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Flavor Relationships among Muscles form the Beef Chuck and Round

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Flavor relationships among muscles from the beef chuck and round[1]

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ABSTRACT: This research compared off-flavor notes and the relationship of pH and heme-iron content to off-flavor for different beef muscles. After grading, knuckles and shoulder clods were removed from 16 USDA Choice and 14 USDA Select beef carcasses, vacuum-packaged, and aged for 7 d. The rectus femoris (REC), vastus medalis (VAM), vastus lateralis (VAL), teres major (TER), infraspinatus (INF), and triceps brachii-long head (TRI) were separated, cut into steaks, and frozen (–16°C). Sensory analysis was conducted using a trained taste panel, with steaks grilled to an internal temperature of 65°C. Heme-iron concentration and pH were determined. The INF had lower ($P < 0.05$) off-flavor intensity ratings and less frequent sour flavor than the other muscles, and the VAL had the most intense ($P < 0.05$) off-flavor ratings and among the greatest frequency of sour, charred, and oxidized flavors. The frequencies of liver-like, bloody, and rancid flavors were not affected by muscle type. Heme-iron concentration did not differ among muscles. Three USDA Select carcasses had intense off-flavor in the muscles. Liver-like flavor was highly negatively correlated with off-flavor intensity for each of the muscles tested. Muscles rated a 5 or below (on an 8-point rating scale, where 1 = extremely intense off-flavor and 8 = no off-flavor) in off-flavor intensity and identified as liver-like by 30% or more of the panelists were grouped together and compared to normal muscles. Those in the liver-flavored group were less frequently identified as charred, probably because the liver-like flavor was so intense. There were no differences between the 2 groups for sour, metallic, bloody, oxidized, or fatty off-flavor notes. Regression equations containing the linear and quadratic functions of heme-iron concentration, muscle pH, and their interaction were established for the frequency of off-flavor notes within each muscle. The REC, TER, VAL, and VAM showed a relationship between pH, heme iron, and off-flavor intensity ($P < 0.05$). Liver-like flavor was explained partially by pH and heme iron in the REC, VAM, and VAL ($R^2 = 0.45$ to 0.55; $P < 0.05$). Few other significant relationships were found. Heme iron and pH were unrelated to metallic, oxidized, or rancid flavors for any of the muscles tested. These data suggest that liver-like off-flavors are specific to individual animals, and that pH and heme iron are not strongly related to off-flavor notes.

Key words: beef, flavor, pH, heme-iron concentration

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INTRODUCTION

Between 1993 and 1998 the wholesale value of the beef rib and loin increased about 4–5%, whereas the value of the beef chuck and round decreased approximately 25% (Cattle Fax, 1998). This loss of value of the beef chuck and round led to development of the muscle profiling project, which characterized the physical, chemical, sensory, and processing characteristics of 39 muscles from the chuck and round (Von Seggern et al., 2005). Using data from the muscle profiling project, the National Cattlemen's Beef Association developed a list of underutilized value cuts which includes the infraspinatus (**INF**), teres major (**TER**), triceps brachii, and rectus femoris (**REC**).

There have been anecdotal reports of off-flavors, especially a liver-like flavor, in some of the value cuts; the incidence and intensity of liver-like flavor in various muscles is unknown. It is important that consumers have a good eating experience with a cut of meat that they have not previously tried in the past. Flavor is highly correlated with overall like in beef (Neely et al., 1998; Goodson et al., 2002). Goodson et al. (2002) concluded that flavor was the most important factor in consumer acceptability of clod steaks.

The objective of this study was to determine the relationship of off-flavors among different value muscles in the beef chuck and round. The relationships between

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off-flavors, pH, and heme-iron content were also explored.

MATERIALS AND METHODS

No approval was obtained from the Institutional Animal Care and Use Committee because samples were obtained from a federally inspected slaughter facility.

Experimental Design

Shoulder clods (IMPS #167; NAMP, 1997) and knuckles (IMPS #114; NAMP, 1997) from 30 A-maturity beef carcasses were collected from Cargill Meat Solutions in Schuyler, NE. Of these, 14 were USDA Select and 16 were USDA Choice. Hot carcass weights ranged from 328.9 and 440.0 kg of carcass weight. The REC, vastus lateralis (**VAL**), vastus medialis (**VAM**), INF, TER, and triceps brachii long-head (**TRI**) were fabricated from each carcass. Two of the VAM muscles were lost, and the total number of muscles used in the study was 178.

