Cooking and Palatability Traits of Beef Longissimus Steaks Cooked with a Belt Grill or an Open Hearth Electric Broiler[1,2]

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ABSTRACT: The objective of this experiment was to compare the effects of belt grill and Open Hearth electric broiler cookery on palatability and cooking traits of longissimus steaks. The longissimus thoracis from carcasses of grain-fed steers or heifers was used. Duplicate measurements were made for Warner-Bratzler shear force at 3 and at 14 d after slaughter (n = 180) and trained sensory evaluation at 14 d after slaughter (n = 91) using both cooking methods. Belt grill-cooked samples had lower ($P < .01$) percentage of cooking losses (21.5 vs 25.8%) and higher ($P < .01$) shear force values (4.6 vs 4.3 kg) than electric broiler-cooked samples. Repeatability of duplicate measurements was higher for cooking losses (.58 vs .23) and shear force values (.85 vs .64) for belt grill than for electric broiler cooked samples. Belt grilled steaks had lower ($P < .01$) cooking losses (20.2 vs 29.8%); higher ($P < .01$) tenderness (7.0 vs 6.7) and juiciness (6.0 vs 5.1); and lower ($P < .02$) connective tissue amount (7.7 vs 7.8), beef flavor intensity (5.0 vs 5.1), and off-flavor (3.2 vs 3.3) ratings than steaks cooked with the electric broiler. Belt grill cooking increased the repeatability of duplicate sensory measurements for tenderness (.87 vs .71), connective tissue amount (.66 vs .30), and juiciness (.51 vs .08) ratings, and cooking losses (.63 vs .18) compared with cooking with the electric broiler. Belt grill cooking increased the precision for measurements of cooking, Warner-Bratzler shear force, and palatability traits of beef longissimus thoracis.

Key Words: Beef, Cooking, Measurement, Methodology, Tenderness

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Introduction

Cooking method and instrumentation are important considerations in studies that include measurement of meat palatability traits. Surveys reveal that consumers use a variety of cooking methods to prepare steaks (Branson et al., 1986; NLSMB, 1995). Thus, scientists should strive to identify a cooking methodology that provides results that are consistent and relevant to consumers. The AMSA (1995) recommended broiling as the cooking method for research steaks and chops. Chrystall et al. (1994) recommended cooking research samples inside a plastic bag in a water bath. Numerous other cooking methods have been used for palatability research including ultrasound (Pohlman et al., 1997), microwave and deep-fat frying (Carpenter et al., 1968), roasting (Cross et al., 1979), impingement oven (Powell et al., 1990), and various methods of grilling or broiling (Berry and Leddy, 1990a; Berry and Bigner, 1995).

We have attempted to identify and eliminate sources of variation in the measurement of meat palatability traits (Wheeler et al., 1994, 1996, 1997). Following these efforts, analyses of our palatability data led us to believe that the largest remaining source of error variance was the cooking process. Even though commonly used in meat palatability research, consistency of cooking obtained from Open Hearth electric broilers has been questioned (Berry and Dikeman, 1994). While searching for a rapid method of cooking beef steaks for a tenderness classification system (Shackelford et al., 1997), we noted that Lyon and Lyon (1993) reported cooking chicken breasts in 58 s with a conveyor-belt grilling system. Preliminary tests on the table-top model described by Lyon and Lyon (1993) indicated that the belt grill was capable of very rapid cooking and seemed to provide more consistent cooking than the open hearth electric broiler. Thus, the objective of this study was to

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determine the repeatability of duplicate measurements of various cooking and palatability traits in longissimus steaks cooked on an open hearth electric broiler or on a belt grill.

Materials and Methods

Animals. The Roman L. Hruska U.S. Meat Animal Research Center (**MARC**) Animal Care and Use Committee approved the use of animals in this study. Crossbred steers and heifers (n = 362) were weaned at approximately 200 d of age and fed a corn-corn silage diet for approximately 260 d. Animals were slaughtered and processed at a commercial packing plant. At 36 h after slaughter, carcasses were fabricated and the wholesale rib was obtained from the right side of each carcass and transported to MARC.

