Evaluation of Dry-Heat Cookery Method on Volatile Flavor Compound Development and Consumer Evaluation of Six Beef Muscles

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Abstract: The objective of this study was to determine the influence of dry-heat cookery on beef flavor development of multiple beef muscles. Beef strip loins, top sirloin butts, paired tenderloins, paired shoulder clods, and chuck rolls were collected from USDA Low Choice carcasses (Small[00]–Small[100] marbling; $N = 20$). Subprimals were wet aged in the absence of light for 21 d at 0°C to 4°C. Subprimals were fabricated into 2.54-cm-thick steaks representative of the following muscles: *Gluteus medius*, *Infraspinatus*, *Longissimus lumborum*, *Psoas major*, *Serratus ventralis*, and *Triceps brachii* and randomly assigned to one of 4 dry-heat cookery methods: charbroiler grill (CHAR), clamshell grill (CLAM), convection oven (OVEN), and salamander broiler (SALA). Steaks were cooked to a medium degree of doneness (71°C) on the randomly assigned cooking method. Untrained consumer panelists ($N = 300$) evaluated each sample for flavor, tenderness, juiciness, and overall liking. No interactions were observed between cooking method and muscle ($P \geq 0.344$) for any palatability traits evaluated. Consumers preferred CHAR steaks ($P < 0.05$) over CLAM steaks for flavor, tenderness, juiciness, and overall liking. Additionally, CLAM steaks were rated lower ($P < 0.05$) than all other methods for tenderness and juiciness. OVEN and SALA steaks were rated higher ($P < 0.05$) than CLAM steaks by consumers for tenderness and juiciness but were similar ($P > 0.05$) to CLAM steaks for overall liking. CHAR steaks produced a greater concentration of Maillard compounds compared with the other cooking methods. Steaks cooked using OVEN and SALA ($P < 0.05$) produced more lipid oxidation products. Additionally, CHAR steaks produced the greatest ($P < 0.05$) total volatile production compared with all other treatments, which may be a result of the combination of Maillard reaction products and the lipid degradation products.

Introduction

Flavor and aroma in meat products are produced principally through cooking (Mottram, 1998). Flavor development occurs through the Maillard reaction and thermal degradation of lipids and thiamin, which produces the characteristic brown color and roasted, brown flavors associated with cooked meat products (Mottram, 1994,1998). Cooking is accomplished through the application of heat. Cooking transfers heat through 3 primary modes: conduction, convection, and radiation (Saravacos and Kostaropoulos, 2016). In general, conduction transfers heat through direct contact with meat, convection transfers heat by circulating hot air over meat surfaces, and radiant heat is passively transferred through the air between a radiant heat source and meat (Murphy et al., 2001; Fabre et al., 2018). Flavor is heat dependent and therefore is likely impacted by heat transfer differences among different dry-heat cookery methods.

Heat transfer rates can also be impacted by product composition (Gardner et al., 2020). Differences in quality grades are attributed to differences in intramuscular fat, which can influence the way that steaks

conduct heat and therefore impact flavor development (O'Quinn et al., 2012; Legako et al., 2015). In addition to quality grade, muscle has a direct impact on palatability ratings from consumers, which may be in part due to differing fiber types, fiber direction, or a combination of these factors influencing flavor development (Hunt et al., 2014; Legako et al., 2015; Chail et al., 2017).

Cooking method is one of the primary factors that consumers have control over in producing a highly - palatable beef product for consumption. However, the majority of the literature surrounding cooking method's impact on palatability has focused primarily on tenderness, rather than all attributes of palatability (Berry, 1993; Savell et al., 1999; Powell et al., 2000; Lawrence et al., 2001; Obuz et al., 2003). Consumers will use a wide variety of cooking methods to cook their meat to provide the optimum combination of tenderness, juiciness, and flavor (Savell et al., 1999; Bagley et al., 2010). Previously, individual muscles have been evaluated by cooking methods for tenderness evaluation, but differentiation among dry-heat cookery methods for flavor analysis is extremely limited in the literature. By matching individual muscles to dry-heat cookery methods that improve flavor, beef marketing can be improved, thus resulting in a better eating experience for the consumer. Additionally, restaurants can better improve the consumer's eating experience by using a variety of cooking methods to better match muscles being served. Therefore, the objective of this study was to determine the influence of dry-heat cookery on beef flavor development of multiple beef muscles.

Materials and Methods

Product selection and subprimal fabrication

Beef strip loins (Institutional Meat Purchase Specifications [IMPS] #180), top sirloin butts (IMPS #184), paired tenderloins (IMPS #189), paired shoulder clods (IMPS #114), and chuck rolls (IMPS #116) were collected from USDA Low Choice carcasses (Small[00]–Small[100] marbling; $N = 20$) from a large commercial beef processing facility. Trained Texas Tech University (TTU) research personnel collected carcass data for yield and quality grade information, including preliminary yield grade, ribeye area, kidney pelvic and heart fat, lean and skeletal maturity, and marbling score. Following selection, all subprimals were transported under refrigeration (0°C to 4°C) to the Gordon W. Davis Meat

Laboratory at TTU. Subprimals were wet aged in the absence of light for 21 d at 0°C to 4°C.

During fabrication, subprimals were fabricated into the following muscles: *Gluteus medius* (GM), *Infraspinatus* (IF), *Longissimus lumborum* (LL), *Psoas major* (PM), *Serratus ventralis* (SV), and *Triceps brachii* (TB). Subprimals were then fabricated into 2.54-cm steaks using a slicer (Berkel X13E, Berkel Equipment, Louisville, KY). Steaks were then randomly assigned within paired subprimals to one of the 4 cooking methods, vacuum packaged, and frozen at −20°C until further analysis.

Proximate analysis and pH

The percentage of moisture, fat, protein, and collagen was determined using an AOAC approved method. Samples were thawed for 12 h at 4°C. Prior to analysis, all accessory muscles and heavy connective tissue were removed, and then samples were cubed into approximately 3-cm³ pieces. Sample pieces were then ground twice through a 4-mm plate on a tabletop grinder (#12 2/3 HP Electric Meat Grinder, Model MG-204182-13, Gander Mountain, St. Paul, MN). Proximate analysis was conducted using near-infrared spectrophotometry (FoodScan, FOSS NIRsystems, Inc., Laurel, MD).

pH was measured using a slurry method, in which 10 g of ground sample after proximate analysis was added to 90 mL of distilled water and stirred with a stir bar until thoroughly mixed. To prevent the pH electrode (Jenway Model-3510, 120 VAC, Cole Parmer, Vernon Hills, IL) from being blocked with sample, all pH measurements were taken through a filter paper cone (Qualitative P8 Fisherbrand Filter Paper, Fisher Scientific, Pittsburgh, PA). Between each sample, the pH electrode was rinsed using distilled water and dried using low lint Kimwipes (Kimberly-Clark; 34120, Uline, Pleasant Prairie, WI).