Sample Collection

Marbling, HCW, fat thickness, rib eye area, and KPH were recorded, and yield grade was calculated. Carcasses were tagged on the knuckles and shoulder clods so the identity could be retained for each animal. The knuckles and shoulder clods were collected by personnel from the University of Nebraska-Lincoln after fabrication and were labeled, vacuum-packed, boxed, and transported to the University of Nebraska Loeffel Meat Laboratory to be stored in a 1°C dark cooler.

Seven days after slaughter, individual muscles were fabricated from the shoulder clods and knuckles, which were labeled so that the carcass identification could be retained. Three muscles (REC, VAL, and VAM) were fabricated from the knuckle, and 3 muscles (INF, TER, and TRI) were fabricated from the shoulder clod. The INF was filleted, and the connective tissue running laterally through the center of the muscle was removed. Each half of the INF was cut into 3 steaks. A small sample was cut from the proximal end of each muscle, minced, and stored at –80°C until used for chemical analysis. The VAM and TER were left as whole muscles because of their small size. The remaining muscles (excluding the INF, VAM, and TER) were cut into 2.54-cm-thick steaks, wrapped in freezer paper, and frozen at –20°C.

Sample Preparation for Chemical Analysis

Muscle samples were cubed, frozen in liquid nitrogen, and pulverized with a Waring blender (Waring Products Division, New Hartford, CT). Pulverized samples were stored at –80°C and used for analysis of moisture content, pH, and heme-iron concentration.

Muscle Characteristics

Pulverized sample was used to measure moisture content using a LECO Thermogravimetric Analyzer-601 (Model 604-100-400, LECO Corp., St. Joseph, MI) with a TGA-601 Windows (version 1.2, LECO Corp.) option. The pH of the samples was determined using a bulb-tip, combination electrode (Orion model 9256 BN, Orion Research Inc., Boston, MA) with an Orion SA 720 pH meter (Orion Research). Ten grams of pulverized sample were homogenized in 90 mL of double-distilled water, and the pH was measured.

Total heme-iron concentration was determined using the method of Hornsey (1956), as modified by Lee et al. (1998). Two grams (±0.01 g) of pulverized sample were weighed into tubes, and the concentration was determined in triplicate. Samples were homogenized using a Polytron (Brinkman Instruments, New York, NY) with 8.1 mL of acetone and 0.2 mL of hydrochloric acid. This mixture was filtered through #2 Whatman filter paper (90 mm in diameter). After 8 samples were filtered, the tubes were stored for approximately 15 min in a dark cabinet to limit light exposure. The filtrate was then read using a Cary 100 Varian UV/Visual Spectrophotometer (Varian Instruments, Sugarland, TX) at an absorbance of 640 nm. The absorbance value was then multiplied by 680 to give the amount of total pigment. Total pigment can be used to calculate heme-iron [total pigment (ppm) × 8.82/100].

Cooking Methods and Steak Preparation for the Taste Panel

Frozen steaks were tempered for 1 d in a 1°C cooler before cooking. The steaks were weighed and trimmed of external fat before cooking. Each steak was cooked to an internal temperature of 65°C on a Vulcan commercial gas grill (model VCCV 36-1, Vulcan Hart Corp., Louisville, KY) set at an approximate temperature of 243°C. Thermocouples were inserted in the approximate center of each steak, and steak temperatures were monitored and recorded by a computer. An Omega handheld digital thermometer model 450-ATT (Omega Engineering Inc., Stamford, CT) was used to confirm the internal temperature. Steaks were turned for the first time after 2 min and then turned as needed to minimize charring.

When the steak reached the desired internal temperature, the steak was removed from the grill and weighed. The steak was then covered in foil for no more than 10 min. The steaks were cut into 1.27 × 1.27 × 2.54-cm steak cubes using a plastic template and placed in double broilers until served (<15 min).

