2007

Unsaturated Fatty Acids and Sodium Affect the Liver-Like Off-Flavor in Cooked Beef

B. E. Jenschke
University of Nebraska - Lincoln

J. M. Hodgen
University of Nebraska - Lincoln

J. L. Meisinger
University of Nebraska - Lincoln

A. E. Hamling
University of Nebraska - Lincoln

D. Moss
University of Nebraska - Lincoln

See next page for additional authors

Unsaturated fatty acids and sodium affect the liver-like off-flavor in cooked beef[1,2,3]

B. E. Jenschke,* J. M. Hodgen,* J. L. Meisinger,* A. E. Hamling,* D. A. Moss,* M. Lundesjö Ahnström,‡ K. M. Eskridge,† and C. R. Calkins*[4]

*Department of Animal Science, †Department of Statistics, University of Nebraska, Lincoln 68583; and ‡Department of Food Science, Swedish University of Agricultural Sciences, PO Box 7051, SE-75007, Uppsala, Sweden

ABSTRACT: Beef knuckles (n = 60) were chosen from a population of 328 knuckles to test a selection procedure and determine the potential causes of liver-like off-flavor. In phase I, 2 independent panelists were allowed to smell the aromas or smell and taste samples of cooked beef to determine the presence or absence of the liver-like off-flavor and off-flavor intensity. The panelists tested knuckles from 5 feedlots, but only identified 29 as having an off-flavor. A kappa statistic was generated to assess the level of agreement of the 2 panelists that indicated the panelists moderately or substantially agreed when judgments were based on smell exclusively or smelling and tasting, respectively. Although the agreement was acceptable (κ = 0.57 and 0.76), there was not enough variation in the liver-like off-flavor and off-flavor intensity for the 2 panelists to detect differences compared with an independent sensory panel. Phase II identified factors that led to the development of the liver-like off-flavor in beef. The M. rectus femoris from knuckles identified from phase I were used. Sensory analysis, proximate composition, heme iron, mineral content, and fatty acid analyses were conducted. Stepwise regression was used to identify factors contributing to the liver-like off-flavor. Specifically, Na, 16:1, *cis* 18:1(n-7), 20:2(n-6), and 20:3(n-6) fatty acids explained (P = 0.021) 46% of the variation of the liver-like off-flavor. Although previously reported as playing a role in the development of the liver-like off-flavor, iron, heme iron, and pH had no effect in this study.

Key words: beef, fatty acid, flavor, liver-like, knuckle

J. Anim. Sci. 2007. 85:3072–3078
doi:10.2527/jas.2007-0038

INTRODUCTION

The Beef Customer Satisfaction Studies have shown that consumers in the United States regard tenderness and flavor as equal in importance (Lorenzen et al., 1999; Savell et al., 1999). Off-flavors in beef have been related to lipid oxidation, elevated pH, and microbial levels (Miller, 2001), which decreases consumer acceptability and ultimately the demand for beef. Therefore, decreasing off-flavors in beef would increase consumer acceptability and the demand for beef.

In recent years, purveyors, retailers, and consumers have reported an increase in the liver-like off-flavor in beef (E. A. Dressler, National Cattlemen's Beef Association, Centennial, CO, personal communication). Previous research has attempted to identify the source of the problem, but with minimal success. Miller (2001) suggested an increase in lipid oxidation, an increase in pH, and improper exsanguination might lead to the formation of the off-flavor. Belk et al. (1993) noted that cuts with no fat trim or cooked to greater degrees of doneness had more of the liver-like off-flavor compared with cuts with trimmable fat or cooked to lower degrees of doneness, whereas Larick et al. (1989) reported that phosphatidylethanolamine and lysophosphatidylcholine significantly contributed to the liver-like off-flavor in beef and bison steaks.

Yancey (2002) reported 8% of the steaks in his study had the liver-like off-flavor. One of the major drawbacks in conducting flavor research is being able to obtain

[1]A contribution of the University of Nebraska Agricultural Research Division.

