity	0.034	0.035^{b}	0.734^{b}
High Humidity	0.027	0.121^{a}	0.646^{b}
Peak Denaturation Temperature (°C)	56.661	65.410	80.518
SEM[2]	0.038	0.024	0.161
P-value	0.866	0.020	0.023

[a,b]Means in the same column lacking a common superscript differ (P < 0.05).

[1]Change in enthalpy presented as change in Joules (J) per g required to denature remaining intact protein.

[2]Standard error (largest) of the least squares means.

perature to completely alter the protein structure. Unlike myofibrillar proteins, sarcoplasmic proteins expand rather than shrink on heating, as well as, forming aggregates and gelatinizing during cooking (Baldwin, 2012). Furthermore, many of these proteins are enzymes, which have shown to have a tenderizing effect when cooked for long periods of time at low temperatures (Tornberg, 2005). Although denatured enzymes would lose functionality, the current data suggest a slower transfer of heat and the potential for an increased window of opportunity for enzyme activity at lower temperatures, particularly in the more interior portions of the steak. Collagen begins to denature and shrink between 64 and 68°C, which results in toughening of meat (McCormick, 1999); however, as meat continues to be held at temperatures greater than 70°C, collagen begins to solubilize and an increase in tenderness is observed (Bailey and Light, 1989). The Δ_H of sarcoplasmic proteins and collagen follows trained sensory tenderness ratings. Lower Δ_H was determined for sarcoplasmic proteins and collagen at ZH and MH, while SSF and sensory tenderness ratings were more favorable at these same humidity levels. Therefore, the differences in the effects of heat on sarcoplasmic proteins and collagen may have played a role in the tenderization of these treatments. Additionally, greater (P = 0.02) amounts of actin remained intact in steaks cooked using MH and HH when compared to steaks cooked using ZH; however, based off Δ_H values, substantial amounts of actin remained intact in all relative humidity levels after the cooking process. The substantial increase in cooking time of steaks cooked with ZH facilitated an increased exposure of proteins to the higher temperatures required to denature actin. Previously, Bertram et al. (2006) showed that Δ_H of all 3 proteins gradually decreased as final internal temperature increased until peaks were practically devoid when samples were cooked to 75°C. Although the current study did not evaluate different internal temperatures, cooking procedures from both studies facilitated differences in heat transfer which appeared to have comparable effects on protein denaturation. Differential scanning calorimetry has been widely used to evaluate thermal properties of meat proteins; however, a definitive relationship between DSC thermograms and meat tenderness has yet to be established.

Collagen

Concentrations of total collagen content remaining in cooked steaks are shown in Table 4. It has been suggested that any collagen gelatinized during cooking would be released with the cook loss (Palka, 1999), thus it was assumed that any changes in collagen solubility would be observed by measuring total collagen remaining in cooked steaks. Steaks cooked with ZH, regardless of oven temperature, had greater ($P < 0.01$) concentrations of collagen than MH and HH steaks. Total collagen content did not have much of an effect on sensory tenderness, since ZH steaks had the greatest concentrations of collagen, but were some of the most tender steaks. Also, the greater collagen content of ZH steaks may have been partially related to the greater cook loss seen in 80°C-ZH steaks, resulting in a more concentrated collagen content. Although many studies have found significant relationships between total collagen and tenderness (Riley et al., 2005), others have been inconsistent in attempting to fully understand and establish the relationship between connective tissue and meat tenderness (Reagan et al., 1976; Seideman et al., 1987). Furthermore, tenderness of strip steaks is affected less by collagen content and more by proteolysis (Koohmaraie and Geesink, 2006), so any differences in total collagen content may have had a smaller influence on perceived tenderness. Although collagen content was greatest in ZH treatments, this may not accurately reflect the heat-induced structural changes in collagen that may have occurred due to an extended cooking time and exposure to temperatures greater than 70°C. Differences in sensory tenderness due to oven temperature cannot be explain by protein denaturation results alone, suggesting that changes in