Taste Panel

Taste panelists were recruited through a classified advertisement in a local newspaper. Of the people who responded to the newspaper advertisement, 7 panelists were trained to evaluate beef muscle. Four additional taste panelists were recruited from staff and graduate students at the University of Nebraska–Lincoln. Training was accomplished using the guidelines and proce-

Table 1. Eight-point hedonic scales used for sensory evaluation

Scale	Tenderness	Connective tissue	Juiciness	Off-flavor intensity
8	Extremely tender	No connective tissue	Extremely juicy	No off-flavor
7	Very tender	Trace amount	Very juicy	Trace off-flavor
6	Moderately tender	Slight amount	Moderately juicy	Slight off-flavor
5	Slightly tender	Small amount	Slightly juicy	Small off-flavor
4	Slightly tough	Modest amount	Slightly dry	Modest off-flavor
3	Moderately tough	Moderate amount	Moderately dry	Moderately off-flavor
2	Very tough	Slightly abundant	Very dry	Very off-flavor
1	Extremely tough	Abundant amount	Extremely dry	Extremely off-flavor

dures of Meilgaard et al. (1991). Panelists were screened for the tastes of sour, sweet, bitter, and salty. Panelists were then trained for evaluation of tenderness, juiciness, connective tissue, and off-flavor intensity. Descriptors for particular off-flavors were constructed through a descriptive panel with the help of a panel leader.

Taste panels were held mid-morning or mid-afternoon, and the panelists were asked to avoid soft drinks, coffee, and food for 1 h before the sampling session. The panelists evaluated 6 to 8 samples per session. All 8 samples were from the same muscle type or were groups of 4 from 2 muscle types. On days that samples from 2 muscles types (such as steaks from the INF and TER) were served, a 5-min break was given to separate the 2 muscles. All steaks were from a uniform location on the muscle. The steaks were from the second to fourth steaks counted from the proximal end of the muscle for the REC, VAL, INF, and TRI. Because of the small size of the TER and VAM, they were cooked as whole muscles. For a day, the order in which each muscle was served was random, and in addition, all steaks within each muscle type were served in random order. Panelists were not aware of which type of steak they were eating.

Panelists were isolated in individual booths to reduce collaboration, and samples were served under red fluorescent light to eliminate visual differences. Distilled water and unsalted crackers were provided for panelists between samples to cleanse their palates. The steak cubes were served to the panelists on ceramic plates. Charred edges were not served to allow for more consistent sampling. The 8-point scales that were used are found in Table 1.

Panelists also identified the presence of off-flavor notes including charred, liver-like, metallic, musty/oxidized, acidic, and sour flavors. Off-flavor note values reflect the percentage of panelists detecting a particular off-flavor note. This percentage was calculated for each individual muscle.

Statistics

Carcass traits were analyzed by ANOVA using the GLM procedure of SAS (SAS Inst. Inc., Cary, NC). Least squares means were separated using the PDIFF option of SAS. Muscle cooking times, off-flavor notes, grades, and normal and off-flavor groups were analyzed by ANOVA using the MIXED procedure of SAS. Fixed effects included muscle and group. Animal within group was blocked and considered a random effect. Least squares means were developed and separated using the PDIFF option. Muscle off-flavor notes were analyzed by ANOVA using the GLM procedure of SAS. Fixed effects included muscle and grade. The linear and quadratic functions, as well as the interaction of heme-iron concentration and pH, were analyzed.

RESULTS AND DISCUSSION

Carcass Data

Except for marbling, the carcass traits of USDA Choice and Select carcasses were similar (Table 2). Some of the data for the USDA Choice cattle was not

Table 2. Effect of USDA grade on carcass traits

	USDA Choice			USDA Select		
Trait	Mean	n	SE	Mean	n	SE
Hot carcass weight, kg	372.63	16	7.76	370.49	14	8.30
Fat thickness, cm	1.37	15	0.14	1.20	14	0.15
Longissimus muscle area, cm^2	85.42	11	3.35	84.39	14	2.97
Percent KPH	2.00[a]	11	0.23	1.14[b]	14	0.20
Yield grade	3.16	15	0.25	3.16	14	0.22
Marbling[1]	446.36[a]	11	7.97	357.86[b]	14	7.07

[a,b]Means within a row with different superscripts differ ($P < 0.01$).
[1]Marbling code: 300 = Slight[00], 400 = small[00], 500 = modest[00].

