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# Effects of Dry-Heat Cookery Method on Beef Strip Loin Steaks of Two Quality Grades Following Sous Vide Preparation

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**Abstract:** The objective of this study was to determine the influence of dry-heat cookery method on beef flavor development in strip loin steaks from 2 USDA quality grades following sous vide preparation. Beef strip loins were selected from 2 USDA quality grades: upper 2/3 Choice (Modest$^{00}$–Moderate$^{100}$) and Select (Slight$^{00}$–Slight$^{100}$ marbling, $n = 20$/grade). Following 21 d of wet aging, strip loins were fabricated into 2.54-cm thick-steaks and randomly assigned to one of 4 dry-heat cookery methods: charbroiler grill (CHAR), clamshell grill (CLAM), convection oven (OVEN), and salamander broiler (SALA). Prior to untrained consumer panel and volatile compound analysis via gas chromatography-mass spectrometry, steaks were cooked under sous vide conditions for 1.5 h, then finished on the assigned cookery method. There were no cooking method × quality grade interactions ($P \geq 0.076$) for all consumer traits evaluated. Overall, SALA steaks received higher ($P < 0.05$) ratings by consumers than CLAM steaks for all palatability traits. OVEN steaks had greater scores ($P < 0.05$) than CLAM steaks for juiciness, tenderness, and overall liking but were similar to CLAM steaks ($P > 0.05$) for flavor. CHAR steaks were similar ($P > 0.05$) to CLAM steaks for flavor but were rated higher ($P < 0.05$) for tenderness, juiciness, and overall liking. Steaks cooked using the OVEN method produced a greater concentration of lipid-derived volatiles, such as alcohols, aldehydes, and carboxylic acids. In direct contrast, CHAR steaks produced a higher concentration of pyrazines and Strecker aldehydes, which are derived from the Maillard reaction. These data indicate that cookery method, and therefore heat transfer method, has a substantially stronger influence on consumer ratings and flavor development than USDA quality grade in this study when steaks are prepared using sous vide methods.

**Key words:** consumers, cooking method, quality grade, sous vide, volatile compounds
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## Introduction

There are many beef cookery methods available for consumers to use. Depending on the method used, beef palatability can be impacted. Generational changes in consumer cooking styles owing to increased time commitments, and social influences, as well as other factors, mean that consumers are looking for easier alternatives to cooking—especially meat products—as many have little to no cooking experience. Sous vide, which is French for "under vacuum," has recently gained popularity in both restaurants and homes as a method that provides a more evenly cooked product. Sous vide, at its core, is low temperature with a long cook time in a vacuum-sealed environment in a circulating water bath (Baldwin, 2012; Dominguez-Hernandez et al., 2018). This method allows for a more evenly cooked product both internally and externally under precise temperature control (Baldwin, 2012). Currently different sous vide approaches are utilized by consumers and food service. However, one common approach includes sous vide preparation followed by utilizing dry-heat cookery, such as a grill or cast iron to achieve a desired amount of flavor and final degree of doneness.

 

Consumers may employ a variety of methods to cook their meat to provide their optimum combination of flavor, tenderness, and juiciness (Savell et al., 1999; Bagley et al., 2010). Generally speaking, cookery methods fall into one of 2 categories: dry or moist heat. Dry-heat cookery methods are those that use direct application of high-temperature heat, whether through application of hot air (convection), a hot pan (conduction), or radiant heat (such as a flame). Moist-heat cookery instead uses liquid as a vector for heat at a substantially lower temperature, resulting in improved tenderness through breakdown of connective tissue via gelatinization (McDowell et al., 1982). Dry-heat cookery methods, such as grilling, broiling, and pan-frying, are more popular than moist-heat cookery, such as braising or stewing (Savell et al., 1999). To date, much work regarding cookery methods have focused on tenderness and have not evaluated the difference among dry-heat cookery methods for flavor development (Berry, 1993; Savell et al., 1999; Powell et al., 2000; Lawrence et al., 2001; Obuz et al., 2003). However, flavor and aroma in meat products is produced principally through dry-heat cooking (Mottram, 1998). Flavor is elucidated from meat products via 2 major pathways: the Maillard reaction and the degradation of lipids. Each of these pathways are impacted by cooking and contribute unique flavor compounds to meat flavor. The Maillard reaction at its most basic form is a nonenzymatic browning reaction between a reducing sugar (carbonyl component) and an amino acid (amine component) at high temperatures (Mottram, 1993). The Maillard reaction can result in a large variety of different compounds, including furans, carbonyls, aldehydes, sulfur and nitrogen compounds, ketones, pyrroles, pyrazines, thiazoles, thiophenes, and furanthiols (Mottram et al., 1982; Mottram, 1993, 1998). These compounds are all influenced by temperature, heat application, and therefore cooking method.

Previous studies have also indicated that differences in intramuscular fat can impact how steaks conduct heat and therefore what volatile and flavor compounds are produced during cooking (O'Quinn et al., 2012; Legako et al., 2016; Gardner and Legako, 2018). Prior studies are conflicted on the true influence of intramuscular fat on volatile compound development. Marbling is responsible in part for the species-specific flavors within a meat product, especially within red meat species (Savell and Cross, 1987). However, despite increased marbling levels, it has not been repeatedly correlated with an increase in volatile flavor compounds (Cross et al., 1980; Mottram et al., 1982; Mottram and Edwards, 1983; Mottram, 1998; Legako et al., 2016). However, Gardner and Legako (2018) observed a more linear response to volatile compound production with steaks of increasing USDA quality grade. Therefore, the objective of this study was to determine the influence of dry-heat cookery method on beef flavor development in 2 USDA quality grades following sous vide preparation.

## Materials and Methods

### *Carcass selection and steak fabrication*

Beef strip loins (Institutional Meat Purchase Specifications #180, NAMP, 2010) were selected from one side from carcasses of 2 USDA quality grades: upper 2/3 Choice (Modest$^{00}$–Moderate$^{100}$) and Select (Slight$^{00}$–Slight$^{100}$ marbling, $n = 20$/grade). 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 vacuum packaged and transported under refrigeration (0°C–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. Strip loins were cut into 2.54 cm steaks from anterior to posterior using a slicer (Berkel X13A-Plus, Berkel, Inc, Houston, TX). Steaks were then randomly assigned within subprimals to one of 4 cooking methods, vacuum packaged, and frozen at −20°C until further analysis. Vacuum packaging occurred through use of a Multivac Baseline F100 (Kansas City, MO) using a forming film (oxygen transfer rate [OTR] of 2 cc/m$^2$/d at 23°C at 0% relative humidity; moisture vapor transmission rate [MVTR] of 7 g/m$^2$/d at 38°C at 100% relative humidity) and nonforming film (OTR of 3 cc/m$^2$/d at 23°C at 0% relative humidity; MVTR of 9 g/m$^2$/d at 38°C at 100% relative humidity).