Table 4. Slice shear force (SSF) values, total collagen content (dry matter basis), and trained sensory ratings[1] for overall tenderness of beef strip steaks cooked to 71°C using two oven temperatures and three levels of humidity

Treatment	SSF, kg	Collagen, mg/g	Overall tenderness
Oven Temperature			
80°C	16.00	15.98	6.50^{a}
204°C	16.78	13.65	6.09^{b}
SEM[2]	0.53	0.92	0.08
P- Value	0.30	0.08	< 0.01
Added Humidity			
Zero Humidity	15.70^{m}	19.36^{m}	6.47^{m}
Mid Humidity	15.59^{m}	12.66^{n}	6.42^{m}
High Humidity	17.88^{n}	12.44^{n}	6.01^{n}
SEM[2]	0.65	1.59	0.14
P- Value	0.02	< 0.01	< 0.01
OT × RH *P*– Value	0.85	0.18	0.81

^{a,b}Means in the same column lacking a common superscript differ ($P < 0.05$) due to oven temperature.

^{m,n}Means in the same column lacking a common superscript differ ($P < 0.05$) due to added humidity.

[1]Attributes were scored using a 10 cm structured line scale: 0 = very tough; 10 = very tender.

[2]Standard error (largest) of the least squares means.

the structure of collagen may have very well contributed to differences in tenderness. Consequently, there could be benefit in using techniques to more specifically evaluate the heat-induced structural changes in collagen due to varying oven temperatures, relative humidity levels, and cooking rates in future studies.

Shear force

Slice shear force values were affected by relative humidity (Table 4). Regardless of oven temperature, steaks cooked with HH produced greater ($P = 0.02$) SSF values than steaks cooked with both ZH and MH. Berry et al. (1977) did not find shear force differences between oven roasted and braised beef *semimembranosus* but did observe lower sensory tenderness ratings for braised samples. Tenderness is known to decrease as cooking rate increases (Cross et al., 1973). In the present study, the increase in SSF values are believed to be the result of an increased cooking rate by the addition of high levels of humidity in the cooking environment. However, the utilization of moderate levels of humidity facilitated a more rapid cooking rate without negatively affecting shear force values.

Trained sensory

Tenderness ratings were influenced by both oven temperature and relative humidity (Table 5). Trained panelists rated steaks cooked at 80°C greater ($P < 0.01$) than those cooked at 204°C for initial tenderness, sustained tenderness, and overall tenderness. Previous literature has shown that reducing oven temperature and cooking rate results in a more tender beef product (King et al., 2003; Christensen et al., 2011). Additionally, steaks cooked with ZH and MH were rated greater ($P < 0.01$) than those cooked with HH for initial tenderness, sustained tenderness, and overall tenderness. Again, these decreases in tenderness appear to be related to cooking rate. Unlike the current findings, many previous studies have reported increases in tenderness as a result of moist-heat cookery when compared to dry-heat cookery; however, many of these studies used moist-heat methods with a slower cooking rate (Kolle et al., 2004) than dry-heat methods used. Therefore, it can be difficult to determine if differences were due to added moisture or cooking rate. In agreement with the current results, however, Berry et al. (1977) found semimembranosus steaks cooked using dry-heat to be more tender than those cooked with moist-heat.

Trained sensory ratings for juiciness were affected by an interaction of the main effects (Table 5). When steaks were cooked at 204°C, relative humidity had no influence ($P > 0.05$) on juiciness. However, when steaks were cooked at 80°C, steaks cooked with MH were rated juicier ($P < 0.01$) than both HH and ZH, respectively. Furthermore, 80°C-ZH steaks were rated as the least juicy ($P < 0.01$) of all treatments and 80°C-MH steaks the juiciest ($P < 0.01$). As expected, juiciness scores followed cook loss percentages. Previous studies have shown that

Table 5. Trained sensory ratings[1] for beef strip steaks cooked to 71°C using two oven temperatures and three levels of humidity