Consumer sensory analysis

Prior to panels, steaks were thawed for 24 h at 2°C to 4°C. Prior to panel evaluation, steaks were cooked to a medium degree of doneness (71°C) on one of 4 randomly assigned cooking methods: charbroiler grill (Cecilware Pro CCP24 Gas Charbroiler, Grindmaster-Cecilware Corp., Louisville, KY) (CHAR), clamshell grill (Cuisinart Griddler Deluxe GR-250, Cuisinart, Stamford, CT) (CLAM), convection oven (Mark V, Blodgett Corp., Burlington, VT) (OVEN), or salamander broiler (36-RB-N Salamander Broiler, Vulcan, Baltimore, MD) (SALA). Cooking surfaces were heated to 200°C ± 10°C and monitored during cooking using

surface thermocouples and dataloggers (Magnetic K thermocouple 88402K; RDXL4SD Datalogger Omega; Stamford, CT). Approximately every 3 min, steaks were flipped on the charbroiler, oven, and salamander to avoid burning on either side and to evenly distribute the heat source. Steaks were cooked to a medium degree of doneness (peak temperature of 71°C), and internal temperature was monitored during cooking using hand-held thermometers (Thermapen Mk4, ThermoWorks, Inc, Salt Lake City, UT), and then immediately placed into in a vacuum bag, then ice. Steaks were vacuum packaged and chilled for approximately 6 h until panel sessions. One hour prior to panel sessions, vacuum-packaged steaks were placed into a circulating water bath (Immersion Circulator SmartVide 6, Sammic, Gipuzkoa, Spain) set at 63.5°C until serving. Owing to the wide variety of muscle sizes being used in the study, this cooking method was used to reduce variation in serving times for consumer panel analysis. After reheating, steaks were cut into steak thickness $\times 1 \times 1$ cm cubes, and 2 cubes were immediately served to each panelist. Five consumers were served 2 sample cubes from each steak.

Consumer panels were conducted using the methods previously administered at TTU (O'Quinn et al., 2012; Legako et al., 2015). Untrained consumer panelists ($N = 300$) were recruited from the Lubbock, Texas, area in groups of 20. An incomplete block design was used to evaluate the samples owing to the number of treatments ($N = 24$). Panelists evaluated each sample for flavor, tenderness, juiciness, and overall liking on unstructured 100-point line scales using a digital ballot (Qualtrics, Provo, UT) on an electronic tablet (iPad, Apple, Inc., Cupertino, CA). Each scale was verbally anchored at each endpoint and midpoint (0 = extremely dislike/ extremely tough/extremely dry; 50 = neither dislike nor like/neither tough nor tender/neither dry nor juicy; 100 = extremely like/extremely tender/extremely juicy). For each steak, 5 consumer responses were collected and averaged before statistical analysis. Additionally, each panelist was also asked to rate each trait as acceptable or unacceptable and designate each sample as unsatisfactory, everyday, better than everyday, or premium quality. Prior to statistical analysis, the sum of consumers rating steaks acceptable was tabulated and set relative to the maximum possible of 5 for each steak. Likewise, within each steak the sum of ratings for each perceived quality level was tabulated and set relative to the maximum possible of 5 for each steak. Demographic data and purchasing motivators were also collected from each consumer. During the panel, panelists were provided with water, apple juice, and unsalted crackers to serve as palate cleansers.

Volatile compound analysis

The methods of Gardner and Legako (2018) were used to determine volatile compound composition of steaks. Steaks designated for volatile compound analysis were prepared as previously described for consumer sensory analysis. Immediately following cooking, steaks were placed in an unsealed bag, then directly submerged into ice, vacuum packaged, and frozen at −20°C until volatile compound analysis. Prior to analysis, steaks were heated to 63.5°C using a circulating water bath for approximately 1 h. Following heating, six 1.27-cm cores were removed from the center of the steak perpendicular to the steak cut surface. The cores were then minced for 10 s using a coffee grinder (4–12 cup Mr. Coffee grinder; Sunbeam Corporation, Boca Raton, FL). Five grams of sample was weighed into 20 mL glass vials (Gerstel Inc., Linthicum, MD). Ten microliters of internal standard (1, 2-dichlorobenzene, 2.5 mg/μL) was pipetted into the vial and then sealed using a polytetrafluoroethylene septa screw cap (#093640-040-00, 1.3 mm; Gerstel Inc.). The samples were then loaded using a Gerstel automatic sampler (MPS; Gerstel, Inc.) for a 5-min incubation time at 65°C in the Gerstel agitator prior to a 20-min extraction time. Solid-phase microextraction was used to collect the volatile compounds from the headspace of the sample with an 85-μm film thickness carboxen polydimethylsiloxane fiber (Supelco Inc., Bellefonte, PA). Volatile compounds extracted from the headspace were placed onto a VF-5 MS capillary column (30 m $\times$ 0.25 mm $\times$ 1.0 μm; Agilent J&W GC Column; Agilent Technologies, Inc., Santa Clara, CA). Authentic standards (Sigma-Aldrich, St. Louis, MO) were used to confirm compound identities through retention time and ion fragmentation pattern.

Statistical analysis

Data were analyzed as a split-plot arrangement using the PROC GLIMMIX procedure of SAS (version 9.4; SAS Institute, Inc., Cary, NC). Subprimal served as the whole-plot factor and cooking method served as the subplot factor, such that individual steak served as the experimental unit. Peak temperature was included in the model as a covariate. For consumer data, panel session and round also served as a random effect. Consumer acceptance and perceived quality level data was analyzed using a binomial distribution. Means were separated using the PDIFF option of SAS. For all analyses, differences were considered significant at $\alpha < 0.05$. The Kenward-Rogers adjustment was used to estimate denominator degrees of freedom.

Results and Discussion

Proximate analysis and pH

Proximate analysis and pH results are presented in Table 1. Raw steaks from the SV and IF had greater ($P < 0.05$) percentages of fat compared with all other muscles. Contrastingly, steaks from the TB and the PM possessed the greatest ($P < 0.05$) percentage of moisture, while the IF contained the lowest ($P < 0.05$) percentage of moisture. For protein percentage, the GM and LL contained the greatest ($P < 0.05$) percentage compared with all other treatments, while the SV had the lowest ($P < 0.05$) percentage of protein. SV steaks possessed the greatest ($P < 0.05$) percentage of collagen compared with all other treatments, while the TB possessed the lowest ($P < 0.05$) percentage of collagen. For pH, PM and IF steaks possessed the greatest pH values ($P < 0.05$) compared with all other treatments. Additionally, the SV was greater ($P < 0.05$) in pH compared with the GM, which was the lowest ($P < 0.05$) in pH values.

Consumer panel demographic characteristics and purchasing motivators

The demographic characteristics of the 300 consumers who participated in the sensory evaluation are presented in Table 2. The majority of participants were Caucasian/White (54.7%) from households of 4 people (27.3%). Participants were 46.3% male and 53.7% female. The consumers were predominately married (54.0%), 30 to 39 years of age (31.0%), and with an annual income of more than $100,000 (22.9%) and some college or technical school education (35.0%).

Table 1. Least-squares means for proximate analysis and pH for beef steaks representing six different muscles of USDA Low Choice carcasses ($N = 20$)

Muscle	Fat, %	Moisture, %	Protein, %	Collagen, %	pH
Gluteus medius	3.4[b]	72.6[bc]	23.0[a]	1.8[bc]	5.4[d]
Infraspinatus	8.0[a]	70.8[d]	19.7[c]	1.9[b]	5.7[a]
Longissimus lumborum	3.9[b]	71.4[cd]	22.7[a]	1.8[bc]	5.5[cd]
Psoas major	3.3[b]	73.4[ab]	21.0[b]	1.8[bc]	5.8[a]
Serratus ventralis	7.3[a]	72.1[c]	18.2[d]	2.2[a]	5.6[b]
Triceps brachii	2.8[b]	74.1[a]	21.7[b]	1.7[c]	5.6[bc]
SEM[1]	0.79	0.43	0.53	0.15	0.04
P value	0.004	<0.001	<0.001	<0.001	<0.001

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

[a–d]Least-squares means without a common superscript differ ($P < 0.05$).