### *Proximate analysis and pH*

The percentage of moisture, fat, protein, and collagen was determined for raw steaks using an AOAC approved method (Anderson, 2007). 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-cm$^3$ 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). The pH electrode was rinsed between samples 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. Steaks were then cooked sous vide for approximately 1.5 h to a medium-rare degree of doneness (63°C) in vacuum packaging in a circulating water bath (Immersion Circulator SmartVide 6, Sammic, Gipuzkoa, Spain) set at 63.5°C. Preliminary data validated consistency of final sous vide steak internal temperature through the described water temperature and duration. Immediately prior to serving to panels, steaks were finished to a medium degree of doneness by removing steaks from each cookery apparatus at a preassigned internal temperature to allow for steaks to rise to a peak temperature of 71°C. Internal steak temperature was monitored at the geometric center of steaks (Thermapen Mk4, Thermoworks, American For, UT). Steaks were finished 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). Finished steaks were cut into steak thickness × 1 × 1 cm cubes, and 2 cubes were served to each panelist. Samples were then immediately served to panelists.

Consumer panels were conducted using the methods previously administered at TTU (O'Quinn et al., 2012; Legako et al., 2015). Untrained consumer panelists ($N = 100$) were recruited from the Lubbock, Texas, area in groups of 20. Panelists evaluated 8 samples, one of each treatment, 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). 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. Each digital ballot consisted of a demographics sheet, a purchasing motivators sheet, and 8 sample ballots. 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 bagged and 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 1.5 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 polytetrafluoroethylene septa and metal screw cap; Gerstel Inc., Linthicum, MD). The samples were then loaded using a Gerstel automatic sampler (MultiPurpose Sampler; 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 × 0.25 mm × 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.

### *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). Strip loin served as the whole-plot factor, and cooking method served as the subplot factor such that steak was the subplot experimental unit. Peak temperature was included in the model as a covariate. For consumer liking data, panel session and round served as a random effect. Consumer acceptance data were analyzed using a binomial distribution. The Kenward-Rogers adjustment was used to estimate denominator degrees of freedom. Significant differences were determined using $\alpha \leq 0.050$.

Multivariate analysis was conducted using MetaboAnalyst 4.0 (Chong et al., 2018) and modified methods described by Antonelo et al. (2020). The volatile compound concentrations obtained from the mass spectrometer and corresponding consumer sensory analysis scores were uploaded to MetaboAnalyst, then subjected to log transformation and Pareto scaling prior to analysis. Supervised partial least squares discriminant analysis (PLS-DA) was performed. Validation of the PLS-DA was completed using a 10-fold cross validation method. $R^2$ (0.77) and $Q^2$ (0.61) were used as indicators to assess goodness of fit for the model. Within the PLS-DA, a variable importance in projection (VIP) plot was used to determine the importance of individual compounds to characterizing and discriminating among cooking methods.

## Results and Discussion

### *Proximate analysis and pH*

Results from proximate analysis are detailed in Table 1. Steaks from the upper 2/3 Choice possessed a greater ($P < 0.05$) percentage of fat and correspondingly lower ($P < 0.05$) moisture percentages compared with Select steaks. As expected, no differences were observed ($P > 0.05$) between USDA quality grades for protein, collagen, and pH.

### *Consumer panel demographic characteristics and purchasing motivators*

The demographic characteristics of the 100 consumers who participated in sensory evaluation are presented in Table 2. The majority of participants were

**Table 1.** Least-squares means for proximate analysis and pH for beef steaks ($N = 160$) from two USDA quality grades[1]

| Quality grade | Fat, % | Moisture, % | Protein, % | Collagen, % | pH |
|---|---|---|---|---|---|
| **Top Choice** | $5.9^a$ | $69.7^b$ | 22.0 | 1.7 | 5.5 |
| **Select** | $2.7^b$ | $71.5^a$ | 21.9 | 1.6 | 5.5 |
| **SEM**[2] | 0.24 | 0.85 | 0.26 | 0.05 | 0.03 |
| ***P* value** | < 0.001 | < 0.001 | 0.731 | 0.589 | 0.914 |

[1]Top Choice: USDA marbling score of $\text{Modest}^{00}$–$\text{Moderate}^{100}$; Select: USDA marbling score of $\text{Slight}^{00}$–$\text{Slight}^{100}$.

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

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

**Table 2.** Demographic characteristics of consumers ($N = 100$) who participated in consumer sensory panels

| Characteristic | Response | Percentage of consumers |
|---|---|---|
| **Gender** | Male | 54.0 |
| | Female | 46.0 |
| **Household size** | 1 person | 11.0 |
| | 2 people | 17.0 |
| | 3 people | 19.0 |
| | 4 people | 31.0 |
| | 5 people | 17.0 |
| | 6 people | 3.0 |
| | >6 people | 2.0 |
| **Marital status** | Single | 39.0 |
| | Married | 61.0 |
| **Age, y** | Under 20 | 4.0 |
| | 20–29 | 17.0 |
| | 30–39 | 37.0 |
| | 40–49 | 24.0 |
| | 50–59 | 10.0 |
| | Over 60 | 8.0 |
| **Ethnic origin** | African American | 1.0 |
| | Asian | 0.0 |
| | Caucasian/White | 54.0 |
| | Hispanic | 42.0 |
| | Native American | 1.0 |
| | Other | 1.0 |
| **Annual household income** | Under \$25,000 | 11.0 |
| | \$25,000–\$34,999 | 9.0 |
| | \$35,000–\$49,999 | 8.0 |
| | \$50,000–\$74,999 | 23.0 |
| | \$75,000–\$100,000 | 20.0 |
| | More than \$100,000 | 29.0 |
| **Education level** | Non-high school graduate | 5.0 |
| | High school graduate | 15.0 |
| | Some college/technical school | 30.0 |
| | College graduate | 37.0 |
| | Post graduate | 13.0 |

**Table 2.** (*Continued*)

| Characteristic | Response | Percentage of consumers |
|---|---|---|
| **Beef consumption per week** | None | 0.0 |
| | 1–3 times | 45.0 |
| | 4–6 times | 35.0 |
| | 7 or more | 20.0 |
| **Most important palatability trait** | Flavor | 47.0 |
| | Juiciness | 14.0 |
| | Tenderness | 39.0 |
| **Degree of doneness preference** | Very rare | 1.0 |
| | Rare | 8.0 |
| | Medium rare | 29.0 |
| | Medium | 31.0 |
| | Medium well | 23.0 |
| | Well done | 7.0 |
| | Very well done | 1.0 |

Caucasian/White (54.0%) from 4-person households (31.0%). Moreover, 54.0% of participants were male, and 46.0% of participants were female. Additionally, 39.0% of participants were single, and 61.0% were married. Most of the consumers were 30 to 39 years old (37.0%) with an annual income of \$50,000–\$74,999 (23.0%) or more than \$100,000 (29.0%) and were college graduates (37.0%). When consuming beef, most consumers considered flavor the most important palatability trait (47.0%), followed by tenderness (39.0%), and most consumers preferred steaks cooked to medium rare (29.0%) or medium (31.0%) and consumed beef 1 to 3 times per week (45.0%).