Table 3. Mean cooking times of various muscles to an endpoint internal temperature of 65°C

Muscle	Cooking time	SE
Teres major	29.44[a]	1.12
Vastus medialis	23.79[b]	1.13
Infraspinatus	22.20[bc]	1.12
Vastus lateralis	19.78[cd]	1.12
Rectus femoris	18.54[d]	1.19
Triceps brachii	17.70[d]	1.12

[a–d]Means with different superscripts differ ($P < 0.05$).

collected, so the number of samples for each trait varies. Hot carcass weight, fat thickness, longissimus muscle area, and yield grade were not significantly different. Only percent KPH ($P < 0.001$) and marbling ($P = 0.001$) were different, which is to be expected because higher marbling value is one of the primary factors that differentiate USDA Choice cattle from USDA Select cattle.

Sensory Analysis

There were no significant grade effects ($P = 0.513$) or interactions of grade and muscle ($P = 0.990$) on cooking time (Table 3). The TER had a ($P < 0.001$) longer cooking time than the other muscles tested, taking approximately 6 minutes longer to cook than the VAM and 12 minutes longer to cook than the TRI. The longer cooking time for the TER was likely due to greater thickness, which required a longer amount of time to reach the required degree of doneness. The REC and TRI took the least time to cook, although they were not different ($P > 0.100$) from the VAL. The VAM and INF were intermediate.

There were no grade effects for any of the muscles and traits. Off-flavor intensity, tenderness, connective tissue, and juiciness differed among muscles (Table 4). The INF had the lowest off-flavor intensity ratings and was among the most tender and juicy of the muscles tested whereas the VAL had the most intense off-flavor ratings, was the least tender, had the most connective tissue, and had the lowest juiciness ratings (Table 4). Shorthose and Harris (1991) described a halo effect in which a sample that has a weak off-flavor flavor is rated more tender or juicy than one with a strong off-flavor. The INF, TER, and VAM had the highest pH values of the muscles tested. A relationship between lower flavor desirability and a high pH has been shown in some beef muscles by other researchers (Dransfield, 1981; Wulf et al., 2002). Although flavor desirability was not measured in this study, it is likely that a high perceived amount of off-flavor intensity would decrease flavor desirability. There were no differences ($P = 0.449$) among muscles for heme-iron concentration.

Off-flavor note values reflect the percentage of panelists detecting a particular off-flavor note. There were no grade × muscle interactions or grade effect for any of the off-flavor notes. This is consistent with the findings of Yancey (2002) who also found no interaction between grade and muscle. Liver-like, bloody, and rancid flavors were not affected by muscle type (Table 5). The lack of any significant differences among muscles for liver-like flavor suggests that if one clod or knuckle muscle is liver-like, all of the clod or knuckle muscles from that carcass are liver-like, and it is not just an individual muscle problem.

The INF, which had the lowest off-flavor intensity, was among the lowest in percentage of panelists detecting sour, metallic, and oxidized flavors. The INF did receive higher ratings for fatty flavor than the other muscles ($P < 0.001$). Yancey (2002) found that the INF had the lowest amount of sour flavor when compared with the psoas major and gluteus medius. The VAL, which had the most intense off-flavor, was among the highest in percentage of panelists detecting sour, charred, and oxidized flavors (Table 5). Most of the other muscles were rated as being intermediate in the percentage of panelists detecting specific off-flavor notes. Wulf et al. (2002) showed an increase in sour and bitter flavors, whereas Yancey (2002) found a higher amount of rancid flavor, in high pH beef as compared to normal. None of our samples were dark cutters, and neither of these trends was shown in our results.

Some of the flavor variation may be explained by differences in fiber type. All of the muscles tested have been classified previously (Kirchofer et al., 2002) according to their fiber type with the REC being classified as white (fast glycolytic), INF and TRI classified as red (slow oxidative), and the others classified as intermediate (glycolytic and oxidative). Zerouala and Stickland

Table 4. The effect of muscle type on sensory characteristics, heme-iron concentration, and pH[1]

Muscle	Tenderness	SE	Connective tissue	SE	Juiciness	SE	Off-flavor intensity	SE	Heme-iron concentration	SE	pH	SE
Infraspinatus	6.50[ab]	0.16	5.77[ab]	0.17	6.22[a]	0.13	6.03[a]	0.16	44.42	1.97	5.70[a]	0.03
Rectus femoris	6.11[b]	0.16	5.44[b]	0.17	5.69[b]	0.13	5.68[b]	0.16	46.25	1.97	5.59[b]	0.03
Teres major	6.58[a]	0.16	5.85[a]	0.17	6.15[a]	0.13	5.41[bc]	0.16	42.99	1.97	5.71[a]	0.03
Triceps brachii	5.45[c]	0.16	4.32[c]	0.17	5.68[b]	0.13	5.54[b]	0.16	45.43	1.97	5.47[c]	0.03
Vastus lateralis	4.66[d]	0.16	3.63[d]	0.17	5.07[c]	0.13	5.10[c]	0.16	45.60	1.97	5.54[bc]	0.03
Vastus medialis	5.45[c]	0.16	4.18[c]	0.17	6.04[a]	0.14	5.58[b]	0.17	47.47	2.02	5.66[a]	0.03