When consuming beef, 50.0% of consumers considered flavor the most important palatability trait, followed by tenderness (38.6%). Additionally, consumers primarily ate beef 1 to 3 times per week (39.3%) or 4 to 6 times per week (37.0%) and preferred their beef cooked to medium rare (34.7%) or medium (32.3%).

Consumers were also asked to rank 15 beef product purchasing motivators (Table 3). Price, USDA grade, color, size, weight, and thickness were the most important ($P < 0.05$), followed by marbling levels, eating satisfaction claims, familiarity of cut, and nutrient content. Moreover, animal welfare, antibiotic use, and growth promotant use were more important ($P < 0.05$) than natural/organic claims, grass-fed diet, packaging type, brand, and grain-fed diet, which were considered the least important ($P < 0.05$).

Consumer sensory analysis

Cooking method. No interactions were observed between cooking method and muscle ($P \geq 0.344$) for any palatability traits evaluated. Consumers preferred CHAR steaks ($P < 0.05$) to CLAM steaks for flavor, tenderness, juiciness, and overall liking (Table 4). Additionally, CLAM steaks were rated lower ($P < 0.05$) than all other methods for tenderness and juiciness. Moreover, OVEN steaks were rated similar ($P > 0.05$) for flavor to both CHAR and CLAM steaks ($P > 0.05$). OVEN and SALA steaks were rated higher ($P < 0.05$) by consumers than CLAM steaks for tenderness and juiciness but were similar ($P > 0.05$) to CLAM steaks for overall liking. SALA steaks were rated similar ($P > 0.05$) to CLAM steaks for flavor. When consumers were asked to rate steaks as acceptable for tenderness or juiciness, CLAM steaks had a lower ($P < 0.05$; Table 5) percentage of steaks rated as acceptable in comparison to all other treatments. No differences were observed ($P = 0.06$) among cooking methods for overall liking, nor were differences observed for the percentage of steaks rated as acceptable for flavor and overall ($P = 0.44, 0.26$). When consumers were asked to designate each sample as unsatisfactory, everyday, better than everyday, or premium quality, CLAM steaks produced a greater ($P < 0.05$) percentage of unsatisfactory steaks than OVEN or CHAR steaks but were similar to SALA ($P > 0.05$; Table 6). Clamshell steaks also produced a greater ($P < 0.05$) percentage of steaks as everyday quality than SALA or CHAR steaks but were similar ($P > 0.05$) to OVEN. No differences were observed ($P = 0.08$) among cooking methods for the percentage of steaks rated as better than everyday quality. CHAR and SALA steaks had the greatest ($P < 0.05$) percentage

Table 2. Demographic characteristics of consumers ($N = 300$) who participated in consumer sensory panels

Characteristic	Response	Percentage of Consumers
Gender	Male	46.3
	Female	53.7
Household Size	1 person	11.0
	2 people	18.3
	3 people	17.0
	4 people	27.3
	5 people	15.6
	6 people	6.3
	>6 people	4.3
Marital Status	Single	46.0
	Married	54.0
Age	Under 20	12.0
	20–29	19.7
	30–39	31.0
	40–49	22.0
	50–59	6.0
	Over 60	9.3
Ethnic Origin	African American	6.7
	Asian	0.3
	Caucasian/White	54.0
	Hispanic	35.7
	Native American	1.0
	Other	0.3
Annual Household Income	Under $25,000	11.0
	$25,000–$34,999	11.0
	$35,000–$49,999	15.7
	$50,000–$74,999	16.3
	$75,000–$100,000	20.0
	More than $100,000	22.9
Education Level	Non-high school graduate	5.0
	High school graduate	23.3
	Some college/technical school	35.0
	College graduate	25.0
	Post graduate	11.6
Beef Consumption Per Week	None	0.0
	1–3 times	39.3
	4–6 times	37.0
	7 or more	23.7
Most Important Palatability Trait	Flavor	50.0
	Juiciness	11.3
	Tenderness	38.6

Table 2. (*Continued*)

Characteristic	Response	Percentage of Consumers
Degree of Doneness Preference	Very rare	0.7
	Rare	4.3
	Medium rare	34.7
	Medium	32.3
	Medium well	15.7
	Well done	9.7
	Very well done	2.6

of steaks rated as premium quality in comparison to CLAM steaks, which produced the lowest ($P < 0.05$) percentage.

Previously, when comparing multiple muscles over a variety of cooking methods, statistical differences have been observed among cooking methods for tenderness score during trained panels; however, the magnitude of the differences are 0.01 to 0.5 on an 8-point scale (Herring and Rogers, 2003). Likewise, multiple studies have determined that Warner-Bratzler shear force values vary within multiple muscles owing to cooking method (Lawrence, et al., 2001; Kerth et al., 2003; Yancey et al., 2011; Fabre et al., 2018). Clearly, prior research and

Table 3. Beef steak purchasing motivators[1] of consumers ($N = 300$) participating in consumer sensory panels

Trait	Importance
Price	67.9[a]
USDA grade	67.6[a]
Size, weight, thickness	66.9[a]
Color	66.8[a]
Marbling level	58.6[b]
Eating satisfaction claims	57.8[b]
Familiarity of cut	57.4[bc]
Nutrient content	55.8[bc]
Animal welfare	50.9[cd]
Antibiotic use in animal	48.4[d]
Growth promotant use	48.2[d]
Natural or organic claims	43.1[e]
Grass-fed	41.0[ef]
Packaging type	40.8[ef]
Brand	40.8[ef]
Grain-fed	37.9[f]
SEM[2]	1.8
P value	<0.001

[1]Purchasing motivators: $0 =$ extremely unimportant, $100 =$ extremely important.

[2]Standard error (largest) of the least-squares means in the same main effect.

[a–f]Least-squares means without a common superscript differ ($P < 0.05$).

Table 4. Least-squares means of palatability ratings[1] of beef steaks from six muscles of USDA Low Choice carcasses ($N = 20$) cooked by four different methods

Treatment	Flavor	Tenderness	Juiciness	Overall Liking
Cooking Method				
Charbroiler	60.1[a]	64.3[a]	55.1[a]	59.8[a]
Clamshell	54.5[b]	55.7[b]	47.2[b]	54.0[b]
Oven	57.9[ab]	62.1[a]	52.0[a]	57.6[ab]
Salamander	56.1[b]	62.7[a]	54.8[a]	57.0[ab]
SEM[2]	1.9	1.5	1.6	1.7
P value	0.023	<0.001	<0.001	0.033
Muscle				
Gluteus medius	53.1[c]	54.9[c]	43.6[d]	51.2[d]
Infraspinatus	58.9[b]	70.3[b]	64.1[a]	62.6[b]
Longissimus lumborum	53.5[c]	55.7[c]	42.0[d]	51.4[d]
Psoas major	64.7[a]	74.9[a]	59.9[a]	67.4[a]
Serratus ventralis	56.2[bc]	56.8[c]	55.2[b]	56.7[c]
Triceps brachii	55.5[c]	54.6[c]	48.8[c]	53.5[cd]
SEM	2.1	1.7	1.7	1.8
P value	<0.001	<0.001	<0.001	<0.001
Method × Muscle				
P value	0.344	0.902	0.487	0.518

[1]Sensory scores: 0 = extremely tough/dry/dislike flavor/dislike overall, 50 = neither dry nor juicy/neither tough nor tender, 100 = extremely juicy/tender/like flavor/like overall.