Experiment 1 (Warner-Bratzler Shear Force)

Sample Processing. At 3 d after slaughter, the ribeye roll (IMPS #112; longissimus thoracis) was removed from 180 ribs. A 12.7-cm-long section was removed from the posterior end of the ribeye roll, vacuum-packaged, aged (2°C) until 14 d after slaughter, and frozen (–30°C) for later evaluation of tenderness (with 14 d of postmortem aging). The remainder of the ribeye roll was vacuum-packaged and immediately frozen (–30°C) for later evaluation of tenderness (with 3 d of postmortem aging).

Using a band saw, each frozen ribeye roll section was sliced to yield four steaks (2.54 cm thick). Beginning at the posterior end of the ribeye roll, steaks were numbered 1 through 8, with steaks 1 through 4 coming from the section that was frozen at 14 d after slaughter and steaks 5 through 8 coming from the section that was frozen at 3 d after slaughter. Steaks 1 and 2 and steaks 3 and 4 (14-d postmortem aging) were used for duplicate measurement of Warner-Bratzler shear force after cooking with either a belt grill or electric broiler, respectively. Steaks 7 and 8 and steaks 5 and 6 (3-d postmortem aging) were used for duplicate measurement of Warner-Bratzler shear force after cooking with either a belt grill or electric broiler, respectively. The effect of postmortem aging time was not of interest, so aging times were pooled to increase the variation in tenderness.

Cooking. Steaks were thawed (5°C) until an internal temperature of 5°C was reached. Belt grill cooking was conducted with a model TBG-60 Magigrill (MagiKitch'n Inc., Quakertown, PA). Belt grill settings (top heat = 163°C, bottom heat = 163°C, preheat = disconnected, height (gap between platens) = 2.16 cm, cook time = 5.7 min) were designed to achieve a final internal temperature of 70°C for 2.54-cm-thick longissimus steaks. After the steaks exited the belt grill, a needle thermocouple probe was inserted into the geometric center of the steak and postcooking temperature rise was monitored with a handheld thermometer (Cole-Parmer, Vernon Hills, IL). The maximum temperature, which occurred about 2 min after the steak exited the belt grill, was recorded as the final cooked internal temperature.

Electric broiler cooking was conducted with a model 450N Open Hearth electric broiler (Farberware, Bronx, NY). The steaks were turned after reaching 40°C and then removed from the grill after reaching a 70°C internal temperature. Temperature was monitored with iron constantan thermocouple wires inserted into the geometric center of each steak and attached to a Beckman Industrial model 205 data logger (Beckman Industrial, San Diego, CA).

Warner-Bratzler Shear Force. Cooked steaks were cooled for 24 h at 4°C. Six round cores (1.27 cm diameter) were removed parallel to the longitudinal orientation of the muscle fibers. Each core was sheared once at the center, perpendicular to the fiber orientation, with a Warner-Bratzler shear attachment using an electronic testing machine (model 4411, Instron Corp., Canton, MA). The crosshead speed was set at 200 mm/min.

Experiment 2 (Trained Sensory Panel Evaluation)

Sample Processing. At 3 d after slaughter, the (IMPS #112) ribeye roll (longissimus thoracis) was removed from 182 ribs. A 17.8-cm-long section was removed from the posterior end of the ribeye roll, vacuum-packaged, aged (2°C) until 14 d after slaughter, and frozen (–30°C) for trained sensory evaluation.

Using a band saw, the frozen ribeye roll section was sliced to yield six steaks (2.54 cm thick). Beginning at the posterior end of the ribeye roll, steaks were numbered 1 through 6. Steak 2 was not used for this experiment. Steak 1 was cooked with the belt grill as described above and used to measure Warner-Bratzler shear force. The 182 animals were blocked by shear force and assigned to either belt grill or electric broiler cooking to ensure that the 91 animals assigned to each cooking method had the same mean shear force and the same degree of variation in shear force (3.44 kg; SD .64).