[a–d]Means within a column (for sensory traits) with different superscripts are ($P < 0.05$) different.
[1]Taste panel scale: 8 = extremely juicy, extremely tender, no connective tissue, or no off-flavor; and 1 = extremely dry, extremely tough, abundant amount of connective tissue, or extreme off-flavor.

Table 5. The effect of muscle type on the percentage of taste panelists detecting each off-flavor note

	Liver		Sour		Metallic		Charred		Bloody		Oxidized		Fatty		Rancid	
Muscle	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Infraspinatus	9.3	2.9	23.2[a]	3.7	8.7[a]	2.2	29.9[b]	4.4	1.6	1.0	9.5[ab]	2.3	14.0[b]	1.3	8.8	1.6
Rectus femoris	9.7	2.9	44.2[b]	3.7	13.4[a]	2.2	20.4[ab]	4.4	3.4	1.0	7.4[a]	2.3	3.2[a]	1.3	4.9	1.6
Teres major	8.8	2.9	48.7[b]	3.7	15.5[ab]	2.2	21.6[ab]	4.4	1.8	1.0	8.5[ab]	2.3	3.3[a]	1.3	5.8	1.6
Triceps brachii	7.7	2.9	49.5[b]	3.7	19.5[b]	2.2	22.2[ab]	4.4	0.8	1.0	13.3[abc]	2.3	1.6[a]	1.3	5.6	1.6
Vastus lateralis	9.1	2.9	48.4[b]	3.7	15.0[ab]	2.2	30.5[b]	4.4	1.3	1.0	17.5[c]	2.3	1.4[a]	1.3	6.8	1.6
Vastus medialis	10.8	3.0	49.0[b]	3.8	17.3[ab]	2.2	14.8[a]	4.6	2.9	1.0	14.6[bc]	2.3	2.3[a]	1.4	7.2	1.6

[a–c]Means within a column (for off-flavor notes) with different superscripts are ($P < 0.05$) different.

(1991) demonstrated that when all oxidative fibers were totaled together, dark-cutting bulls and steers exhibited a significantly greater amount of oxidative metabolism through number and relative area, suggesting that oxidative muscles depleted their stores of glycogen faster than glycolytic fibers do, which would result in a higher pH for oxidative muscles. The INF, TER, and VAM showed this relationship; muscles that had a high amount of oxidative muscle fibers had the highest pH. The trend was not shown for the TRI, which also is an oxidative muscle and only had a moderate pH.

When the off-flavor intensity scores were assessed, it appeared that when one muscle of a given carcass was rated as having off-flavors, most of the muscles evaluated from that carcass were rated as having off-flavors (Table 6). Table 6 gives the mean off-flavor intensity scores of the first 10 carcasses that were collected. Sixteen of the 18 muscles from animals 6, 7, and 8 had off-flavor intensity scores below 5. The most extreme cases of liver-like flavor came from these 3 carcasses. When liver-like flavor was evident in one muscle, it tended to be represented in all muscles from that carcass. Out of the 18 muscles from these 3 carcasses, 15 of the muscles had more than one-third of the panel describing the off-flavor as liver-like. Every one of the muscles from carcasses 6, 7, and 8 had liver-like off-flavors indicated by at least one of the panelists; that is, none of the muscles were given a 0 in percentage of panelist's describing the flavor as liver-like. The three carcasses that had the highest incidence of liver-like flavor were all USDA Select and came off the rail in a row. This would suggest that liver-like flavor is related to something that the entire animal experiences; it tends to be shown in each of the muscles studied when it exists in the carcass. It also suggests that a lower value muscle could be sacrificed to find out which carcasses have this off-flavor, which could be of value to restaurants as well as to companies that export.