	80°C			204°C				*P*-value		
Trait	Zero humidity	Mid humidity	High humidity	Zero humidity	Mid humidity	High humidity	SEM[2]	Oven temp	Added humidity	OT × RH
Initial Tenderness	6.86^{am}	6.82^{am}	6.41^{an}	6.39^{bm}	6.47^{bm}	6.14^{bn}	0.13	< 0.01	< 0.01	0.70
Sustained Tenderness	6.53^{am}	6.38^{am}	5.92^{an}	5.56^{bm}	6.00^{bm}	5.56^{bn}	0.14	< 0.01	< 0.01	0.73
Overall Tenderness	6.72^{am}	6.62^{am}	6.17^{an}	6.21^{bm}	6.22^{bm}	5.84^{bn}	0.14	< 0.01	< 0.01	0.81
Juiciness	4.18^{z}	6.10^{w}	5.72^{x}	5.36^{y}	5.28^{y}	5.23^{y}	0.12	0.63	< 0.01	< 0.01
Beefy/Brothy	5.63^{w}	5.07^{xy}	4.97^{y}	5.26^{x}	5.15^{xy}	5.08^{xy}	0.15	0.38	< 0.01	0.01
Browned/Grilled	4.79^{m}	4.24^{n}	4.10^{o}	4.73^{m}	4.61^{n}	4.28^{o}	0.20	0.09	< 0.01	0.19
Buttery/Fat	2.22^{y}	2.56^{wx}	2.33^{xy}	2.74^{w}	2.63^{w}	2.23^{y}	0.11	0.05	0.01	0.01
Burnt	0.65	0.50	0.64	0.66	0.39	0.67	0.14	0.84	0.15	0.82
Bloody/Metallic	1.10^{y}	1.90^{w}	1.66^{wx}	1.09^{y}	1.34^{y}	1.37^{xy}	0.11	< 0.01	< 0.01	0.04
Livery	0.07	0.02	0.03	0.01	0.02	0.07	0.01	0.73	0.32	0.08
Oxidized	0.06	0.05	0.02	0.05	0.11	0.11	0.03	0.10	0.80	0.41

[a,b]Least square means in the same row without a common superscript differ ($P < 0.05$) due to oven temperature.

[m-o]Least square means in the same row without a common superscript differ ($P < 0.05$) due to added humidity.

[w-z]Least square means in the same row without a common superscript differ ($P < 0.05$) due to an over temperature × realtive humidity interaction.

[1]Attributes were scored using a 10 cm structured line scale: 0 = very tough, very dry, and not present; 10 = very tender, very juicy, and very intense.

[2]Standard error of the least squares means.

moist-heat cookery yields a juicier product due to a decrease in evaporative moisture loss (Bowers et al., 2012).

Beefy/brothy, buttery/fat, and bloody/metallic flavor intensities were influenced by an oven temperature by relative humidity interaction (Table 5). When cooked at 204°C, relative humidity had no influence ($P > 0.05$) on ratings for beefy/brothy intensity; but, when steaks were cooked at 80°C, ZH produced the most intense ($P < 0.01$) beefy/brothy flavors. Furthermore, 80°C-ZH samples had the greatest beefy/brothy intensity ($P < 0.01$) of all treatments. Cooking steaks with ZH also produced the least intense ($P = 0.04$) bloody/metallic flavors, regardless of oven temperature. Adding relative humidity increased ($P = 0.04$) bloody/metallic intensity for both oven temperatures; however, 80°C-MH and 80°C-HH steaks had a more intense ($P = 0.04$) bloody/metallic flavor than both 204°C-MH and 204°C-HH steaks. Cooking with HH decreased ($P = 0.01$) buttery/fat intensity at 204°C; but, similar trends were not seen at 80°C. Steaks cooked at 80°C-MH produced a more intense ($P = 0.01$) buttery/fat flavor than 80°C-ZH steaks, with 80°C-MH steaks performing similarly ($P > 0.05$) to both relative humidity levels.