[2]This project was funded in part by beef and veal producers and importers through their $1-per-head checkoff and was produced for the Cattlemen's Beef Board and state beef councils by the National Cattlemen's Beef Association.

[3]The authors wish to thank M. P. Carlson for his assistance with the mineral analysis.

[4]Corresponding author: ccalkins1@unl.edu

Received January 17, 2007.
Accepted July 12, 2007.

enough samples that have the off-flavor. Our laboratory found that distinct and objectionable aromas were emitted when cooking samples that had liver-like off-flavor, and we hypothesized that individuals could identify candidate muscles for the liver-like off-flavor by cooking a small piece of muscle tissue and smelling the aromas. If this methodology proved successful, one could then increase the probability of choosing subprimals with the liver-like off-flavor compared with random selection to try to identify the causes of the off-flavor.

Specifically, the objectives of this study were to determine if smelling aromas while cooking was successful at identifying samples containing the liver-like off-flavor, and to determine if fatty acid and mineral content, pH, heme iron, or fat and moisture content were related to the liver-like off-flavor.

MATERIALS AND METHODS

Phase I

Sample Procurement. No approval was obtained from the Institutional Animal Care and Use Committee because samples were obtained from a federally inspected slaughtering facility. Beef knuckles (IMPS #167; NAMP, 2007) were selected from Premium Protein Products in Hastings, NE. Candidate beef carcasses that could be source verified were identified before fabrication. A total of 5 feedlots had cattle (A maturity) slaughtered at this particular abattoir during the sampling period. Before slaughter, university personnel visited each feedlot to assess management practices to gain an understanding of how the cattle were finished. Additionally, animals that had spent time in the medical pen or that the feedlot had classified as bullers were identified in case these factors affected the prevalence of the off-flavor.

During the slaughter, liver scores were recorded as described by Brink et al. (1990). Livers with no abscesses were scored as 0, livers with 1 or 2 small abscesses (less than 2.5-cm diam.) were rated as A–, livers with 2 to 4 small abscesses were scored as A, and livers with large abscesses (larger than 2.5-cm diam.) were rated as A+. Knuckles of a known source were randomly tagged before fabrication from feedlots that university personnel had visited. No attempt to balance the number of knuckles based on liver score classification was made. On the fabrication line, university personnel removed the tagged knuckles and cut a small portion (2- to 4-mm slice; ~10 g) of the M. rectus femoris (knuckle center; IMPS #167E; NAMP, 2007) to be tested by 2 highly trained independent panelists.

The panelists were in an isolated room with air purifiers (models 30200 and 30055, Hunter Fan Co., Memphis, TN) to limit extraneous aromas. The panelists cooked the small portion of the knuckle center on a 12-in electric skillet (The West Bend Co., West Bend, WI) that was set at 171°C and smelled aromas emitted from the piece of meat while it cooked. Samples were cooked individually, and the pan was wiped clean between samples. The panelists classified the aroma as good or bad on 328 knuckles. Samples with objectionable odors were classified as bad, whereas those lacking objectionable odors were classified as good. Thirty-one good knuckles and 29 bad knuckles were vacuum-packaged and shipped to the Loeffel Meat Laboratory at the University of Nebraska. After a 7-d aging period, three 2.54-cm-thick M. rectus femoris steaks were cut from the cranial end of the muscle, wrapped in freezer paper, and frozen (–16°C) until chemical and sensory analysis were conducted within 3 mo. The most proximal steak of each knuckle was minced, frozen in liquid nitrogen, pulverized (model 51BL32, Waring Commercial, Torrington, CT), and used for chemical analysis (stored at –80°C), whereas the next most proximal steak was used to verify the selection procedure. The most distal steak was used for trained sensory analysis.