Liver-like flavor is negatively correlated ($P < 0.008$) with off-flavor intensity ratings (Table 7). The ratings ranged from r = –0.48 for the VAL to r = –0.77 for the VAM. This would suggest that the presence of liver-like flavor is associated with off-flavor intensity. Charred flavor was also strongly and negatively correlated with off-flavor intensity ratings for the TER, TRI, and VAL. Sour flavors were positively correlated with off-flavor intensity ratings in the TER and TRI. Although this seems contradictory, it is possible that for those steaks, the strong correlations between liver-like, as well as charred, flavors with off-flavor intensity may overwhelm the sour flavor, making it seem like the flavor is less intense. For the REC, TER, and VAM, pH was negatively correlated with off-flavor intensity, suggesting that a higher pH would receive lower off-flavor intensity scores. Rancid off-flavor was correlated ($P < 0.001$) with off-flavor intensity ratings in the VAM, and

Table 6. Mean off-flavor intensity scores[1] and the percentage of panelists recognizing liver-like flavors

		Off-flavor intensity scores						Percentage of panelists who recognized liver-like flavor					
Animal	Grade[2]	Infra-spinatus	Rectus femoris	Teres major	Triceps brachii	Vastus lateralis	Vastus medialis	Infra-spinatus	Rectus femoris	Teres major	Triceps brachii	Vastus lateralis	Vastus medialis
1	C	6.86	6.38	4.00	6.44	5.29	4.40	0.00	0.00	20.00	11.10	25.00	10.00
2	C	7.25	6.00	6.67	6.00	4.29	5.90	0.00	0.00	0.00	11.10	0.00	10.00
3	C	6.20	6.56	6.10	6.00	4.13	6.20	0.00	0.00	10.00	12.50	0.00	0.00
4	C	7.13	6.50	5.56	5.78	5.71	6.33	0.00	12.50	11.10	0.00	0.00	0.00
5	C	6.33	6.75	5.50	5.22	5.33	5.00	0.00	12.50	0.00	0.00	0.00	0.00
6	S	3.78	3.78	1.60	2.22	3.00	2.30	66.70	44.40	30.00	44.40	62.50	60.00
7	S	4.88	3.38	2.67	4.00	3.57	4.60	12.50	50.00	66.70	11.10	42.90	60.00
8	S	3.88	4.88	4.90	4.50	3.57	3.90	100.00	50.00	50.00	37.50	37.50	60.00
9	S	5.43	6.50	6.90	5.56	4.14	5.60	0.00	25.00	0.00	0.00	12.50	10.00
10	S	6.60	6.25	4.67	2.89	3.78	5.67	0.00	0.00	11.10	11.10	0.00	0.00

[1]Taste panel scale: 8 = no off-flavor, and 1 = extreme off-flavor.
[2]C = USDA Choice; S = USDA Select.

Table 7. Correlations between off-flavor intensity ratings and the percentage of panelists rating a particular off-flavor

Muscle	Liver-like	Metallic	Sour	Charred	Oxidized	Rancid	Fatty	Bloody	pH	Heme iron
Infraspinatus	–0.72***	0.19	0.05	–0.08	–0.02	0.04	0.10	–0.01	–0.12	–0.24
Rectus femoris	–0.70***	–0.33	0.08	–0.03	0.04	–0.13	0.18	0.04	–0.41**	–0.17
Teres major	–0.68***	–0.04	0.46*	–0.74***	–0.21	–0.24	–0.16	0.22	–0.43*	0.04
Triceps brachii	–0.55**	–0.12	0.45*	–0.79***	–0.07	–0.05	0.12	0.02	–0.21	–0.09
Vastus lateralis	–0.48**	–0.11	0.28	–0.70***	–0.07	–0.26	–0.17	0.14	–0.21	–0.51**
Vastus medialis	–0.77***	–0.08	0.05	–0.22	–0.20	–0.60***	–0.18	0.27	–0.62***	–0.34

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

heme-iron concentration was correlated with off-flavor intensity in the VAL. There were no significant correlations ($P > 0.05$) for metallic, oxidized, fatty, or bloody off-flavor notes.