Trained Sensory Panel Analysis. Steaks 3 and 4 were used for the first replication of sensory panel evaluation, and steaks 5 and 6 were used for the second replication of sensory panel evaluation. Steaks were thawed and cooked with either a belt grill or an electric broiler, as described above. Steaks cooked with the belt grill were cut and served immediately after cooking. Steaks cooked with the electric broiler were held at 70°C for 20 to 30 min after cooking before they were cut and served, depending on when they finished cooking relative to the order they were scheduled to be served. An eight-member sensory panel was selected and trained according to procedures described by Cross et al. (1978). Panelists seated in individual booths evaluated eight experimental samples in one session on each of 3 d per week. Sample presentation order was balanced across treatment. Each session was initiated with a nonexperimental warm-up sample. Unsalted crackers, apple juice, and room temperature distilled water were provided to cleanse the palate between samples. Each panelist received three cubes (1.3 cm × 1.3 cm × cooked steak thickness) from each sample. Sensory panelists scored steaks for tenderness, ease of fragmentation, juiciness, amount of connective tissue, and beef flavor intensity on 8-point scales (1 = extremely tough, difficult, dry, none, or bland; 8 = extremely tender, easy, juicy, abundant, or intense). Off-flavor was scored on a 4-point scale (4 = none; 1 = intense).

Statistical Analysis. The data were analyzed by analysis of variance with the GLM procedure for a completely randomized design (SAS, 1989). For Warner-Bratzler shear force (Exp. 1), steaks from 3 and 14 d of aging time were coded as different samples to increase the variation in tenderness because the aging time difference was not of interest. Sensory data were pooled across panelists. Cooked temperature was included in a preliminary model, but was not significant for any trait ($P > F$ .41 to .99) and was deleted from the final models. The final models included sample and cook method in Exp. 1, and sample nested within cook method and cook method in Exp. 2. Least squares means were calculated (SAS, 1989). Repeatability of various traits was determined on duplicate measurements. Data were analyzed by PROC VARCOMP (SAS, 1989) for the random effect of sample to get the estimated variance components (σ^2_{sample} and σ^2_{error}). Repeatability = $\sigma^2_{sample}/(\sigma^2_{sample} + \sigma^2_{error})$.

Results and Discussion

The belt grill instrument cooks by passing the product between two electrically heated metal platens on Teflon®-coated conveyor belts. Thus, the product is heated on top and bottom simultaneously. The temperature of the platens, the speed of the belts, and the size of the gap between the platens can be adjusted, depending on specific cooking needs. The continuous flow design causes the cooking end point to be based on time rather than a specific temperature. Thus, preliminary tests are necessary to obtain the cooking temperature and time settings that provide the end point temperature desired. Cooking with constant time also makes it even more critical for steaks to have consistent initial temperatures when cooking commences. In addition, the fixed size of the gap that the steaks pass through and the need for consistent contact on the top and the bottom of the steak make it essential that steaks are consistent in thickness.

Warner-Bratzler Shear Force (Exp. 1)

Mean Warner-Bratzler shear force values were greater ($P < .01$) for steaks cooked with the belt grill than for steaks cooked with the electric broiler (Table 1). However, the SD and range in shear force were similar between the two cooking methods. Steaks for Warner-Bratzler shear force measurement had lower ($P < .01$) cooking losses, smaller SD in cooking losses, and a much smaller range in cooking losses when cooked with the belt grill than when cooked with the electric broiler. The mean cooked temperature was .4°C higher ($P < .01$) for steaks cooked with the belt grill than for steaks cooked with the electric broiler. Thus, belt grill constant time cooking resulted in cooked temperatures very near the targeted end point temperature of 70°C.

Table 1. Descriptive statistics for cooking, shear force, and sensory traits of longissimus thoracis steaks cooked by belt grill or electric broiler

	Belt grill					Electric broiler					
Trait	n	Mean	SD	Min.	Max.	n	Mean	SD	Min.	Max.	P > F
Warner-Bratzler shear force, kg	360	4.6	1.1	2.4	8.8	360	4.3	1.0	1.8	8.4	.001
Cooking losses, %	360	21.5	2.0	11.7	26.7	360	25.8	4.7	13.2	45.2	.001
Cooked temperature, °C	360	70.4	1.4	66.3	78.3	360	70.0	.2	70.0	75.0	.001
Trained sensory evaluation											
Tenderness[a]	182	7.0	.8	4.8	8.0	182	6.7	.9	3.9	8.0	.003
Ease of fragmentation[a]	182	7.0	.8	4.7	8.0	182	6.7	.9	3.8	8.0	.008
Amount of connective tissue[a]	182	7.7	.3	6.3	8.0	182	7.8	.2	7.0	8.0	.001
Juiciness[a]	182	6.0	.3	5.2	7.0	182	5.1	.5	3.6	6.4	.001
Beef flavor intensity[a]	182	5.0	.3	3.9	5.8	182	5.1	.3	4.1	6.0	.016
Off-Flavor[b]	182	3.2	.3	2.4	3.7	182	3.3	.2	2.4	3.9	.004
Cooking losses, %	181	20.2	1.5	15.8	23.6	179	29.8	2.9	19.4	42.2	.001
Cooked temperature, °C	182	69.1	1.1	66.0	72.6	182	70.0	.2	70.0	72.5	.001

[a]1 = extremely tough, difficult, abundant, dry, and bland; 8 = extremely tender, easy, none, juicy, and intense.
[b]1 = intense; 4 = none.