Selection Procedure. Because aging plays a pivotal role in the development of beef flavor, the 60 knuckles were screened again after the 7-d aging period. In the first part of the procedure, the panelists (n = 2) were only allowed to smell the aromas emitted while cooking. The panelists were instructed to identify only the absence or presence of objectionable aromas. Samples were cooked individually, and panelists smelled aromas emitted during cooking. After cooking, panelists were given a 1-min break. The next part of the procedure allowed panelists to smell and taste a different sample of cooked M. rectus femoris muscle. After smelling the aromas, the panelists bisected the cooked piece of meat and tasted the sample. Again, the presence or absence of an off-flavor was recorded. In both cases, air purifiers (models 30200 and 30055, Hunter Fan Co.) were used. The remaining portion of the muscle was cooked on an electric skillet. The temperature of the skillet was approximately 171°C, and it took approximately 15 s to cook the sample. Panelists were given a 5-min break after every 10 samples. When smelling and tasting the samples, the panelists were served distilled water and unsalted, saltine crackers for palate cleansing.

Statistical Analysis. Data were analyzed in a 2×2 contingency table, using the FREQ procedure and the AGREE option of SAS (SAS Inst. Inc., Cary, NC). To test the agreement beyond chance between the 2 panelists, a kappa statistic was calculated for each test. The procedure of Landis and Koch (1977) was used, resulting in kappa values of < 0 as indicative of poor agreement; 0.00 to 0.20 as slight agreement; 0.21 to 0.40 as fair agreement; 0.41 to 0.60 as moderate agreement; 0.61 to 0.80 as substantial agreement; and 0.81 to 1.00 as almost perfect agreement.

To validate the selection procedure, steaks for which the 2 panelists agreed on the classification were placed in their respective groups (off-flavor absent or off-flavor present). For the purpose of validation, steaks for which the panelists disagreed (n = 7) were omitted from this analysis. A 1-way analysis of variance (ANOVA) was conducted using the MIXED procedure of SAS, where

Table 1. Mineral concentrations of M. rectus femoris

Mineral	Concentration[1]	SD
Na	503.22	56.84
Mg	249.34	18.50
P	2,021.00	100.86
Ca	49.15	7.73
Mn	0.05	0.06
Fe	20.89	4.36
Cu	0.84	0.20
Zn	48.15	6.63

[1]Expressed as μg/g on a wet tissue basis.

liver-like or overall off-flavor served as the dependent variable and the classification groups were the independent variables. Additionally, the posthoc probability of making a type II error (power) was determined.

Phase II

Mineral Analysis. Two grams of frozen, pulverized meat sample was placed in a Teflon container with 5 mL of concentrated nitric acid and held at 65°C for approximately 15 h (Braselton et al., 1981). After a cooling period, the contents of the container were poured into a 50-mL volumetric flask and brought to volume with double distilled, deionized water. Trace minerals were quantified using an inductively coupled plasma spectrometer (Plasma 40 Emission Spectrometer, Perkin-Elmer Corp., Norwalk, CT) and an ultrasonic nebulizer (model U-5000AT, CETAC Technologies Inc., Omaha, NE). Bovine liver (National Bureau of Standards, Gaithersburg, MD) of a known mineral concentration was run after the calibration to ensure proper calibration. Because Mn was not detected in some samples, a considerable amount of variation in relation to the mean was reported (Table 1).

Fatty Acid Analysis. Twenty grams of muscle tissue were blended with 300 mL of chloroform:methanol (2:1, vol/vol) to extract lipid. The extract was filtered and mixed with 100 mL of double distilled, deionized water. After the phases separated, the lipid layer was transferred, and the solvents were evaporated by heating under vacuum at 80°C for approximately 1.5 min (Folch et al., 1957). After extraction, the lipids were methylated using boron-trifluoride in 14% methanol (Morrison and Smith, 1964) and dissolved in hexane. The resulting fatty acid methyl esters were then analyzed with a Hewlett-Packard Gas Chromatograph (model 6890 series, Agilent Technologies, Santa Clara, CA). A fused silica column [(30 m × 0.25 mm (i.d.)] containing a 0.25-μm film thickness (Agilent Technologies, Santa Clara, CA), with helium serving as the carrier gas (flow rate = 1.1 mL/min) was used to separate fatty acid methyl esters. Initially, the oven temperature was held at 165°C for 28 min; then, the oven temperature was raised 1.5°C/min until the temperature reached 185°C; once at 185°C, the oven temperature was raised 10°C/min until it reached 200°C; finally, the oven temperature was held at 200°C for 10 min. The injector and flame ionization detector temperatures were each set at 250°C.