In an attempt to explore the off-flavor intensity ratings among these muscles, the muscles were grouped (Tables 8 and 9). All muscles that at least 30% of the panelists recognized as having a liver-like off-flavor were placed together in an off-flavor grouping, whereas the other muscles were left in a normal group. This resulted in 2/30 (6.7%) of the INF and TRI, 3/30 (10.0%) of the REC, TER, and VAL, and 3/28 (10.7%) of the VAM muscles being considered off-flavored while the rest were considered normal. There were no group effects or group × muscle interactions for sour, metallic, fatty, bloody, or oxidized off-flavor notes (Table 8). When grouped this way, the percentage of panelists detecting liver-like scores was very high ($P < 0.001$), which is to be expected because this is how they were grouped (Table 9). Charred flavors were significantly lower for the TER ($P < 0.001$), the TRI ($P = 0.490$), and the VAL ($P = 0.008$) in the off-flavor group than in the normal group. The trend could be because the intense liver-like flavor overwhelms the charred flavor. Off-flavor samples were less rancid for the VAM than normal samples ($P < 0.001$). These data suggest that liver-like flavor does not co-occur with other off-flavor notes or that the liver-like flavor overwhelms other, more subtle, flavor differences.

Regression equations containing the linear and quadratic functions of heme-iron concentration, muscle pH, and their interaction were established for the off-flavor intensity and the frequency of off-flavor notes within each muscle (Table 10). There were no significant relationships among off-flavor intensity or off-flavor notes for the TRI. There were also no significant relationships among muscles for metallic, oxidized, or rancid off-flavor notes. This is surprising because other research has shown that a greater heme-iron content increases lipid oxidation (Johns et al., 1989; Monahan et al., 1993), which would increase oxidized flavors. Perhaps total iron would have shown a relationship with oxidized flavor because other researchers have suggested that heme iron is not the only source of transition metals that initiate the Fenton reaction (Love and Pearson, 1974). It is also surprising that there is not a significant impact of heme-iron concentration on metallic flavor. It seems logical that a greater amount of a metal (iron) would increase metallic flavor, and other researchers have found a link between metallic flavor and myoglobin content (Miller, 2001).

There were no relationships between pH, heme-iron concentration, and off-flavor intensity or off-flavor notes for the INF, which is in contrast with the results of Yancey (2002) who found that myoglobin levels were moderately correlated with liver-like flavor in the INF. There were significant relationships ($R^2 = 0.45$ to 0.53) between pH, heme-iron concentration, and liver-like flavor in the REC ($P > 0.001$), VAL ($P = 0.003$), and VAM ($P = 0.006$).

Heme iron and pH explained some ($R^2 = 0.36$ to 0.53) of the off-flavor intensity (Table 10) of the REC ($P = 0.021$), TER ($P = 0.019$), VAL ($P = 0.019$), and VAM ($P = 0.001$). Bloody flavor notes in the INF ($P = 0.034$) and VAL ($P = 0.05$) showed a relationship ($R^2 = 0.33$ and 0.31, respectively) with heme-iron concentration

Table 8. The effect of muscle type on the percentage of panelists detecting each off-flavor note

	Sour		Metallic		Bloody		Oxidized		Fatty	
Muscle	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Infraspinatus	14.3[a]	6.8	4.7[c]	4.3	0.9	2.0	4.8[a]	4.4	10.1	2.6
Rectus femoris	28.3[a]	5.8	18.3[ab]	3.6	1.9	1.7	4.1[a]	3.7	1.9	2.2
Teres major	37.4[b]	5.8	13.1[bc]	3.6	1.0	1.7	10.8[ab]	3.7	3.3	2.2
Triceps brachii	34.3[b]	6.8	24.3[a]	4.3	0.4	2.0	17.8[b]	4.4	0.9	2.6
Vastus lateralis	38.4[b]	5.8	14.3[abc]	3.6	0.7	1.7	19.2[b]	3.7	0.7	2.2
Vastus medialis	47.9[b]	5.8	14.1[abc]	3.6	1.6	1.7	17.0[b]	3.7	2.7	2.2

[a–c]Means within a column (for sour, metallic, bloody, oxidized, and fatty) with different superscripts are ($P < 0.05$) different.