In addition to a demographics survey, participants were also asked to rate the importance of 15 different purchasing motivators for beef products (Table 3). Price, color, USDA grade, size, and eating satisfaction claims were ranked as the most important ($P < 0.05$) traits. Additionally, familiarity of cut, marbling levels, antibiotic use, nutrient content, growth promotant use, animal welfare, packaging types, and natural/organic claims were more important ($P < 0.05$) than brand, grass-fed, or grain-fed.

**Table 3.** Beef strip loin steak purchasing motivators[1] of consumers ($N = 100$) participating in consumer sensory panels

| Trait | Importance |
|---|---|
| **Price** | 71.8[a] |
| **Color** | 71.2[a] |
| **USDA grade** | 71.2[a] |
| **Size, weight, thickness** | 67.4[ab] |
| **Eating satisfaction claims** | 64.6[abc] |
| **Familiarity of cut** | 64.4[bcd] |
| **Marbling levels** | 61.7[bcd] |
| **Antibiotic use in animal** | 57.0[cde] |
| **Nutrient content** | 56.2[cdef] |
| **Growth promotant use in animals** | 55.8[def] |
| **Animal welfare** | 52.4[efg] |
| **Packaging type** | 50.2[efg] |
| **Natural or organic claims** | 47.8[fgh] |
| **Brand** | 47.4[gh] |
| **Grass-fed** | 46.5[gh] |
| **Grain-fed** | 39.5[h] |
| **SEM**[2] | 3.0 |
| ***P* value** | < 0.001 |

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

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

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

## *Consumer sensory analysis*

**Cooking method.** There were no cooking method × quality grade interactions ($P \geq 0.076$) for all consumer traits evaluated (Table 4). Overall, SALA steaks were rated higher ($P < 0.05$) by consumers than CLAM steaks for all palatability traits. OVEN steaks had greater rating scores ($P < 0.05$) than CLAM steaks for juiciness, tenderness, and overall liking but were similar to CLAM steaks ($P > 0.05$) for flavor liking. The CHAR steaks were similar ($P > 0.05$) to CLAM steaks for flavor liking but were rated greater ($P < 0.05$) for tenderness, juiciness, and overall liking. When asked whether samples were acceptable for each palatability trait, a greater percentage ($P < 0.05$) of SALA steaks were designated as acceptable for flavor, tenderness, juiciness, and overall acceptability than CLAM steaks (Table 5). SALA steaks had the greatest percentage ($P < 0.05$) of steaks rated as acceptable for juiciness in comparison to all other treatments, which were similar ($P > 0.05$). For flavor acceptability, a similar percentage of OVEN and CHAR steaks were denoted as acceptable ($P > 0.05$). However, a greater percentage of OVEN steaks were designated as acceptable in comparison to CLAM steaks ($P < 0.05$). CLAM steaks had the lowest percentage of steaks rated as acceptable ($P < 0.05$) for tenderness in comparison to all other treatments, which were similar ($P > 0.05$). Overall, SALA steaks had a higher percentage of steaks rated as acceptable for overall liking ($P < 0.05$) compared with CLAM steaks; however, CHAR and OVEN steaks were intermediate and comparable with all methods ($P > 0.05$). However, when asked to designate each sample as unsatisfactory, everyday,

**Table 4.** Least-squares means for consumer panel ratings[1] of beef strip loin steaks of two USDA quality grades ($N = 160$) cooked on four different dry cookery methods

| Treatment | Flavor liking | Tenderness | Juiciness | Overall liking |
|---|---|---|---|---|
| **Cooking method** | | | | |
| Charbroiler | 60.7$^{ab}$ | 63.0$^{a}$ | 53.8$^{a}$ | 59.5$^{a}$ |
| Clamshell | 55.9$^{b}$ | 55.1$^{b}$ | 45.7$^{b}$ | 52.5$^{b}$ |
| Oven | 62.0$^{ab}$ | 65.7$^{a}$ | 61.4$^{a}$ | 63.5$^{a}$ |
| Salamander | 63.9$^{a}$ | 65.4$^{a}$ | 57.4$^{a}$ | 63.0$^{a}$ |
| SEM[2] | 3.3 | 3.5 | 3.6 | 3.4 |
| *P* value | 0.031 | 0.008 | 0.002 | 0.006 |
| **Quality grade** | | | | |
| Top Choice[3] | 58.8 | 60.2$^{b}$ | 52.8 | 57.8 |
| Select[4] | 62.4 | 64.4$^{a}$ | 56.3 | 61.5 |
| SEM | 1.7 | 1.7 | 1.7 | 1.7 |
| *P* value | 0.054 | 0.039 | 0.100 | 0.066 |
| **Method × quality grade** | | | | |
| *P* value | 0.076 | 0.970 | 0.967 | 0.645 |

[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 (cooking method or quality grade).

[3]USDA marbling score of Modest$^{00}$–Moderate$^{100}$.

[4]USDA marbling score of Slight$^{00}$–Slight$^{100}$.

[a,b]Least-squares means in the same main effect (cooking method or quality grade) without a common superscript differ ($P < 0.05$).