Table 2. Fatty acid concentrations of M. rectus femoris

Fatty acid	Concentration[1]	SD
14:0	20.75	9.06
14:1	4.23	2.03
15:0	11.39	7.90
16:0	147.90	51.14
16:1	16.68	7.60
18:0	54.15	19.04
18:1	162.96	60.26
cis 18:1(n-7)	25.77	25.61
18:2	46.19	21.27
18:3	1.42	0.88
20:0	1.47	0.79
20:1	0.90	0.88
20:2(n-6)	3.60	2.20
20:3(n-6)	11.66	7.36
20:4	0.98	5.42
20:5	1.57	1.36
22:5	3.46	2.57
22:6	0.10	0.24

[1]Expressed as mg/100 g of intramuscular fat extracted.

Identification of fatty acids was made by comparing the sample chromatograms with chromatograms of known standards. Heptadecanoic acid (17:0) was added as the internal standard just before loading onto the gas chromatograph and therefore was not included in the statistical analysis. Individual fatty acid methyl esters were expressed as milligrams per gram of intramuscular fat (Table 2). Total run time for the analysis was 65 min.

pH. The pH of each muscle was obtained by using a spear-tip combination probe (Cat No. 476456, Corning, Corning, NY) attached to a pH meter (model SA 720, Orion, Boston, MA). The probe was placed approximately 5.0-cm deep into the primal at 2 random locations. The subsequent average represented the pH of the muscle. The pH probe was calibrated with buffers of a known pH (4.00 and 7.00 Thermo Electron Corp., Beverly, MA).

Heme Iron Concentration. The acidified acetone procedure outlined by Hornsey (1956), as modified by Lee et al. (1998), was used to quantify heme iron content in duplicate. After extraction and filtration, the filtrate was read at 640 nm using a Cary 100 UV/Visual spectrophotometer (Varian Instruments, Sugar Land, TX). The absorbance value was multiplied by 680 to give the total amount of pigment. Heme iron [(mg/kg); ppm] was determined by using the following equation: total pigment × 0.882.

Proximate Analysis. Two grams of pulverized muscle tissue in duplicate were used to quantify moisture and ash using a using a Leco Thermogravimetric Analyzer (model 604-100-400, Leco Corporation, St. Joseph, MI). Total fat was determined as outlined by the AOAC (1990) using the Soxhlet extraction procedure.

Sensory Analysis. Steaks were cooked to an internal temperature of 70°C on an electric broiler (model FSR200, Farberware Inc., Prospect, IL). Internal temperature was monitored with a digital thermometer (model 450-ATT, Omega Engineering, Stamford, CT) with a type T thermocouple (Omega Engineering). When the internal temperature reached 35°C, the steak was turned once and cooked until the final temperature was reached. After cooking, the steaks were placed in double broilers to keep warm. The steak was cut into 1.27 × 1.27 × 2.54-cm cubes and served warm to the panelists, approximately 5 min postcooking.

Panelists (n = 8) for this study (phase II) were selected and trained according to the guidelines and procedures outlined by Meilgaard et al. (1991). During training, panelists were served hamburger patties with varying levels of beef liver to anchor them on the 15-point scale (defined below). For training purposes, hamburger patties were formulated with 1, 3, 5, and 7% percent liver and these percentages corresponded with a 1, 3, 5, and 7 on the 15-point scale, respectively. Panelists were trained to identify the specific off-flavors (liver-like and off-flavor intensity) contributing to the off-flavor score for the steak. Specific off-flavors were reported on a 15-point scale (zero = no off-flavor; 15 = extreme off-flavor). The panelists received approximately 35 h of training. To prevent bias, panelists were seated in individual booths equipped with red fluorescent lights and partitioned to reduce collaboration between panelists and to eliminate visual differences (Meilgaard et al., 1991). Each panelist was served distilled water and unsalted, saltine crackers and given 3 min between samples to cleanse their palates. Six samples, identified using 3-digit codes, were served on each day.