[2]Standard error (largest) of the least-squares means in the same main effect.

[a–c]Least-squares means in the same main effect (cooking method or muscle) without a common superscript differ ($P < 0.05$).

Table 5. Consumer acceptability percentages of beef steaks from 6 muscles of USDA Low Choice carcasses ($N = 20$) cooked by 4 different methods

Treatment	Flavor Acceptability	Tenderness Acceptability	Juiciness Acceptability	Overall Acceptability
Cooking Method				
Charbroiler	81.2	89.5[a]	79.3[a]	82.4
Clamshell	81.8	82.8[b]	69.3[b]	79.2
Oven	83.7	90.5[a]	78.5[a]	82.8
Salamander	80.1	89.8[a]	76.4[a]	79.3
SEM[1]	0.2	0.2	0.1	0.1
P value	0.442	0.001	<0.001	0.264
Muscle				
Gluteus medius	77.0[c]	80.5[c]	64.9[c]	74.6[b]
Infraspinatus	83.0[b]	92.2[b]	87.4[a]	85.9[a]
Longissimus lumborum	80.3[bc]	82.1[c]	61.0[c]	74.4[b]
Psoas major	89.0[a]	97.5[a]	84.3[a]	89.7[a]
Serratus ventralis	79.3[bc]	82.1[c]	78.0[b]	78.3[b]
Triceps brachii	79.6[bc]	83.3[c]	73.2[b]	78.6[b]
SEM[1]	0.2	0.4	0.2	0.2
P value	<0.001	<0.001	<0.001	<0.001
Method × Muscle				
P value	0.231	0.909	0.316	0.599

[1]Standard error (largest) of the least-squares means in the same main effect.

[a–c]Least-squares means in the same main effect (cooking method or muscle) without a common superscript differ ($P < 0.05$).

this study point to the influence of cookery on beef tenderness.

Less information is available that is specific to the impact of cooking method on beef flavor. However, recent work indicates that consumers can differentiate among multiple palatability traits—including flavor—owing to cooking method. Sepulveda et al. (2019) reported that beef strip loin steaks cooked on a flat-top grill were rated lower by consumers than steaks cooked on a charbroiler grill, clamshell grill, and salamander broiler for tenderness, juiciness, flavor liking, and overall liking. Overall, this study is an agreement with past works that reveal that cooking method influences beef palatability. Furthermore, this study indicates that both beef tenderness and flavor are differentiated by cooking method.

Muscle. PM steaks were rated higher ($P < 0.05$; Table 4) than all other muscles for flavor, tenderness, and overall liking. Additionally, PM steaks had the greatest ($P < 0.05$) percentage of steaks rated as acceptable for flavor and tenderness. Consumers rated IF steaks similar ($P > 0.05$) to PM steaks for juiciness

and had a similar percentage of steaks rated as acceptable for juiciness and overall acceptability. For flavor, tenderness, and overall liking, IF steaks were rated lower ($P < 0.05$) than PM steaks but higher ($P < 0.05$) than all other muscles. Consumers rated SV steaks similar ($P > 0.05$) to IF, GM, LL, and TB steaks for flavor. SV steaks were also rated higher ($P < 0.05$) than GM, LL, and TB steaks for juiciness, but they were similar ($P > 0.05$) to TB steaks for overall liking. Consumers rated GM, LL, and TB steaks the lowest ($P < 0.05$) for flavor, tenderness, and overall liking.

When asked to rate steaks as acceptable for flavor, PM steaks had the greatest percentage of steaks rated as acceptable ($P < 0.05$), followed by IF steaks, which were similar ($P > 0.05$) to LL, SV, and TB steaks but higher ($P < 0.05$) than GM steaks. A similar trend was observed for tenderness acceptability; however, IF steaks had a greater ($P < 0.05$) percentage of steaks rated as acceptable for tenderness than all other muscles with the exception of PM. Consumers rated a greater percentage of PM and IF steaks as acceptable

Table 6. Consumer perceived quality level percentages for beef steaks of six muscles of USDA Low Choice carcasses ($N = 20$) cooked by four different methods

Treatment	Unsatisfactory Quality	Everyday Quality	Better than Everyday Quality	Premium Quality
Cooking Method				
Charbroiler	16.4[b]	41.8[c]	26.3	11.3[a]
Clamshell	22.0[a]	49.5[a]	20.8	4.1[c]
Oven	16.2[b]	48.3[ab]	26.9	5.3[bc]
Salamander	20.1[ab]	42.6[bc]	24.4	8.5[ab]
SEM[1]	0.1	0.09	0.1	0.3
P value	0.030	0.014	0.077	<0.001
Muscle				
Gluteus medius	25.0[a]	51.3[a]	19.2[c]	2.8[d]
Infraspinatus	15.3[b]	35.8[b]	36.0[a]	11.7[b]
Longissimus lumborum	24.6[a]	53.1[a]	17.1[c]	3.1[d]
Psoas major	9.6[c]	40.2[b]	28.7[b]	18.5[a]
Serratus ventralis	21.4[a]	41.0[b]	28.8[b]	8.1[bc]
Triceps brachii	19.7[ab]	52.4[a]	20.7[c]	5.9[cd]
SEM	0.2	0.1	0.1	0.3
P value	<0.001	<0.001	<0.001	<0.001
Method × Muscle				
P value	0.344	0.742	0.761	0.208

[1]Standard error (largest) of the least-squares means in the same main effect.

[a–c]Least-squares means in the same main effect (cooking method or muscle) without a common superscript differ ($P < 0.05$).

($P < 0.05$) for juiciness compared with all other muscles, followed by SV and TB steaks ($P < 0.05$); LL and GM steaks had the lowest ($P < 0.05$) percentage of steaks rated as acceptable for juiciness. For overall acceptability, PM and IF steaks had the highest percentage of steaks rated as acceptable ($P < 0.05$) compared with all other muscles ($P < 0.05$). When asked to designate samples as unsatisfactory, everyday, better than everyday, or premium quality, consumers rated a greater percentage of GM, LL, SV, and TB steaks as unsatisfactory ($P < 0.05$) compared with IF or PM steaks. PM steaks had the lowest ($P < 0.05$) percentage of steaks rated as unsatisfactory. A similar trend was observed for the percentage of steaks rated as everyday quality. SV, PM, and IF steaks had the lowest ($P < 0.05$) percentage of steaks rated as everyday quality, compared with GM, LL, and TB, which were greater ($P < 0.05$). For better-than-everyday quality, IF steaks produced the greatest ($P < 0.05$)

percentage of steaks, followed by PM and SV, which were greater ($P < 0.05$) than LL, GM, and TB steaks. PM had the greatest percentage of steaks rated as premium quality ($P < 0.05$), followed by IF, which was greater ($P < 0.05$) than SV, GM, and LL.