**Table 5.** Percentage of beef strip loin steaks of two quality grades cooked on four dry cookery methods rated as acceptable for flavor, tenderness, juiciness, and overall liking ($N = 160$)

| Treatment | Flavor acceptability | Tenderness acceptability | Juiciness acceptability | Overall acceptability |
|---|---|---|---|---|
| **Cooking method** | | | | |
| Charbroiler | 84.2$^{ab}$ | 87.6$^{a}$ | 72.1$^{b}$ | 83.7$^{ab}$ |
| Clamshell | 79.0$^{b}$ | 76.6$^{b}$ | 67.1$^{b}$ | 76.2$^{b}$ |
| Oven | 87.3$^{a}$ | 86.6$^{a}$ | 74.1$^{b}$ | 81.7$^{ab}$ |
| Salamander | 88.3$^{a}$ | 91.4$^{a}$ | 82.9$^{a}$ | 88.3$^{a}$ |
| SEM[1] | 0.3 | 0.3 | 0.2 | 0.3 |
| *P* value | 0.050 | < 0.001 | 0.006 | 0.020 |
| **Quality grade** | | | | |
| Top Choice[2] | 84.4 | 84.7 | 73.1 | 81.7 |
| Select[3] | 85.6 | 87.8 | 75.9 | 84.1 |
| SEM | 0.3 | 0.2 | 0.1 | 0.2 |
| *P* value | 0.666 | 0.213 | 0.384 | 0.381 |
| **Method × quality grade** | | | | |
| *P* value | 0.056 | 0.963 | 0.692 | 0.855 |

[1]Standard error (largest) of the least-squares means in the same main effect (cooking method or quality grade).

[2]USDA marbling score of Modest$^{00}$–Moderate$^{100}$.

[3]USDA marbling score of Slight$^{00}$–Slight$^{100}$.

[a,b]Least-squares means in the same main effect (cooking method or quality grade) without a common superscript differ ($P < 0.05$).

better than everyday, or premium quality, no differences were observed among cooking methods ($P > 0.05$) for the percentages of steaks rated as everyday, better than everyday, or premium quality (Table 6). In contrast, a higher percentage of CLAM steaks were rated as unsatisfactory quality ($P < 0.05$) in comparison to CHAR and SALA steaks, but CLAM steaks were similar to OVEN steaks ($P > 0.05$).

None of the prior literature has discussed the impact of sous vide cooking followed by finishing the cooking process on a dry-heat cookery method. Primarily, the majority of the discussion about cooking method—without sous vide—has revolved around its impact on tenderness, specifically Warner-Bratzler shear force (Wheeler et al., 1998; Powell et al., 2000; Lawrence et al., 2001; Herring and Rogers, 2003; Obuz et al., 2003, 2004; McKenna et al., 2004; Bowers et al., 2012). Additionally, the previous literature has focused on the tenderness of *longissimus lumborum* steaks in comparison to other lower quality muscles, such as the *semimembranosus*, as attempts to reduce the impact of greater concentrations of connective tissue and large fiber size to improve tenderness ratings by consumers. However, when directly comparing cooking methods, clamshell grills have been found to be more consistent, rapid, and repeatable for research applications in comparison to electric broilers (McKenna et al., 2004). The results from the current study, however, indicate that clamshell grills may be detrimental to flavor research and may actually reduce consumer ratings of grilled beef strip loin steaks, especially for the palatability traits of tenderness, juiciness, and overall liking, as it was ranked the lowest for each of those traits.

**Quality grade.** Quality grade did not influence ($P \geq 0.07$) flavor, juiciness, overall liking, or acceptability, as consumers rated both Top Choice and Select steaks similar for flavor, juiciness, and overall liking (Table 6). However, consumers rated Select steaks higher for tenderness over Top Choice steaks ($P = 0.04$). There was no difference ($P = 0.210$) in acceptability of any trait (Table 7). When consumers were asked to rate each sample as unsatisfactory, everyday quality, better than everyday quality, or premium quality, quality grade did not impact ($P \geq 0.080$) the percentage of steaks rated as unsatisfactory, everyday

**Table 6.** Percentage of beef strip loin steaks ($N = 160$) of two quality grades cooked on four dry cookery methods rated identified as different perceived quality levels by consumer panelists ($N = 100$)

| Treatment | Unsatisfactory quality | Everyday quality | Better than everyday quality | Premium quality |
|---|---|---|---|---|
| **Cooking method** | | | | |
| Charbroiler | 15.5$^{b}$ | 52.5 | 25.0 | 6.4 |
| Clamshell | 26.5$^{a}$ | 46.0 | 22.4 | 3.7 |
| Oven | 18.3$^{ab}$ | 51.0 | 21.4 | 7.7 |
| Salamander | 12.4$^{b}$ | 53.0 | 23.0 | 9.2 |
| SEM[1] | 0.3 | 0.1 | 0.2 | 0.4 |
| *P* value | 0.004 | 0.485 | 0.855 | 0.244 |
| **Quality grade** | | | | |
| Top Choice[2] | 18.4 | 53.8 | 24.1 | 4.5$^{b}$ |
| Select[3] | 16.9 | 47.5 | 21.8 | 9.1$^{a}$ |
| SEM | 0.2 | 0.1 | 0.1 | 0.3 |
| *P* value | 0.594 | 0.078 | 0.441 | 0.016 |
| **Method × quality grade** | | | | |
| *P* value | 0.216 | 0.141 | 0.232 | 0.360 |

[1]Standard error (largest) of the least-squares means in the same main effect (cooking method or quality grade).

[2]USDA marbling score of Modest$^{00}$–Moderate$^{100}$.

[3]USDA marbling score of Slight$^{00}$–Slight$^{100}$.

$^{a,b}$Least-squares means in the same main effect (cooking method or quality grade) without a common superscript differ ($P < 0.05$).

**Table 7.** Interaction of dry-heat cookery method[1] and USDA quality grade[2] on production of volatile compounds produced by beef strip loin steaks

| | Hexanoic acid, methyl ester | 1-octen-3-ol | 2-pentylfuran | Pentanal |
|---|---|---|---|---|
| **Top Choice** | | | | |
| Charbroiler | 0.31$^{b}$ | 5.79$^{b}$ | 1.52$^{b}$ | 1.95$^{bc}$ |
| Clamshell | 0.42$^{b}$ | 4.85$^{b}$ | 1.07$^{b}$ | 2.71$^{bc}$ |
| Oven | 0.49$^{b}$ | 5.30$^{b}$ | 1.40$^{b}$ | 2.19$^{bc}$ |
| Salamander | 0.38$^{b}$ | 5.82$^{b}$ | 1.49$^{b}$ | 3.63$^{abc}$ |
| **Select** | | | | |
| Charbroiler | 0.49$^{b}$ | 3.56$^{b}$ | 1.15$^{b}$ | 1.31$^{c}$ |
| Clamshell | 0.34$^{b}$ | 6.20$^{b}$ | 2.50$^{b}$ | 4.00$^{b}$ |
| Oven | 0.93$^{a}$ | 13.50$^{a}$ | 5.63$^{a}$ | 6.17$^{a}$ |
| Salamander | 0.33$^{b}$ | 4.54$^{b}$ | 1.33$^{b}$ | 2.09$^{bc}$ |
| SEM[3] | 0.11 | 2.21 | 0.83 | 0.99 |
| *P* value | 0.007 | 0.044 | 0.016 | 0.021 |

[1]Cooking methods included charbroiler grill, clamshell grill, convection oven, and salamander broiler.