Statistical Analysis. Stepwise regression using the REG procedure and STEPWISE option of SAS was used to analyze the data. The liver-like off-flavor served as the dependent variable, whereas analytical data variables served as independent variables. A minimum significance level of 0.15 was required to enter the model. Residuals were analyzed for normality using the UNIVARIATE procedure, whereas colinearity was assessed using the COLLINOINT option in PROC REG. Additionally, models were generated to determine the amount of variation that saturated and unsaturated fatty acids and minerals contributed to the liver-like off-flavor. The CORR procedure was used to quantify the relationship between overall off-flavor and the liver-like off-flavor.

RESULTS AND DISCUSSION

Phase I

Contingency tables of responses are shown in Tables 3 and 4. Agreement was greater when the panelists were allowed to smell and taste the sample. According to the guidelines outlined by Landis and Koch (1977), panelists moderately agreed when ratings were made exclusively on smell and substantially agreed when based on smell and taste.

Table 3. Contingency table of responses given by the 2 trained panelists based exclusively on smell[1]

	Panelist 1	
Panelist 2	Off-flavor absent	Off-flavor present
Off-flavor absent	22	9
Off-flavor present	4	25

[1] $\kappa = 0.57$.

Statistical validation of the selection procedure revealed that not enough variation in the liver-like off-flavor and off-flavor intensity existed to be able to segregate into 2 different populations (Tables 5 and 6). The *P*-values for all of the attributes indicated no statistical difference between the 2 populations defined by the selection procedure. The power of the test, or the chance of detecting a difference that really exists, was too low in this study, indicating there was not a big enough difference between populations to be able to detect any differences using this procedure. Typically, statisticians recommend that an experiment have a power value of at least 80%. The greatest power value in the current study was only 22%. For each attribute with each selection method, the size of difference needed to reach a power level of 80% was calculated. For off-flavor intensity differences to be detected exclusively on smell, a difference of 8.75 times larger than the observed difference in off-flavor intensity was needed, whereas the liver-like off-flavor only needed a difference of 1.32 times larger than observed to be detected by smell and tasting.

Due to low power values, it is not possible to determine if the selection procedure was effective at distinguishing between good and bad samples. In order to determine the efficacy of the new procedure, the selection procedure would need to be applied to more than 60 beef knuckles, or a population with less variance, which would increase statistical power. Based of this data, power values of 0.80 would be attained for the liver-like flavor and off-flavor intensity by testing 178 and 182 samples based exclusively on smell. When smelling and tasting samples, 151 and 155 samples would be needed, respectively.

A total of 328 knuckles, which came from 5 different feedlots, were tested by the 2 panelists. Utilizing smell-

Table 4. Contingency table of responses given by the 2 trained panelists based on smell and taste[1]

	Panelist 1	
Panelist 2	Off-flavor absent	Off-flavor present
Off-flavor absent	32	3
Off-flavor present	4	21

[1] $\kappa = 0.76$.

Table 5. Comparison between the mean sensory ratings of the laboratory evaluations and the trained sensory panel based exclusively on smell

	Classification[2]				
Attribute[1]	Good	Bad	$P > F$	Power	Variation[3]
Liver-like	0.10	0.13	0.512	0.10	3.30
Off-flavor intensity	1.25	1.28	0.770	0.06	8.75

[1]0 = No off-flavor and 15 = extreme off-flavor, as rated by trained sensory panel.
[2]Classification is based on the laboratory classification.
[3]Multiple of variation needed in attributes to have a power value of 0.80.

ing and tasting, feedlot A had 5.0% off-flavored samples (1 of 20), feedlot B had 9.4% (5 of 53), feedlot C had 6.7% (10 of 148), feedlot D had 12.5% (9 of 72), and feedlot E had 14.3% (5 of 35; Jenschke et al., 2006). No relationships between any of the preslaughter traits or liver scores and the prevalence of off-flavors existed.