Table 9. The effect of normal vs. off-flavor group[1] and muscle on percentage of panelists detecting each off-flavor note

	Liver				Charred				Rancid			
Muscle	Normal	SE	Off-flavor	SE	Normal	SE	Off-flavor	SE	Normal	SE	Off-flavor	SE
Infraspinatus	3.6[b]	1.5	83.3[a]	5.4	5.6	15.7	31.7	4.3	0.0	6.0	9.5	1.6
Rectus femoris	5.1[b]	1.5	48.2[a]	4.4	23.2	13.2	20.6	4.3	7.9	4.9	4.6	1.6
Teres major	4.0[b]	1.5	48.9[a]	4.4	69.2[a]	13.2	16.7[b]	4.3	6.7	4.9	6.0	1.6
Triceps brachii	5.2[b]	1.5	41.0[a]	5.4	52.1[a]	15.7	19.7[b]	4.3	5.2	6.0	5.7	1.6
Vastus lateralis	4.4[b]	1.5	47.6[a]	4.4	64.9[a]	13.2	26.9[b]	4.3	13.1	4.9	6.2	1.6
Vastus medialis	5.0[b]	1.5	60.0[a]	4.4	20.0	13.2	14.9	4.5	23.3[a]	4.9	5.3[b]	1.7

[a,b]Means within a row with different superscripts are different ($P < 0.05$).
[1]Off-flavor group includes all muscles with an off-flavor intensity score of 5 or less, when the flavor note indicated was liver-like. Normal is all other muscles.

Table 10. Coefficients of determination and *P*-values for regression equations relating pH and heme-iron content to off-flavor intensity and frequency of off-flavor notes detected by the taste panel[1]

	Off-flavor		Liver		Metallic		Sour		Charred		Oxidized		Rancid		Bloody	
Muscle[2]	CD[3]	*P*-value	CD	*P*-value	CD	*P*-value	CD	*P*-value	CD	*P*-value	CD	*P*-value	CD	*P*-value	CD	*P*-value
INF	6.79	0.768	4.78	0.866	27.37	0.081	31.85	0.041	5.13	0.850	15.38	0.363	5.45	0.835	32.98	0.034
REC	35.93	0.021	54.78	<0.001	5.49	0.832	39.51	0.011	16.18	0.333	6.55	0.780	21.38	0.182	4.03	0.899
TER	36.56	0.019	29.42	0.060	0.85	0.994	32.22	0.039	41.50	0.008	16.40	0.325	22.50	0.158	13.65	0.432
TRI	15.50	0.358	8.00	0.705	2.13	0.967	3.15	0.934	20.92	0.192	17.20	0.298	15.31	0.365	1.00	0.992
VAL	36.50	0.019	46.90	0.003	12.01	0.505	25.57	0.105	32.95	0.035	15.67	0.352	3.25	0.930	30.68	0.050
VAM	52.86	0.001	45.00	0.006	19.26	0.275	3.11	0.944	7.25	0.772	16.63	0.360	32.09	0.055	6.30	0.816

[1]The regression model included pH, pH^2, heme-iron, heme-iron^2, and pH × heme iron.
[2]INF = Infraspinatus; REC = Rectus femoris; TER = Teres major; TRI = Triceps brachii; VAL = Vastus lateralis; and VAM = Vastus medialis.
[3]CD = Coefficient of determination.

and pH. Heme-iron concentration and pH influenced sour flavor (R^2 = 0.32 to 0.40) in the INF (P = 0.041), REC (P = 0.011), and TER (P = 0.039). Charred flavor in the TER (P = 0.008) and VAL (P = 0.035) was also influenced (R^2 = 0.42 and 0.33, respectively). Although heme-iron concentration and pH appear to contribute to off-flavor, there is no clear pattern, except for perhaps off-flavor intensity, where 4 of the 6 muscles tested had significant relationships between pH, heme-iron concentration, and off-flavor intensity.

The low frequency of off-flavors (e.g., 2 or 3 out of 30 were classified as having liver-like off-flavor) may have distorted the true relationship between off-flavor and pH/heme iron. Such a situation would help explain why one muscle might have a high relationship (e.g., REC at R^2 = 0.55 for frequency of liver-like off-flavor) and another a low relationship (e.g., INF at R^2 = 0.05) to these muscle traits. Further study is needed with a greater number of off-flavored samples to clarify this situation.

IMPLICATIONS

These data suggest that when one muscle from a carcass contains liver-like off-flavor notes, all of the muscles studied are likely to contain that flavor. Muscles from the chuck and round have different off-flavor amounts as well as different sensory characteristics. Heme-iron concentration and pH influenced off-flavor in some muscles, although the relationship is not strong.

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