[2]Top Choice: USDA marbling score of Modest$^{00}$–Moderate$^{100}$, Select: USDA marbling score of Slight$^{00}$–Slight$^{100}$.

[3]Standard error (largest) of the least-squares means in the same main effect (cooking method or quality grade).

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

quality, or better than everyday quality (Table 8). However, a greater percentage of Select steaks were rated as premium quality ($P < 0.05$) than Top Choice steaks. Increased levels of marbling and therefore higher quality grades have typically been associated with higher consumer ratings of tenderness, juiciness, and flavor (O’Quinn et al., 2012; Corbin et al., 2014; Lucherk et al., 2016). These studies had a much wider range of quality grades (Prime to Standard) rather than the smaller window in the present study (upper 2/3 Choice and Select). However, because of variation within quality grades and the reduced marbling score range, consumers may have rated the 2 grades similarly. Other studies have reported similar results from similar quality grades (Savell et al., 1987; Legako et al., 2016; Wilfong et al., 2016; Vierck et al., 2018). Additionally, sous vide preparation has been implicated in reducing tenderness variation within steaks (Baldwin, 2012). Sous vide allows for the degradation of proteins, including myofibrillar, sarcoplasmic, and connective tissue proteins (Baldwin, 2012; Dominguez-Hernandez et al., 2018). Connective tissue proteins specifically are impacted by the low-temperature, long–cook-time method of sous vide cooking (Baldwin, 2012). By exposing these proteins to gelatinization through sous vide cooking, this may have contributed to the reduced tenderness variation observed between quality grades (Baldwin, 2012; Dominguez-Hernandez et al., 2018).

### *Volatile compound analysis*

Fifty-three volatile flavor compounds were evaluated from various flavor development pathways, including the Maillard reaction and lipid degradation. Primarily, these compounds were impacted by the main effect of cooking method ($n = 28$) and the interaction between cooking method and USDA quality grade ($n = 4$). No compound evaluated was solely impacted ($P \geq 0.06$) by USDA quality grade.

Four compounds—hexanoic acid, methyl ester, 1-octen-3-ol, pentanal, and 2-pentylfuran—were all impacted ($P \leq 0.044$; Table 7) by the interaction of cooking method and USDA quality grade. These lipid-derived products were present ($P < 0.05$) in the greatest concentration in Select OVEN steaks compared with all other treatments. These compounds are typically associated with lipid degradation through thermal oxidation during cooking or lipid oxidation

**Table 8.** Least-squares means of volatile compounds produced from beef strip loin steaks prepared using four dry-heat cookery methods

| | Cooking method[1] | | | | | |
|---|---|---|---|---|---|---|
| **Compound, ng/g sample** | **CHAR** | **CLAM** | **OVEN** | **SALA** | **SEM[2]** | ***P* value** |
| ***Maillard reaction products*** | | | | | | |
| *Pyrazines* | | | | | | |
| Methylpyrazine | 1.90$^{a}$ | 0.40$^{b}$ | 0.15$^{b}$ | 0.19$^{b}$ | 0.60 | < 0.001 |
| 2,5-dimethylpyrazine | 3.48$^{a}$ | 0.81$^{b}$ | 0.21$^{c}$ | 0.33$^{bc}$ | 0.19 | < 0.001 |
| 2-ethyl-3,5-dimethylpyrazine | 2.79$^{a}$ | 0.74$^{b}$ | 0.27$^{b}$ | 0.28$^{b}$ | 0.22 | < 0.001 |
| 3-ethyl-2,5-dimethylpyrazine | 3.02$^{a}$ | 0.80$^{b}$ | 0.28$^{b}$ | 0.29$^{b}$ | 0.24 | < 0.001 |
| Trimethylpyrazine | 3.48$^{a}$ | 0.58$^{b}$ | 0.20$^{b}$ | 0.21$^{b}$ | 0.27 | < 0.001 |
| *Strecker aldehydes* | | | | | | |
| 3-methylbutanal | 0.83$^{b}$ | 1.52$^{a}$ | 0.65$^{b}$ | 1.13$^{ab}$ | 0.18 | 0.007 |
| Isobutyraldehyde | 5.22$^{b}$ | 9.31$^{a}$ | 4.50$^{b}$ | 6.01$^{b}$ | 0.81 | < 0.001 |
| Methional | 4.33$^{a}$ | 2.67$^{b}$ | 2.70$^{b}$ | 2.28$^{b}$ | 0.33 | < 0.001 |
| Phenylacetaldehyde | 1.26$^{a}$ | 0.97$^{b}$ | 0.95$^{b}$ | 0.76$^{b}$ | 0.10 | 0.006 |
| *Maillard ketones* | | | | | | |
| 2,3-butanedione | 20.01$^{b}$ | 56.75$^{a}$ | 29.48$^{b}$ | 36.27$^{b}$ | 6.69 | 0.001 |
| 3-hydroxy-2-butanone | 38.17$^{c}$ | 93.94$^{a}$ | 69.29$^{b}$ | 73.96$^{ab}$ | 8.44 | < 0.001 |
| ***Lipid degradation products*** | | | | | | |
| *Aldehydes* | | | | | | |
| Butanal | 0.25$^{bc}$ | 0.49$^{a}$ | 0.22$^{c}$ | 0.38$^{ab}$ | 0.06 | 0.003 |
| Decanal | 4.37$^{a}$ | 1.94$^{b}$ | 3.97$^{a}$ | 1.38$^{b}$ | 0.34 | < 0.001 |
| Dodecanal | 6.07$^{a}$ | 3.30$^{b}$ | 4.71$^{a}$ | 2.82$^{b}$ | 0.51 | < 0.001 |
| Hexanal | 31.08$^{b}$ | 62.44$^{a}$ | 79.23$^{a}$ | 49.41$^{ab}$ | 11.16 | 0.020 |
| Nonanal | 9.14$^{ab}$ | 6.95$^{bc}$ | 11.50$^{a}$ | 5.42$^{c}$ | 1.33 | 0.008 |
| Octanal | 3.00$^{ab}$ | 2.52$^{b}$ | 1.29$^{a}$ | 1.97$^{b}$ | 0.48 | 0.005 |
| *Alcohols* | | | | | | |
| 1-hexanol | 0.49$^{b}$ | 0.74$^{b}$ | 1.45$^{a}$ | 0.58$^{b}$ | 0.26 | 0.015 |
| 1-octanol | 6.90$^{b}$ | 4.58$^{bc}$ | 9.92$^{a}$ | 3.40$^{c}$ | 1.06 | < 0.001 |
| 1-pentanol | 3.27$^{b}$ | 8.96$^{a}$ | 9.44$^{a}$ | 7.02$^{ab}$ | 1.89 | 0.036 |
| *Carboxylic acids* | | | | | | |
| Benzoic acid | 7.28$^{a}$ | 3.84$^{b}$ | 2.23$^{b}$ | 2.76$^{b}$ | 1.25 | 0.022 |
| Heptanoic acid | 2.50$^{ab}$ | 1.82$^{bc}$ | 2.97$^{a}$ | 1.37$^{c}$ | 0.28 | < 0.001 |
| Octanoic acid | 57.64$^{a}$ | 28.59$^{b}$ | 60.59$^{a}$ | 25.72$^{b}$ | 4.55 | < 0.001 |
| *Hydrocarbons* | | | | | | |
| 2-heptanone | 1.27$^{b}$ | 1.26$^{b}$ | 1.91$^{a}$ | 1.12$^{b}$ | 0.20 | 0.022 |
| D-limonene | 0.030$^{b}$ | 0.072$^{a}$ | 0.066$^{a}$ | 0.060$^{a}$ | 0.001 | 0.001 |
| Decane | 2.10$^{a}$ | 1.32$^{b}$ | 1.50$^{b}$ | 1.18$^{b}$ | 0.13 | < 0.001 |
| Toluene | 13.33$^{a}$ | 9.43$^{b}$ | 8.38$^{b}$ | 7.67$^{b}$ | 1.25 | 0.006 |
| p-Xylene | 70.87$^{a}$ | 26.43$^{b}$ | 24.73$^{b}$ | 23.29$^{b}$ | 5.51 | < 0.001 |
| ***Total volatile production*** | 1,611.29$^{a}$ | 965.59$^{bc}$ | 1,308.73$^{ab}$ | 791.15$^{c}$ | 131.61 | < 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 row.