Cooked temperature was included in the statistical model in a preliminary analysis of data from steaks cooked with the belt grill. That analysis was conducted to determine whether the variation in cooked temperature resulting from constant time cooking had induced variation in any palatability traits. Cooked temperature did not affect any trait ($P > F$ .41 to .99); thus, it was eliminated from the final models.

Furthermore, cooking errors occasionally occur with electric broiler cooking due to human error or equipment failure (see maximum cooked temperatures from Table 1). These errors are more likely when cooking large numbers of steaks and monitoring temperatures of numerous steaks simultaneously. In addition, variation in the length of time required for inserting the thermocouple wires can cause unwanted variation in initial steak temperature (Berry and Leddy, 1990b; Wheeler et al., 1996).

Trained Sensory Evaluation (Exp. 2)

In contrast to Warner-Bratzler shear force, steaks cooked with the belt grill had higher ($P < .01$) tenderness and ease of fragmentation (a measure of muscle fiber tenderness) ratings than steaks cooked with the electric broiler (Table 1). We cannot explain the discrepancy in estimated tenderness between shear force and sensory tenderness rating for the two cooking methods. However, the magnitude of the differences was small in both cases and, therefore, may not be of practical importance. The amount of connective tissue, beef flavor intensity, and off-flavor ratings were lower ($P < .02$) for steaks cooked with the belt grill than in steaks cooked with the electric broiler. However, the magnitude of the differences in any of these sensory traits implied they would be of little practical importance. Juiciness ratings were higher ($P < .01$) in steaks cooked with the belt grill than in steaks cooked with the electric broiler, which are likely due to the decreased cooking losses. These differences in juiciness and cooking loss were likely due to a longer cooking time and the postcooking holding time in electric broiler-cooked steaks.

Despite the fact that the electric broiler had a higher cooking temperature (225 vs 163°C), the conduction heating of the belt grill was much faster than convection heating with the electric broiler. No consistent effects of rapid cooking (using charbroiling or combination broiler-grilling) on palatability traits of longissimus steaks have been reported compared with slower cooking using Open Hearth electric broiling or grilling (Berry and Leddy, 1990a; Berry, 1993; Berry and Bigner, 1995). Lyon and Lyon (1993) reported that, compared with cooking in a bag submersed in a water bath, cooking chicken breasts with a belt grill increased cooked yield, moisture, and measures of juiciness with no affect on modified Warner-Bratzler shear force. Berry et al. (1981) reported that cooking for a constant time (35 min) was a suitable alternative to cooking to constant temperature (70°C) when using an Open Hearth electric broiler to cook longissimus lumborum steaks. However, Wheeler et al. (1996) disagreed with that conclusion because of reduced repeatability of duplicate measurements of Warner-Bratzler shear force, despite similar mean shear force values.

As with shear force steaks, sensory evaluation steaks had lower ($P < .01$) cooking losses, smaller SD in cooking losses, and a much smaller range in cooking losses when cooked with the belt grill than when cooked with the electric broiler (Table 1). In contrast to shear force steaks, the mean cooked temperature for sensory steaks was lower ($P < .01$) for steaks cooked with the belt grill than for steaks cooked with the electric broiler. However, as for shear force steaks, the belt grill cooked sensory steaks very near the desired end point temperature of 70°C using constant time cooking. All sensory steaks cooked with the belt grill were within 4°C of 70°C.

The belt grill settings used in these experiments resulted in slower cooking than the settings reported by Shackelford et al. (1997) for our tenderness classification system. The cooking time in the classification system needed to be kept to a minimum, so the highest heat setting available (260°C) was used. At 260°C, the time required to cook a 2.54-cm-thick steak to 70°C was 4.33 min. However, these settings resulted in substantial crust formation on the steak surface. Preliminary experiments determined that the amount of crust on the steak surfaces using those settings interfered with the trained sensory panel's ability to evaluate the samples. Because cooking time was not a limiting factor for routine laboratory shear force and sensory evaluations, we used a lower heating temperature (163°C) and a longer cooking time of 5.7 min in order to avoid the excessive crust formation. Nonetheless, this cooking time is relatively rapid for 2.54-cm-thick steaks.