It is important to note the lack of interactive effect between cooking method and quality grade. This indicates that, rather than selecting an optimum cooking for each individual muscle, a variety of cooking applications can be used with equal success on high-quality muscles. In the 2010 National Beef Tenderness Survey, IF (top blade) steaks were rated the highest out of LL (top loin) steaks and GM (top sirloin) steaks for overall liking, tenderness, and juiciness but were similar to the LL for flavor like and flavor level (Guelker et al., 2013). Hunt et al. (2014) reported similar consumer ratings for GM, SV, and LL steaks, which were similar for tenderness, juiciness, and flavor. Nyquist et al. (2018) reported similar results, as the IF outperformed the LL and TB for flavor liking, juiciness, tenderness, and overall liking. However, the SV was reported to be similar to the IF for juiciness but was lower for all other traits evaluated (Nyquist et al., 2018). However, these results directly contrast the findings from Legako et al. (2015). Legako et al. (2015) observed that steaks from Low Choice PM, LL, and GM were rated similar for tenderness, juiciness, flavor liking, and overall liking. Carmack et al. (1995) also reported no differences among GM, IF, LL, PM, SV, and TB for beef-flavor intensity, tenderness, or juiciness. This may be due to the wide range of muscles used in these studies, which also included traditionally low-quality muscles such as the *semimembranosus* and *semitendinosus*, which have typically been drier and tougher than the muscles used in the present study. Additionally, for chuck muscles specifically, Kukowski et al. (2005) reported that LL and IF steaks were rated similar for tenderness, juiciness, and flavor intensity but higher than both the SV and TB.

Volatile compound analysis

Seventy-two compounds were evaluated for their contribution to beef flavor development. Of these compounds, 19 compounds were impacted by the interaction of cookery method and muscle, 26 compounds were solely impacted by the cooking method main effect, and 24 compounds were impacted by muscle alone. As described subsequently, themes emerged for volatile compounds dependent on cooking method and/or muscle. Similar—but more complex—further results were observed for volatile compounds where interactions were present. Taken alone, the interactions

are difficult to interpret. As a result, main effects will be discussed first, followed by significant interactions to help facilitate the description of important results.

Cooking method. When evaluating differences in compounds produced from various dry-heat cookery methods, very different profiles emerged among methods. CHAR steaks produced a greater concentration of Maillard compounds, including Strecker aldehydes, pyrazines, and sulfur-containing compounds compared with the other cooking methods evaluated

(Table 7). Specifically, for Strecker aldehydes, CHAR steaks produced the greatest ($P < 0.05$) concentration of 2-methylbutanal, benzaldehyde, and phenylacetaldehyde compared with OVEN and SALA steaks. However, an opposite trend existed for 3-methylbutanal, where OVEN steaks produced the lowest ($P < 0.05$) concentration compared with all other treatments. CHAR steaks produced the greatest ($P < 0.05$) concentration of methylpyrazine and trimethylpyrazine compared with all other treatments. Additionally, for trimethylpyrazine, CLAM steaks produced a greater

Table 7. Volatile compounds from beef steaks of six muscles of USDA Low Choice carcasses ($N = 20$) cooked by four different methods influenced by cooking method ($P \leq 0.05$)[1]

Compound, ng/g	Cooking Method				SEM[2]	P Value
	CHAR	CLAM	OVEN	SALA		
Strecker Aldehydes						
3-methylbutanal	2.76[a]	2.07[a]	1.32[b]	2.20[a]	0.27	<0.001
2-methylbutanal	3.31[a]	1.80[bc]	1.07[c]	2.11[b]	0.34	<0.001
Benzaldehyde	34.48[a]	29.10[ab]	20.54[c]	26.17[bc]	2.56	0.002
Phenylacetaldehyde	1.123[a]	1.030[a]	0.557[c]	0.697[b]	0.045	<0.001
Pyrazines						
Methyl-pyrazine	4.05[a]	1.23[b]	0.57[b]	0.75[b]	0.27	<0.001
Trimethylpyrazine	3.73[a]	1.51[b]	0.48[c]	0.69[c]	0.17	<0.001
Sulfur-Containing Compounds						
Methanethiol	3.27[ab]	4.50[a]	3.19[b]	2.79[b]	0.57	0.027
Dimethyl disulfide	0.026[b]	0.082[a]	0.036[b]	0.042[b]	0.016	0.040
Carbon disulfide	4.56[b]	4.10[b]	4.87[b]	7.61[a]	0.33	<0.001
2-methyl thiophene	0.801[a]	0.309[b]	0.239[b]	0.212[b]	0.056	<0.001
Lipid-Derived Alcohols						
1-octanol	4.81[b]	4.90[b]	7.29[a]	4.55[b]	0.49	<0.001
Carboxylic Acids						
Acetic acid	3.37[b]	3.04[b]	3.19[b]	4.26[a]	0.15	<0.001
Heptanoic acid	1.88[b]	1.72[b]	2.68[a]	1.73[b]	0.11	<0.001
Nonanoic acid	0.559[bc]	0.636[ab]	0.434[c]	0.719[a]	0.057	<0.001
Octanoic acid	63.87[b]	62.86[b]	79.56[a]	57.86[b]	4.13	0.002
Esters						
Hexanoic acid, methyl ester	0.604[ab]	0.351[b]	1.032[a]	0.745[ab]	0.174	0.048
Nonanoic acid, methyl ester	0.250[bc]	0.232[c]	0.282[a]	0.274[ab]	0.010	0.001
Propanoic acid, methyl ester	0.877[a]	0.761[b]	0.724[b]	0.777[b]	0.035	0.007
Ketones						
2-pentanone	0.301[a]	0.193[b]	0.207[b]	0.237[b]	0.020	<0.001
Lipid-Derived Aldehydes						
Decanal	2.25[a]	1.68[b]	1.81[b]	1.98[ab]	0.13	0.021
Heptanal	12.43	14.08	16.76	16.22	1.70	0.234
Nonanal	7.74[b]	10.57[a]	7.42[b]	6.55[b]	0.87	0.007
Pentanal	0.99[c]	1.58[bc]	2.24[ab]	2.63[a]	0.38	0.011
Hydrocarbons						
Toluene	18.00[a]	7.08[bc]	5.70[c]	8.28[b]	0.91	<0.001
Pentane	4.11[b]	4.65[b]	5.91[ab]	7.12[a]	0.74	0.006
Total Volatile Production	1,955.99[a]	966.34[b]	989.17[b]	1,120.21[b]	92.80	<0.001

[1]Cooking methods included charbroiler grill (CHAR), clamshell grill (CLAM), convection oven (OVEN), and salamander broiler (SALA).

[2]Standard error (largest) of the least-squares means in the same main effect.

[a–c]Least-squares means in the same column without a common superscript differ ($P < 0.05$).

($P < 0.05$) concentration than OVEN or SALA steaks but were still lower ($P < 0.05$) than CHAR steaks. Moreover, CLAM and CHAR steaks produced the greatest concentration of sulfur-containing compounds. For methanethiol, CLAM steaks produced the greatest ($P < 0.05$) concentration compared with OVEN and SALA steaks but were similar ($P > 0.05$) to CHAR steaks. Similarly, CLAM steaks produced a greater ($P < 0.05$) concentration of dimethyl disulfide compared with all other cooking methods. However, for carbon disulfide, SALA produced the greatest ($P < 0.05$) concentration compared with all other treatments. Additionally, CHAR steaks produced the greatest ($P < 0.05$) concentration of 2-methylthiophene compared with all other treatments. For Maillard products, CHAR and CLAM steaks followed a similar trend, indicating that more direct applications of heat increased Maillard product production.