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

during storage (Min and Ahn, 2005). Additionally, in studies evaluating wide ranges of USDA quality grades, steaks with lower quality grades—such as Select or Standard—produce a greater amount of similar volatile alcohols, aldehydes, and ketones derived from lipid sources compared with Prime and Choice (Legako et al., 2016). It has been speculated that this is due to greater proportions of unsaturated fatty acids present in Select steaks in comparison to steaks with greater marbling scores having a more saturated fatty acid composition (De Smet et al., 2004; Legako et al., 2015). Combined with the increased lipid degradation products produced by the OVEN method (main effects described later), it is logical that this combination of Select OVEN steaks produced the greatest concentration of the lipid oxidation products.

A similar trend existed for lipid degradation products affected by the cooking method main effect. OVEN steaks produced ($P < 0.05$) the greatest concentration of lipid-derived alcohols (1-hexanol, 1-octanol, and 1-pentanol) compared with all other treatments. Similarly, OVEN steaks also produced ($P < 0.05$) the greatest concentration of 2-heptanone and d-limonene compared with all other treatments. However, when examining the group of lipid-derived aldehydes, CHAR and OVEN steaks produced ($P < 0.05$) the highest concentration of decanal, dodecanal, nonanal, and octanal. This may be due to the re-volatilization of lipids as they strike the heat source (the radiant flame of the charbroiler grill or the hot air of the convection oven) and are aerosolized back on to the exposed surface of the steak. Previous work has indicated that lipids can be lost in meat products through evaporative and drip losses during the cooking process (Sigler et al., 1978). Lipids lost through the evaporative portion of cook loss have the opportunity to be re-circulated on to the steak, especially in a closed environment, such as a convection oven. The evaporative, volatile nature of flavor compounds are used to an advantage during the smoking process, in which volatile compounds—such as aldehydes, alcohols, carbonyls, and esters—are circulated through the smoke and absorbed by the meat product (Maga, 1987). This process could be emulated with the lipids reacting with the flames and being reabsorbed by the steak during the cooking process.

Contrastingly, CLAM steaks produced ($P < 0.05$) the greatest concentration of butanal and hexanal. The direct application of heat likely rapidly decomposed the lipid fraction of the steak, resulting in rapid breakdown into these lipid oxidation products. These 2 aldehydes are noted for their contribution to oxidized and off-flavors, which likely reduced the consumer scores for flavor liking in CLAM steaks. Similar to the aldehydes, the carboxylic acids were present in the highest amounts in both CHAR and OVEN steaks, with the notable exception of benzoic acid. Benzoic acid was produced ($P < 0.05$) in the greatest concentration in CHAR steaks compared with all other treatments. Carboxylic acids, such as butanoic and hexanoic acid, contribute to sour, sweaty, and rancid off-flavors observed in meat products (Spanier et al., 2004; Stetzer et al., 2008; Kerth and Miller, 2015). Additionally, carboxylic acids are formed during oxidation of aldehydes or alcohols, which are considered secondary products of lipid oxidation (Min and Ahn, 2005; Bekhit et al., 2013). This indicates that CHAR steaks are producing end-products of lipid oxidation, possibly produced through a longer thermal oxidation of lipids. In comparison, CLAM steaks produced a greater concentration of hexanal, which is a secondary product of lipid oxidation. This indicates that CLAM steaks have less of an opportunity to be oxidized further into carboxylic acids, whereas CHAR steaks continued to be oxidized during that cooking process. A similar trend existed for decane, toluene, and p-xylene, lipid-derived hydrocarbons. CHAR steaks produced ($P < 0.05$) the greatest concentration of these lipid compounds compared with all other treatments.