Phase II. A significant ($P = 0.021$) regression was derived, which explains 46% of the variation in the liver-like off-flavor (Table 7). The beta values of 20:2(n-6) and 20:3 (n-6) indicate that these fatty acids have the greatest effect on the liver-like off-flavor. In regards to 20:2(n-6), for every 1 mg/100 g increase in this fatty acid, the liver-like off-flavor is expected to increase 0.13 sensory units. In terms of 20:3(n-6), for every 1 mg/100 g increase, the liver-like off-flavor is expected to decrease 0.03 sensory units. Sodium, 16:1, and *cis* 18:1(n-7) had a significant effect on the liver-like off-flavor due to their inclusion in the model, but the contribution was minimal, as indicated by a smaller beta value. Regression models were derived using minerals, saturated, and unsaturated fatty acids which explained 12, 13, and 40% of the variation in the liver-like off-flavor, respectively.

A significant ($P < 0.001$) regression equation was also derived for off-flavor intensity, which explained 56% of the variation (Table 8). Zinc, Fe, P, and Ca were included in the final model but had a minimal effect on off-flavor intensity. However, a 1 mg/100 g increase in 20:5 and 20:2(n-6) would increase off-flavor intensity 0.13 and 0.35 units, respectively. A 1 mg/100 g increase in 22:5 would decrease off-flavor intensity –0.25 units, which is contrary to what would be expected (Miller, 2001). When minerals, SFA, and unsaturated fatty acids were analyzed individually, they contributed to 8, 14, and 37% of the variation in off-flavor intensity, which was similar to the liver-like off-flavor. Because these trends were similar, a simple correlation revealed a strong relationship between the liver-like off-flavor and overall off-flavor intensity ($r = 0.56$; $P < 0.001$).

Others have found a relationship with fatty acids and the liver-like off-flavor. Camfield et al. (1997) reported 18:1(n-7) ($r = -0.32$) and 20:2(n-6) ($r = 0.38$) were related to the liver-like off-flavor in beef, which follows the same trend as data presented here. However, no statistical significant relationship with 16:1 was observed and the correlation with 20:3(n-6) was not reported by Camfield et al. (1997) in regards to the liver-like off-flavor. Yancey et al. (2006) reported that *trans* 18:1(n-9), 16:1, and 17:1 were negatively related in the M. gluteus medius and individually explained approximately 20% of the variation in the liver-like off-flavor, whereas oleic acid was positively related and explained 21% of the variation in the liver-like off-flavor. Linoleic acid (18:2) was negatively correlated ($r = -0.19$) with the liver-like off-flavor in the M. psoas major.

Data from the current study also indicate unsaturated fatty acids [(20:3(n-6) and 20:2(n-6)] play a pivotal role in the development of the liver-like off-flavor. Collectively, all of the unsaturated fatty acids accounted for 40% of the variation in the liver-like off-flavor. Although oxidative rancidity was not measured in this study, we hypothesize that the oxidation of lipids plays a role in the development of the liver-like off-flavor. Yancey et al. (2006) reported that lipid oxidation, as quantified by the presence of malonaldehyde, had minimal effects on the liver-like off-flavor. However, Hodgen (2006) indicated a strong correlation with the liver-like off-flavor and primary by-products of oleic, linoleic, and arachidonic acids as identified by mass spectrometry. Miller (2001) noted that various fatty acids are related to the

Table 6. Comparison between the mean sensory ratings of the laboratory evaluations and the trained sensory panel based on smell and taste

	Classification[2]				
Attribute[1]	Good	Bad	$P > F$	Power	Variation[3]
Liver-like	0.14	0.09	0.226	0.22	1.32
Off-flavor intensity	1.23	1.27	0.631	0.08	4.90

[1]0 = no off-flavor and 15 = extreme off-flavor, as rated by trained sensory panel.
[2]Classification is based on the laboratory classification.
[3]Multiple of variation needed in attributes to have a power value of 0.80.