Steaks cooked using OVEN and SALA ($P < 0.05$) produced more lipid oxidation products, including carboxylic acids and esters. Specifically, OVEN steaks produced the greatest ($P < 0.05$) concentrations of 1-octanol, octanoic acid, and heptanoic acid compared with all other treatments. SALA steaks produced the greatest ($P < 0.05$) concentration of acetic acid and pentanal compared with all other treatments. For nonanoic acid, methyl ester, pentanal, and pentane, OVEN and SALA steaks produced a greater ($P < 0.05$) concentration than CHAR or CLAM steaks. In direct contrast, however, CHAR steaks produced the greatest ($P < 0.05$) concentration of propanoic acid, methyl ester, 2-pentanone, and toluene compared with all other treatments. Additionally, CHAR steaks produced the greatest ($P < 0.05$) total volatile production compared with all other treatments, which may be a result of the combination of Maillard reaction products and the lipid degradation products. This increase in lipid-derived products may be produced by recirculation of lipid products throughout the cooking process. As the cooking process occurs, lipids are dripped down into the flames during the cooking process, then aerosolized back onto the cooking surface and steak of the oven, charbroiler grill, and the salamander broiler. OVEN and SALA steaks also produced the lowest concentration ($P < 0.05$) of sulfur-containing compounds and pyrazines, which indicates that radiant and convection heat transfer methods produce lower concentrations of Maillard products owing to their less-direct heat application and transfer. However, because the CHAR grill is also a radiant heat transfer, it may explain the increase in lipid-derived products produced by this cooking method.

Muscle. When evaluating the impact of muscle on flavor development, the SV stood out as the muscle that produced the greatest ($P < 0.05$; Table 8) concentration of total volatile compounds compared with all other muscles with the exception of the GM (Table 10). Across the classes of compounds, the SV produced the greatest ($P < 0.05$) concentration of 2,3-butanediol, carbon disulfide, 1-octen-3-ol, octanoic acid, 2-propanone, 2-pentanone, octane, and pentane. This increase in total volatile compound production may be due to the plentiful flavor precursors present in the SV. The SV has been well-established as a muscle with a high fat percentage in comparison to other muscles within a USDA quality grade (Hunt et al., 2016; Nyquist et al., 2018). Hunt et al. (2016) reported that SV steaks possessed greater concentrations of fatty acids, which can interact with products formed during the Maillard production and produce compounds key to flavor development.

Similarly, the GM produced greater ($P < 0.05$) concentrations of Maillard reaction products, including benzaldehyde and methylpyrazine, compared with all other treatments, with the exception of the TB. This contributed to an increased ($P < 0.05$) total concentration compared with IF and LL steaks. In direct contrast, the IF produced the lowest concentration of most compounds. The PM also produced a wide range of compounds; however, it was not to the extremes possessed by the SV. This intermediate effect may contribute to the increased ratings by consumers for flavor liking (Table 4), rather than swinging the pendulum to one extreme (lipid degradation) to the other (Maillard reaction products). These major differences in muscle were not observed in the previous literature. Previously, Hunt et al. (2016) and Legako et al. (2015) observed differences among muscles for Strecker aldehydes and carboxylic acids, as well as certain ketones, including 2,3-butanedione. In the study conducted by Legako et al. (2015), the *semimembranosus* outproduced the SV for the Maillard-derived compounds, whereas the SV produced greater concentrations of lipid-derived carboxylic acids. No differences were observed among muscles for pyrazines or sulfur-containing compounds in Legako et al. (2015). These differences were further echoed in Hunt et al. (2016). This may be due to differing cooking methodologies, as the steaks in the current study were cooked using a variety of different dry-heat methods. Different heat applications may have allowed for further development of certain compounds, such as those derived from lipid degradation.

Table 8. Volatile compounds from beef steaks of six muscles of USDA Low Choice carcasses ($N = 20$) cooked by four different methods influenced by muscle ($P \leq 0.05$)[1]

Compound, ng/g	GM	IF	LL	PM	SV	TB	SEM[2]	P Value
				Muscle				
Strecker Aldehydes								
Acetaldehyde	15.4[bc]	9.6[c]	12.1[bc]	16.8[abc]	24.1[a]	19.5[ab]	3.20	0.018
3-methylbutanal	2.38[ab]	1.35[c]	2.21[abc]	1.73[bc]	2.97[a]	1.88[bc]	0.33	0.002
2-methylbutanal	3.18[a]	0.88[b]	1.88[b]	1.35[b]	3.39[a]	1.75[b]	0.44	<0.001
Benzaldehyde	30.05[ab]	20.82[c]	24.21[bc]	25.35[bc]	27.25[bc]	37.70[a]	3.14	0.003
Phenylacetaldehyde	1.048[a]	0.698[bc]	0.831[b]	0.680[c]	0.802[bc]	1.05[a]	0.053	<0.001
Maillard Intermediate								
2,3-butanediol	36.60[cd]	58.45[bc]	21.45[d]	78.65[ab]	84.91[a]	40.50[cd]	15.75	<0.001
Pyrazines								
Methyl-pyrazine	2.15[a]	1.46[bc]	1.51[abc]	0.95[c]	1.92[ab]	1.91[ab]	0.30	0.026
Sulfur-Containing Compounds								
Methanethiol	3.63[ab]	2.15[b]	2.81[b]	3.30[b]	5.41[a]	3.34[b]	0.79	0.050
Carbon disulfide	5.11[bc]	4.38[cd]	4.29[cd]	5.61[b]	8.45[a]	3.87[d]	0.41	<0.001
Lipid-Derived Alcohols								
Ethanol	9.50[a]	3.88[b]	7.30[ab]	7.72[ab]	10.22[a]	11.04[a]	1.79	0.029
1-octen-3-ol	2.73[bc]	2.81[bc]	1.95[c]	3.81[b]	6.48[a]	3.11[bc]	0.67	<0.001
Carboxylic Acids								
Acetic acid	3.51[b]	2.93[c]	3.01[c]	3.77[ab]	4.03[a]	3.53[b]	0.17	<0.001
Heptanoic acid	1.74[cd]	2.01[bc]	1.62[d]	2.18[ab]	2.50[a]	1.94[bcd]	0.13	<0.001
Octanoic acid	69.66[b]	60.26[b]	45.84[c]	64.89[b]	85.34[a]	70.23[b]	4.84	<0.001
Esters								
Hexanoic acid, methyl ester	0.532[b]	0.468[b]	0.476[b]	1.327[a]	0.848[ab]	0.444[b]	0.208	0.010
Ketones								
2-propanone	62.5[b]	32.2[cd]	29.5[d]	56.9[b]	88.8[a]	50.4[bc]	6.7	<0.001
2-pentanone	0.215[bc]	0.211[bc]	0.178[c]	0.246[b]	0.339[a]	0.218[bc]	0.024	<0.001
Lipid-Derived Aldehydes								
Heptanal	12.90[b]	11.67[b]	12.80[b]	16.46[ab]	20.69[a]	14.73[b]	2.11	0.024
Pentanal	1.25[b]	1.36[b]	1.25[b]	2.30[ab]	3.37[a]	1.64[b]	0.47	0.005
Hydrocarbons								
Toluene	11.99[a]	7.25[c]	8.67[bc]	7.37[c]	10.72[ab]	12.58[a]	1.07	<0.001
Octane	1.89[b]	1.32[bc]	1.44[bc]	1.97[b]	3.07[a]	1.15[c]	0.26	<0.001
Pentane	5.02[bc]	3.74[c]	3.34[c]	6.04[b]	9.41[a]	5.10[bc]	0.90	<0.001
Total Volatile Production	1,402.58[ab]	1,038.64[c]	1,006.69[c]	1,136.19[bc]	1,627.38[a]	1,336.07[b]	106.76	<0.001

[1]Muscles included Gluteus medius (GM), Infraspinatus (IF), Longissimus lumborum (LL), Psoas major (PM), Serratus ventralis (SV), and Triceps brachii (TB).