Measurement of Repeatability

Repeatability of duplicate measurements was calculated as the proportion of the total variance that can be attributed to the sample. Thus, repeatability is an indication of the precision of a measurement. Repeatabilities of Warner-Bratzler shear force and tenderness ratings for steaks cooked with the belt grill were higher than for steaks cooked with the electric broiler (Table 2). Ease of fragmentation, amount of connective tissue, and juiciness ratings also had higher repeatabilities in steaks cooked with the belt grill than in steaks cooked with the electric broiler. Repeatabilities for beef flavor intensity and off-flavor ratings for steaks were similar regardless of cooking method. Repeatability of cooking losses in shear force and sensory steaks was higher for steaks cooked with the belt grill than for steaks cooked with the electric broiler. The total variance and, particularly, the error

Table 2. Variance components and repeatabilities for cooking, shear force, and sensory traits of longissimus thoracis steaks cooked by belt grill or electric broiler

	Belt grill			Electric broiler		
	Variance component			Variance component		
Trait	Carcass	Error	Repeatability	Carcass	Error	Repeatability
Warner-Bratzler shear force, kg	1.12	.20	.85	.68	.38	.64
Cooking losses, %	2.32	1.72	.58	5.19	17.09	.23
Cooked temperature, °C	.42	1.63	.20	.00	.09	.00
Trained sensory evaluation						
Tenderness[a]	.50	.07	.87	.55	.22	.71
Ease of fragmentation[a]	.52	.07	.88	.56	.23	.71
Amount of connective tissue[a]	.05	.02	.66	.01	.02	.30
Juiciness[a]	.05	.05	.51	.02	.20	.08
Beef flavor intensity[a]	.06	.06	.52	.05	.04	.56
Off-Flavor[b]	.03	.03	.51	.03	.03	.44
Cooking losses, %	1.49	.86	.63	1.52	6.87	.18
Cooked temperature, °C	.43	.90	.32	.00	.05	–.01

[a]1 = extremely tough, difficult, abundant, dry, and bland; 8 = extremely tender, easy, none, juicy, and intense.
[b]1 = intense; 4 = none.

variance for cooking losses was much larger in steaks cooked with the electric broiler than in steaks cooked with the belt grill. Repeatability of cooked temperature was low regardless of cooking method, as would be expected.

For steaks cooked with the belt grill, the repeatabilities of Warner-Bratzler shear force and tenderness rating were relatively high and were higher than most of the repeatabilities previously reported from our laboratory (.56 to .87) in longissimus cooked with the electric broiler and prepared using standard conditions (Wheeler et al., 1996, 1997). Repeatabilities for tenderness rating were similar and for Warner-Bratzler shear force were slightly lower on longissimus steaks cooked with the electric broiler than previously reported from our laboratory. The amount of variation in a trait affects the repeatability of measuring that trait (Wheeler et al., 1997); thus, the lower repeatability for shear force of electric broiler cooked steaks may be due to lower variation in this data set (SD = 1.0 kg) than in previous data (SD = 1.7 kg; Wheeler et al., 1997). All other sensory traits and cooking losses for belt grill-cooked steaks had moderate repeatabilities. It seems that more inherent sample-to-sample variation in cooking losses and, thus, juiciness may exist than we have been able to consistently detect using electric broiling. The consistency of cooking obtained with electric broilers has been previously questioned (Wheeler et al., 1996, 1997) and may be related to inconsistent heating temperatures (Berry and Dikeman, 1994).

These data indicate that belt grill cooking for collecting research data could reduce cooking errors, reduce cooking time, and improve measurement precision of palatability traits in longissimus with little effect on the means for palatability traits. We have not compared these cooking methods in other muscles and do not know whether the effects would be similar to those in the longissimus.

Implications

Use of the belt grill in place of the electric broiler for cooking when collecting research data should increase precision of evaluation of differences and lead to more accurate interpretation of research results. Increased precision would result in more accurate evaluations and require fewer experimental observations to detect significant treatment differences.

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