Table 7. Estimates for the intercept and beta coefficients for independent variables to predict liver-like off-flavor intensity[1,2]

Item	Estimate[3]	SEM
Intercept	–0.2095	0.1848
Na	0.0008	0.0004
16:1	–0.0048	0.0025
cis 18:1(n-7)	–0.0020	0.0007
20:2(n-6)	0.1301	0.0335
20:3(n-6)	–0.0333	0.0100

[1]*P*-value for the model = 0.021.
[2]R^2 = 0.46.
[3]β_0 for intercept and β_1 for the remaining items.

development of warmed-over flavor. Camfield et al. (1997) reported a significant direct correlation with 22:5 and the flavor aromatic cowy; however, no relationship with off-flavor intensity was reported. Further understanding of manipulation of unsaturated fatty acids in muscle tissue could prove beneficial in reducing the incidence of the liver-like off-flavor. Additionally, the relationship between lipid oxidation and the liver-like off-flavor and off-flavor intensity should continue to be explored. Saturated fatty acids have not been shown to have an effect on the development of the liver-like off-flavor. Data from this study indicate that 15:0 significantly affects the liver-like off-flavor (r = 0.27; P = 0.050). No other SFA were significant, and the model with all of the SFA explained a small portion of the variation (R^2 = 0.15).

Others have also indicated minerals, specifically iron, heme iron, and myoglobin, might play a role in the development of the liver-like off-flavor. Miller (2001) suggested cuts with greater levels of myoglobin have been associated with the liver-like off-flavor, and Yancey et al. (2006) noted the liver-like off-flavor increased in the M. gluteus medius as iron increased. Meisinger et al. (2006) reported that 55% of the variation of the liver-like off-flavor in the M. rectus femoris was due to heme iron content and pH. In the current study, neither heme iron nor pH was a part of the regression equation, and the simple correlations were not significant (data not shown). In fact, minerals collectively only accounted for 12% of the variation in the liver-like off-flavor. No other published data has indicated a relationship with the liver-like off-flavor and Na. Even though the relationship was small in this study (β_1 = 0.0008), we hypothesize that Na may accentuate the liver-like off-flavor, thus making it easier to detect. Zinc, P, and Ca were also significant in the model for off-flavor intensity, but no other published data indicate a relationship with off-flavor intensity and these minerals.

Table 8. Estimates for the intercept and beta coefficients for independent variables to predict off-flavor intensity[1,2]

Item	Estimate[3]	SEM
Intercept	2.7532	0.7797
Zn	0.0251	0.0073
Fe	–0.0203	0.0085
P	–0.0009	0.0004
Ca	–0.0115	0.0046
20:2(n-6)	0.1341	0.0425
20:5	0.3507	0.0596
22:5	–0.2545	0.0497

[1]*P*-value for the model < 0.001.
[2]R^2 = 0.56.
[3]β_0 for intercept and β_1 for the remaining items.

Data from this study indicate individual fatty acids, Na, and long chain unsaturated fatty acids play a significant role in the development of the liver-like off-flavor. Further research into the relation between lipid oxidation, particularly measurement of lipid oxidation, and the liver-like off-flavor should be conducted. Because distribution of off-flavors varied among feedlots, future research should investigate preslaughter factors that might lead to off-flavor development. Future studies to manipulate the unsaturated fatty acid and mineral profiles of muscle might prove beneficial in lowering the incidence of the liver-like off-flavor in beef.

LITERATURE CITED

AOAC. 1990. Official Methods of Analysis. 15th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Belk, K. E., R. K. Miller, L. L. Evans, S. P. Liu, and G. R. Acuff. 1993. Flavor attributes and microbial levels of fresh beef roasts cooked with varying foodservice methodology. J. Muscle Foods 4:321–337.