[2]Standard error (largest) of the least-squares means in the same main effect.

[a–c]Least-squares means in the same main effect without a common superscript differ ($P < 0.05$).

Interaction of cooking method and muscle. When evaluating the interactive effects of dry-heat cookery and muscle, much of the main effects from cooking method and muscle were further echoed. CHAR steaks from GM, IF, and SV subprimals produced the greatest ($P < 0.05$; Table 9) concentration of methional, a Strecker aldehyde. Similar trends existed across for Maillard reaction products, including isobutyraldehyde, 2,5-dimethypyrazine, 3-ethyl-2,5-dimethylpyrazine, and 2-3-ethyl-3,5-dimethylpyrazine. However, for 3-hydroxy-2-butanone, a Maillard intermediate ketone, CLAM SV and SALA GM steaks produced the greatest ($P < 0.05$) concentration compared with all other treatments. These results indicate that cookery method greatly influences the Maillard reaction. It is widely recognized that the Maillard reaction is dependent on high heat. Therefore, it is safe to conclude that differences in heat transfer among the cooking methods influence the Maillard reaction. Recent work indicates that quality grade or fat content influences thermophysical properties of beef steaks (Gardner et al., 2020). These interactive results may therefore be the result of

Table 9. Maillard reaction–derived volatile compounds from beef steaks of six muscles of USDA Low Choice carcasses ($N = 20$) cooked by four different methods with an interaction ($P \leq 0.05$)

Compound, ng/g	Strecker Aldehydes		Sulfur Compounds		Pyrazines			Maillard Ketones	
	Methional	Isobutyraldehyde	Dimethyl sulfide	Dimethyl sulfone	2,5-dimethylpyrazine	3-ethyl-2,5-dimethylpyrazine	2-ethyl-3,5-dimethylpyrazine	2,3-butanedione	3-hydroxy-2-butanone
Treatment									
Charbroiler									
GM	4.67[a]	18.98[abc]	7.36[cde]	0.648[bc]	9.95[a]	8.36[a]	7.79[a]	90.60[abcd]	148.18[bcd]
IF	4.47[a]	6.68[ed]	4.69[def]	0.378[c]	5.33[de]	4.03[c]	3.68[c]	18.60[g]	31.21[ij]
LL	2.87[b]	11.29[cde]	4.23[def]	0.613[bc]	8.02[bc]	6.59[b]	6.00[b]	39.46[efg]	67.03[ghij]
PM	1.89[cde]	11.44[cde]	6.69[cdef]	0.516[bc]	4.04[ef]	3.14[cd]	2.93[cd]	55.83[defgh]	98.35[cdefghi]
SV	4.04[a]	19.03[abc]	6.59[cdef]	0.838[bc]	6.69[cd]	6.25[b]	5.86[b]	73.65[bcde]	109.35[bcdefg]
TB	2.24[bc]	5.87[ed]	5.91[def]	0.245[c]	9.07[ab]	6.29[b]	5.69[b]	26.23[fg]	46.85[ghij]
Clamshell									
GM	1.46[cde]	7.75[ed]	5.70[def]	0.203[c]	3.99[ef]	3.08[cd]	2.79[cd]	39.44[efg]	63.89[ghij]
IF	1.39[cde]	3.42[e]	4.07[def]	0.283[c]	2.14[fgh]	1.60[ef]	1.46[ef]	14.51[g]	23.38[j]
LL	1.06[e]	7.26[ed]	4.37[def]	0.310[c]	1.30[hi]	1.07[ef]	0.96[ef]	27.67[fg]	41.20[hij]
PM	1.35[cde]	8.88[ed]	6.64[cdef]	0.650[bc]	1.63[ghi]	0.69[f]	0.61[f]	58.85[cdef]	87.57[defghij]
SV	1.76[cde]	24.81[a]	6.99[cdef]	2.700[a]	1.79[ghi]	1.61[ef]	1.47[ef]	129.40[a]	225.89[a]
TB	1.32[cde]	7.70[ed]	4.03[ef]	0.270[c]	3.37[fg]	2.29[de]	2.10[de]	44.63[efg]	68.37[fghij]
Oven									
GM	1.38[cde]	8.05[ed]	12.55[ab]	0.467[bc]	0.58[hi]	0.46[f]	0.41[f]	92.52[abcd]	154.30[bc]
IF	1.56[cde]	5.60[ed]	4.84[def]	0.691[bc]	0.55[hi]	0.41[f]	0.33[f]	18.44[g]	47.05[ghij]
LL	1.27[ed]	7.77[ed]	2.99[f]	0.951[bc]	0.26[i]	0.25[f]	0.24[f]	44.34[efg]	78.20[efghij]
PM	1.56[cde]	8.56[de]	6.69[cdef]	0.740[bc]	0.68[hi]	1.00[ef]	0.76[f]	70.31[bcde]	105.46[cdefgh]
SV	2.20[bc]	10.29[cde]	5.25[def]	1.246[bc]	0.79[hi]	0.85[ef]	0.72[f]	88.43[bcd]	140.26[bcde]
TB	1.19[ed]	7.34[ed]	8.14[cd]	0.440[bc]	0.92[hi]	1.00[ef]	0.82[ef]	42.83[efg]	78.48[efghij]
Salamander									
GM	1.85[cde]	12.80[bcd]	10.14[bc]	0.755[bc]	1.08[hi]	0.91[ef]	0.84[ef]	104.46[ab]	175.00[ab]
IF	1.84[cde]	7.16[ed]	7.29[cde]	0.449[bc]	0.99[hi]	0.80[f]	0.75[f]	43.21[efg]	70.31[fghij]
LL	1.80[cde]	10.62[cde]	5.87[def]	0.634[bc]	1.16[hi]	0.95[ef]	0.89[ef]	53.02[efgh]	92.19[cdefghi]
PM	1.51[cde]	13.78[bcd]	5.94[def]	0.886[bc]	0.62[hi]	0.43[f]	0.40[f]	77.01[bcde]	136.19[bcdef]
SV	2.09[bcd]	13.58[bcd]	7.77[cde]	0.888[bc]	1.20[hi]	0.93[ef]	0.87[ef]	87.92[bcd]	144.94[bcd]
TB	2.98[b]	21.06[ab]	14.67[a]	1.445[b]	1.42[hi]	1.27[ef]	1.20[ef]	97.63[abc]	155.35[bc]
SEM[2]	0.37	3.58	1.48	0.411	0.74	0.58	0.50	16.01	26.67
P value	<0.001	0.030	0.002	0.018	<0.001	<0.001	<0.001	0.042	0.020

[1]Muscles included Gluteus medius (GM), Infraspinatus (IF), Longissimus lumborum (LL), Psoas major (PM), Serratus ventralis (SV), and Triceps brachii (TB).

[2]Standard error (largest) of the least-squares means in the same main effect.

[a–i]Least-squares means in the same main effect (cooking method or muscle) without a common superscript differ ($P < 0.05$).

compositional differences between muscles impacting thermophysical properties and thus the Maillard reaction.