Both browned/grilled and burnt flavor intensities were affected ($P < 0.01$) by relative humidity. Zero humidity steaks produced the most ($P < 0.01$) and HH steaks the least ($P < 0.01$) intense ratings for browned/grilled flavors. Browned/grilled flavors are associated with Maillard reaction products that occur on the surface of cooked meat (Mottram, 1998) and these reactions are inhibited in moist cooking environments (Kerth and Miller, 2015). It is evident in the current study, by evaluating external color and sensory scores, that increasing moisture to the cooking environment inhibited the non-enzymatic browning process. This conclusion is further supported by Isleroglu et al. (2014) who measured a decrease in the production of Maillard reaction products after adding humidity to the cooking environment of chicken.

No differences ($P > 0.05$) were observed among burnt, livery, or oxidized off-flavors (Table 5). Ratings for livery and oxidized intensity were low in some samples but were not present in most samples evaluated by panelists. These low intensity ratings would not be expected to play a role in the flavor perception of consumers. In the current study, intensity ratings for livery and oxidized were collected to ensure that these off-flavors were not introduced during the reheating of steaks in the water bath. Oxidation can occur during the storage and reheating of cooked meat, which is commonly referred to as "warmed over flavor" (Mottram, 1998); however, vacuum packaging steaks immediately after cooking and reheating in the absence of oxygen prevented oxidation and the development of warmed over flavor in sensory steaks.

Although it was not the objective of the treatment design, 80°C-HH (100% humidity) and 204°C-ZH (dry-heat) treatments had comparable cooking rates (17.53 versus 17.00 min, respectively). This allowed for the evaluation of the effects of adding 100% humidity to the cooking environment on sensory development when cooking rates were similar. Neither initial, sustained, nor overall tenderness differed between dry-heat and 100% humidity cooking; however, cooking with 100% humidity produced juicier ($P < 0.01$) steaks. Greater flavor intensities were recorded for dry-heat cooking, as panelists rated steaks cooked using dry-heat more ($P < 0.01$) intense for beefy/brothy, browned/grilled, and buttery/fat flavors; and less ($P < 0.01$) for bloody/metallic. Although juiciness was more favorable for 100% humidity cooking, dry-heat cooking produced more favorable flavors. While consumer sensory and acceptability was not evaluated in the current study, recent consumer studies have found flavor to be the most influential palatability trait when determining consumer overall acceptability of beef (O'Quinn et al., 2012; Hunt et al., 2014; Legako et al., 2016), particularly when tenderness is acceptable. Therefore, it is suggested that the advantages in the flavor of dry-heat cooked steaks would be more desirable to consumers over steaks cooked in the presence of 100% humidity, when cooking rate is kept similar. Based off these observations, future work emphasizing the influence of added humidity on sensory development would provide further insight into possible factors affecting these variables.

Conclusions

Adding humidity to the cooking environment was expected to improve tenderness of beef strip steaks; however, the current findings show humidity had a negative effect on tenderness development. It appears that tenderness was affected more by cooking rate, which was altered by both oven temperature or humidity level. Adding humidity increased the cooking rate of strip steaks at both oven temperatures, but this difference was substantially more evident at 80°C. A slower cooking rate is believed to be responsible for a more tender product because of an increased exposure time to heat, better facilitating the thermal breakdown of proteins and likely the solubilization of collagen. Adding moderate levels of humidity to the cooking environment improved the efficiency of the cooking process without affecting tenderness attributes. Cooking at 80°C with no humidity produced a tender product; however, it was exceptionally dry and produced more roast-like flavors that may not be desirable when consuming a steak product. At 80°C, the addition of 50% humidity allowed for

a drastic decrease in cooking time without sacrificing tenderness and juiciness; however, it hindered the development of browned/grilled flavors. At 204°C, the addition of 35% humidity decreased cooking time while only minimally affecting browned/grilled flavor development. Further work is warranted to understand how the observed differences in tenderness and flavor attributes would influence consumer acceptability.

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