Braselton, W. E., G. L. Meerdink, H. D. Stowe, and S. R. Tonsager. 1981. Experience with multielemental analysis in diagnostic clinical toxicology and nutrition. Pages 111–126 in Proc. Annu. Meet. Am. Assoc. Vet. Lab Diagn., St. Louis, MO.

Brink, D. R., S. R. Lowry, R. A. Stock, and J. C. Parrott. 1990. Severity of liver abscesses and efficiency of feed utilization of feedlot cattle. J. Anim. Sci. 68:1201–1207.

Camfield, P. K., A. H. Brown, Jr., P. K. Lewis, L. Y. Rakes, and Z. B. Johnson. 1997. Effects of frame size and time-on-feed on carcass characteristics, sensory attributes, and fatty acid profiles of steers. J. Anim. Sci. 75:1837–1844.

Folch, J., M. Lees, and G. H. S. Stanley. 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. 226:497–509.

Hodgen, J. M. J. 2006. Factors influencing off-flavor in beef. PhD Diss. University of Nebraska, Lincoln.

Hornsey, H. C. 1956. The color of cooked cured pork. I. Estimation of nitric oxide-haem pigments. J. Sci. Food Agric. 7:534–540.

Jenschke, B. E., A. E. Hamling, J. M. Hodgen, J. L. Meisinger, D. A. Moss, M. Lundesjö Ahnström, and C. R. Calkins. 2006. A novel procedure to identify off-flavored beef steaks. J. Anim. Sci. 84(Suppl. 2):170. (Abstr.)

Landis, J. R., and G. G. Koch. 1977. The measurement of observer agreement for categorical data. Biometrics 33:159–173.

Larick, D. K., B. E. Turner, R. M. Koch, and J. D. Crouse. 1989. Influence of phospholipids content and fatty acid composition of individual phospholipids in muscle from bison, Hereford and Brahman steers on flavor. J. Food Sci. 54:521–526.

Lee, B. J., D. G. Hendricks, and D. P. Cornforth. 1998. Antioxidant effects of carnosine and phytic acid in a model beef system. J. Food Sci. 63:394–398.

Lorenzen, C. L., T. R. Neely, R. K. Miller, J. D. Tatum, J. W. Wise, J. F. Taylor, M. J. Buyck, J. O. Reagan, and J. W. Savell. 1999. Beef customer satisfaction: Cooking method and degree of doneness effects on the top loin steak. J. Anim. Sci. 77:637–644.

Meilgaard, M., G. V. Civille, and B. T. Carr. 1991. Sensory Evaluation Techniques, 2nd ed. CRC Press Inc., Boca Raton, FL.

Meisinger, J. L., J. M. James, and C. R. Calkins. 2006. Flavor relationships among muscles from the beef chuck and round. J. Anim. Sci. 84:2826–2833.

Miller, R. K. 2001. Beef Flavor: A White Paper. A paper prepared for the National Cattlemen's Beef Association, Centennial, CO.

Morrison, W. R., and L. M. Smith. 1964. Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron fluoride-methanol. J. Lipid Res. 5:600–608.

NAMP. 2007. The Meat Buyers Guide. North Am. Meat Processors Assoc., Reston, VA.

Savell, J. W., C. L. Lorenzen, T. R. Neely, R. K. Miller, J. D. Tatum, J. W. Wise, J. F. Taylor, M. J. Buyck, and J. O. Reagan. 1999. Beef customer satisfaction: Cooking method and degree of doneness effects on the top sirloin steak. J. Anim. Sci. 77:645–652.

Yancey, E. J. 2002. Determination of factors causing livery flavor in steaks from the beef loin and chuck. PhD Diss. Kansas State Univ., Manhattan, KS.

Yancey, E. J., J. P. Grobbel, M. E. Dikeman, J. S. Smith, K. A. Hachmeister, E. C. Chambers, IV, P. Gadgil, G. A. Milliken, and E. A. Dressler. 2006. Effects of total iron, myoglobin, hemoglobin, and lipid oxidation of uncooked muscles on livery flavor development and volatiles of cooked beef steaks. Meat Sci. 73:680–686.