Cooking method and muscle also interacted to influence lipid degradation products (Table 10). The content of butanal, octanoic acid, methyl ester, 1-octene, hexanal, 2-heptanone, and decane of CLAM SV and OVEN SV steaks were greater ($P < 0.05$) than all other treatments. In agreement with the main effects, CLAM and OVEN cooking methods facilitated greater production of lipid-derived volatile compounds. Of further interest was the dependence on the SV for this many lipid degradation compounds. Presently, it is unclear what mechanism may have led the SV to have increased lipid-derived volatile compounds. Fat contents of the SV were high but comparable with the IF, whereas contents of lipid degradation compounds were lower. As described earlier, muscle greatly influences lipid-derived volatile compounds. However, these results indicated that fat content is not the driving factor in lipid-derived volatile compounds in this study. This may implicate fatty acid composition differences among muscles as a contributing factor in lipid degradation and resulting volatile compounds.

Table 10. Lipid-degradation–derived volatile compounds from beef steaks of six muscles[1] of USDA Low Choice carcasses ($N = 20$) cooked by four different methods with an interaction ($P \leq 0.05$)

Compound, ng/g	Carboxylic Acids		Ester	Alkenes		Aldehydes		Ketone	Alkanes	
	Benzoic acid	Butanoic acid	Octanoic acid, methyl ester	1-octene	p-Xylene	Butanal	Hexanal	2-heptanone	Decane	Tetradecane
Charbroiler Grill										
GM	0.238[cd]	79.18[ab]	0.364[cd]	1.41[bcd]	17.40[a]	1.04[abc]	14.82[c]	1.46[bcdef]	1.338[bc]	1.48[f]
IF	0.438[cd]	26.25[ef]	0.306[cd]	0.63[de]	11.22[b]	0.34[de]	8.89[c]	1.56[bcde]	0.850[cde]	23.83[a]
LL	0.524[cd]	21.30[ef]	0.410[cd]	1.63[bc]	11.02[b]	0.60[cde]	14.43[c]	1.30[defg]	1.522[ab]	4.69[def]
PM	0.390[cd]	55.53[bcde]	0.390[cd]	0.95[cde]	6.36[c]	0.61[cde]	53.40[bc]	1.64[bcde]	1.326[bcd]	3.95[def]
SV	0.423[cd]	54.24[bcde]	0.467[cd]	3.19[a]	12.27[b]	1.05[abc]	32.00[bc]	1.89[bc]	1.867[a]	1.44[f]
TB	0.344[cd]	26.71[def]	0.256[c]	0.56[de]	14.09[ab]	0.30[de]	8.57[c]	1.09[efgh]	0.767[de]	12.60[bcd]
Clamshell Grill										
GM	0.202[d]	30.39[def]	0.300[cd]	0.66[de]	2.23[d]	0.41[de]	13.60[c]	0.81[gh]	0.814[de]	6.41[bcdef]
IF	0.306[cd]	22.25[ef]	0.240[d]	0.57[de]	2.27[d]	0.16[e]	20.96[c]	1.11[efgh]	0.900[cde]	9.18[bcdef]
LL	0.174[d]	16.41[f]	0.314[cd]	0.58[de]	1.94[d]	0.38[de]	27.88[c]	0.69[h]	0.822[de]	10.71[bcde]
PM	0.176[d]	50.24[bcde]	0.352[cd]	0.82[de]	1.80[d]	0.47[de]	80.04[bc]	1.27[defg]	0.992[cde]	7.47[bcdef]
SV	1.887[bc]	114.47[a]	1.056[a]	1.79[b]	4.66[cd]	1.42[a]	39.59[bc]	1.61[bcde]	1.973[a]	2.25[ef]
TB	0.422[cd]	30.72[cdef]	0.321[cd]	0.67[de]	3.46[cd]	0.40[de]	35.82[bc]	1.42[bcdef]	0.693[e]	13.19[bc]
Convection Oven										
GM	0.231[d]	45.71[bcdef]	0.400[cd]	1.05[bcde]	1.66[d]	0.41[de]	42.47[bc]	1.63[bcde]	0.894[cde]	1.95[ef]
IF	0.279[cd]	35.87[cdef]	0.391[cd]	0.87[de]	2.34[d]	0.28[de]	29.59[c]	1.42[defg]	0.844[de]	3.53[ef]
LL	0.344[cd]	24.81[ef]	0.506[bcd]	1.13[bcde]	1.31[d]	0.41[de]	50.71[bc]	1.30[defg]	0.917[cde]	1.65
PM	0.295[cd]	54.84[bcde]	0.746[b]	1.40[bcd]	2.01[d]	0.44[de]	61.76[bc]	1.99[b]	1.101[bcde]	2.17[ef]
SV	0.556[cd]	64.77[bc]	0.561[bc]	3.24[a]	3.14[cd]	0.56[cde]	244.70[a]	2.96[a]	1.117[bcde]	1.54[ef]
TB	0.353[cd]	38.04[cdef]	0.397[cd]	0.88[cde]	2.85[cd]	0.38[de]	17.25[c]	1.28[defg]	0.965[cde]	2.16[ef]
Salamander Broiler										
GM	0.367[cd]	61.72[bcd]	0.394[cd]	1.39[bcd]	2.65[d]	0.67[bcde]	66.51[bc]	1.34[cdef]	1.170[bcde]	1.80[ef]
IF	0.411[cd]	51.20[bcde]	0.378[cd]	0.52[e]	2.15[d]	0.36[de]	67.88[bc]	1.26[defgh]	1.527[ab]	5.49[cdef]
LL	0.412[cd]	21.83[ef]	0.382[cd]	0.54[de]	2.54[d]	0.56[cde]	67.71[bc]	0.89[fgh]	0.983[cde]	2.67[ef]
PM	0.383[cd]	64.13[bcd]	0.436[cd]	0.77[de]	1.93[d]	0.74[bcd]	33.65[bc]	1.15[efgh]	1.271[bcd]	13.88[b]
SV	3.800[b]	62.58[bcd]	0.451[cd]	1.28[bcde]	2.78[cd]	0.73[bcd]	106.72[b]	1.74[bcd]	1.138[bcde]	1.87[f]
TB	5.727[a]	64.98[bc]	0.490[bcd]	1.28[bcde]	3.26[cd]	1.15[ab]	39.34[bc]	1.42[bcdef]	1.11[bcde]	5.68[cdef]
SEM[2]	1.058	14.81	0.111	0.36	1.41	0.21	30.71	0.23	0.240	3.73
P value	<0.001	0.024	0.008	0.004	0.011	0.034	0.005	0.038	0.003	0.001

[1]Muscles included Gluteus medius (GM), Infraspinatus (IF), Longissimus lumborum (LL), Psoas major (PM), Serratus ventralis (SV), and Triceps brachii (TB).

[2]Standard error (largest) of the least-squares means in the same main effect.

[a–f]Least-squares means in the same column without a common superscript differ ($P < 0.05$).

Conclusions

These data indicate that dry-heat cookery method has a very strong influence on flavor development of beef steaks across a variety of muscles. Volatile compound production was dependent on both cooking method and muscle. Interaction between cooking method and muscle for volatile compounds may be due to compositional differences among muscles that affect the Maillard reaction or extent of lipid degradation. However, as stated, consumers found no interactive effects between cooking method and muscle for flavor. Therefore, the detected differences in flavor chemistry may not outweigh consumer perception of tenderness and overall palatability. Muscles that are very tender, such as the PM or the IF, may therefore be highly palatable, regardless of cooking method.

Acknowledgments

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