When evaluating volatile compounds produced as a result of the Maillard reaction, CHAR steaks dominated the landscape. CHAR steaks produced ($P < 0.05$) the highest concentration of all pyrazines compared with all other treatments. Additionally, CHAR steaks produced the greatest concentration of methional and phenylacetaldehyde, 2 Strecker aldehydes. However, 4 notable exceptions to this trend occurred in Maillard ketones and 2 Strecker aldehydes. Steaks cooked using CLAM produced ($P < 0.05$) the greatest concentration of 3-methylbutanal, isobutyraldehyde, 2,3-butanedione, and 3-hydroxy-2-butanone compared with all other treatments. This is likely due to the direct conduction of the heat source off the clamshell grill. The extremely rapid, continual application of heat from both sides of the steak would result in a more rapid cooking process and reduce the completion of the Maillard reaction, thus producing a greater concentration of intermediary products (such as Strecker aldehydes) and Maillard ketones (such as 3-hydroxy-2-butanone) (grill finish times: CHAR 227.3 s ± 103.6; CLAM: 126.7 s ± 58.3; OVEN: 397.2 s ± 75.4; and SALA: 180.0 s ± 45.2). These compounds can undergo further reactions, such as heterocyclization, resulting in the pyrazines observed in the CHAR steaks. It is likely that, because the CHAR method is not as rapid as the CLAM method, steaks had more time to produce a greater concentration of final products, such as pyrazines. It appears that the CLAM method halts the Maillard reaction before heterocyclization can occur, but CHAR allows the Maillard reaction to further proceed. Previous work indicates that searing increases the production of Maillard reaction products when compared with steaks cooked entirely in an oven situation (Yoo et al., 2020). Yoo et al. (2020) observed that, when steaks were cooked using a searing method, the concentration of reducing sugars was depleted and triggered an increase in Maillard reaction products. A similar trend was observed in the current study with CHAR and CLAM steaks, in which CHAR and CLAM cooking methods produced divergent concentrations of specific Maillard reaction compounds, including pyrazines (CHAR) and Maillard intermediate ketones (CLAM). Overall, CHAR and OVEN steaks produced ($P < 0.05$) the greatest total concentration of volatile compounds compared with SALA steaks when all compounds were considered. This result is likely due to an accumulation of Maillard end-products following CHAR cooking and lipid oxidation products with OVEN cookery, as described earlier.

It is interesting to note that only one sulfur-containing compound, methional, was impacted by cooking method. This depression in sulfur-containing volatile flavor compound production is likely due to the sous vide cooking process prior to cooking. Moist-heat cookery, such as a sous vide or boiling environment, has been linked to a significant detriment in volatile compounds characteristic of meat cooked in a high-temperature environment (Utama et al., 2018). Steaks were only finished from a medium-rare degree of doneness (63°C) to medium (71°C) following sous vide preparation, which may have severely restricted the flavor development possible and reduced the appearance of sulfur-containing compounds in the final product. Despite the possible influence from sous vide preparation, it is clear that cooking method has a much stronger influence on consumer ratings and volatile flavor production in comparison to USDA quality grade when prepared using sous vide.

## *Multivariate analysis*

When combined with the sensory data into the PLS-DA, the model was able to discriminate among cooking methods with a reasonable degree of accuracy ($R^2 = 0.77$; Figure 1). As described with the univariate

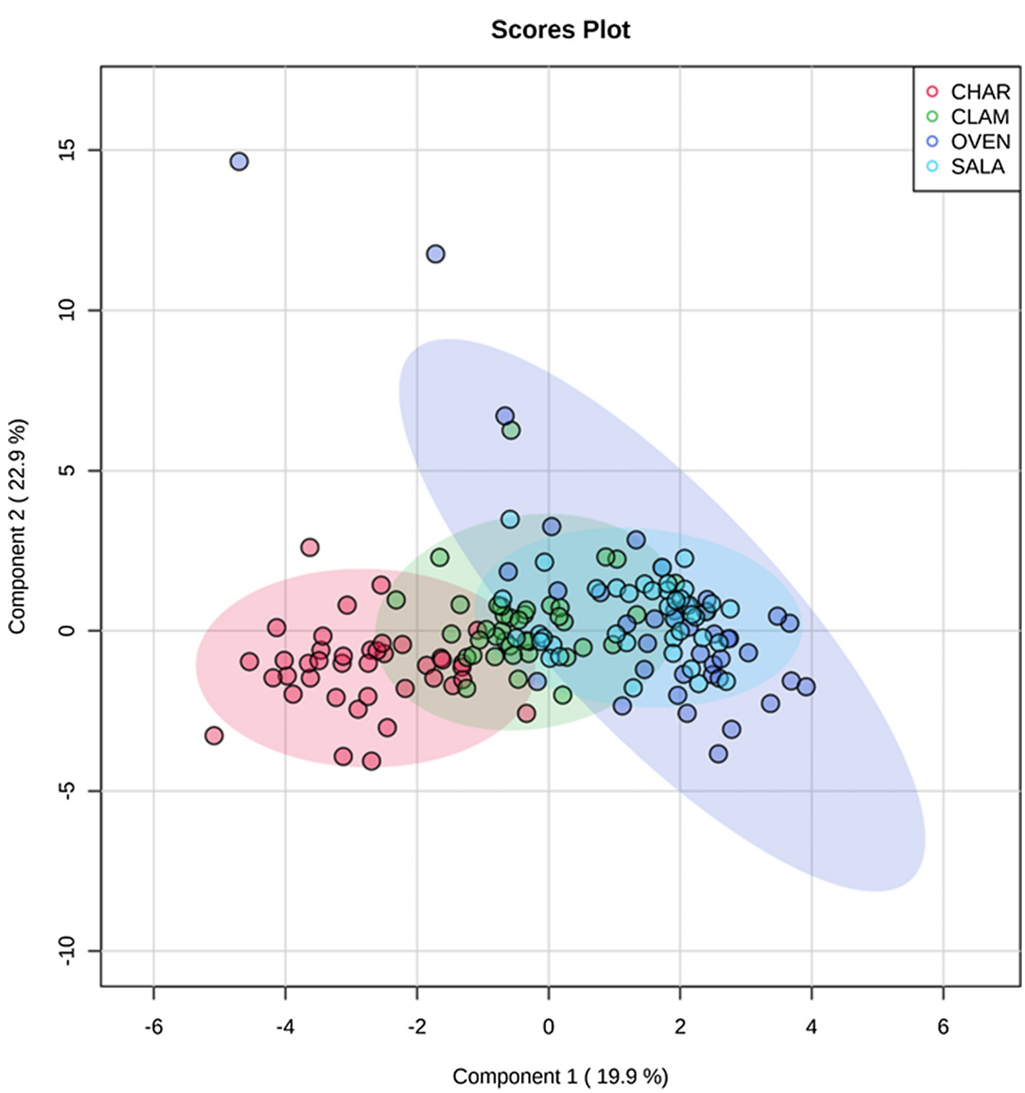


**Figure 1.** Partial least squares regression discriminant analysis (PLS-DA) of beef strip loin steaks prepared using 4 dry-heat cookery methods[1].
**[1]Cooking methods included charbroiler grill (CHAR), clamshell grill (CLAM), convection oven (OVEN), and salamander broiler (SALA).**

analysis, the greatest variation existed between the CHAR and OVEN steaks. Once the VIP plot (Figure 2) was completed within the PLS-DA, it revealed that the top 15 compounds that contributed to differences observed among cooking methods were methylpyrazine, 2,5-dimethylpyrazine, 3-ethyl-2,5-dimethylpyrazine, 2-ethyl-3,5/6-dimethylpyrazine, 2-ethyl-3,5-dimethylpyrazine, trimethylpyrazine, D-limonene, 1-octen-3-ol, 3-hydroxy-2-butanone, pentanal, 1-hexanol, p-xylene, 1-pentanol, dimethyl-disulfide, and hexanal. The pyrazines were the most influential in determining CHAR steaks, whereas lipid-derived compounds (such as D-limonene) and alcohols (such as 1-hexanol and 1-pentanol) were more influential in determining the OVEN steaks. As previously discussed, pyrazines are produced as an end-product of the Maillard reaction following heterocyclization (Mottram, 1993). The results from the multivariate analysis further echo the univariate analysis in this regard, as the compounds that were present in the greatest amount in the CHAR steaks were also the driving force behind the ability of the model to sort steaks into their respective treatment groups, according to the VIP plot. Additionally, to determine OVEN steaks from other cooking treatments, lipid-derived compounds, including pentanal, 1-hexanol, 1-pentanol, and hexanal, were stronger drivers in comparison to Maillard-derived compounds, such as methylpyrazine or trimethylpyrazine. This was likely due to a greater influence of lipid oxidation during the cooking process. The process of re-volatilizing lipids to be placed on the steak during the cooking process may have created more lipid compounds on OVEN samples.

These results reenforce the relationships observed between the volatile compounds produced by the individual cooking methods. However, the large variation in compounds produced—such as the high concentration of Maillard products produced by the CHAR steaks in comparison to the high–lipid-oxidation products in the

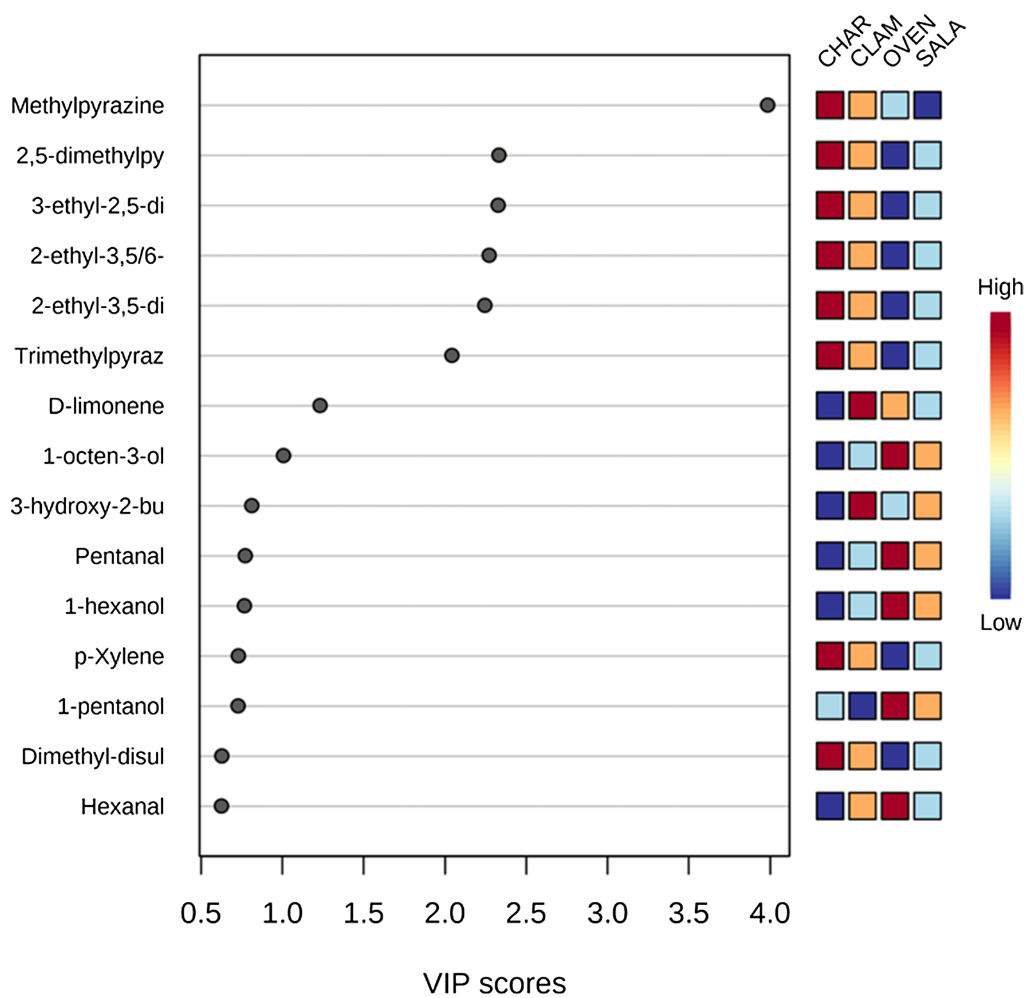


**Figure 2.** Variable importance in projection (VIP) plot of volatile flavor compounds of beef strip loin steaks prepared using 4 dry-heat cookery methods[1].

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

OVEN steaks—may have divided consumers in terms of flavor liking and overall liking. However, it is clear that steaks cooked using radiant flame (SALA or CHAR) or convection (OVEN) were much more successful with consumer ratings in comparison to steaks using conduction (CLAM). Additionally, when sous vide is added into the preparation of steaks, it appears that the impact of overall flavor development is reduced, which makes the type of compounds produced even more important. Steaks cooked using the CLAM method produced higher concentrations of certain Strecker aldehydes, lipid oxidation aldehydes, and lipid-derived alcohols. The particular combination of these compounds may be those that are detracting to consumers' flavor liking scores.

# Conclusions

These results indicate that, when steaks are prepared using sous vide cooking followed by dry-heat cookery, cooking method and heat transfer have a stronger influence on consumer palatability ratings and flavor development compared with USDA quality grade. Further work is needed to evaluate the impact of sous vide cookery prior to grilling on steaks differing in USDA quality grade to determine whether tenderness differences are truly minimized between grades following sous vide preparation. Furthermore, these data clearly reveal that dry-heat cookery heavily influences final beef volatile flavor compound profile. As a result, opportunity exists for consumers and food service groups to select cookery methods that direct ultimate beef flavor chemistry.

### *Acknowledgments*

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