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Chemical and Sensory Properties of Beef of Known Source and Finished on Wet Distillers Grains Diets Containing Varying Types and Levels of Roughage

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Chemical and sensory properties of beef of known source and finished on wet distillers grains diets containing varying types and levels of roughage[1,2,3]

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ABSTRACT: Beef knuckles (n = 160) were obtained from source-verified cattle finished on 30% wet distillers grains plus solubles enriched with varying levels of alfalfa hay (4 or 8%), corn silage (6 or 12%), or corn stalks (3 or 6%) based on NDF. Proximate analysis, pH, oxidation-reduction potential, fatty acid composition, and sensory analysis were conducted on the rectus femoris muscle to determine if roughage inclusion, in conjunction with wet distillers grains plus solubles and cattle source, affects beef flavor with particular interest in liver-like off-flavor. Proximate analysis, fat content, and oxidation-reduction potential were unaffected ($P \geq 0.129$) by diet or source. For s.c. adipose tissue, cattle from Nebraska (NE) had greater amounts of MUFA ($P = 0.048$) and unsaturated fatty acids ($P = 0.068$) but less SFA ($P = 0.065$) when compared with cattle from South Dakota. Diet affected s.c. adipose tissue levels of 15:0, 17:0, and n-3 fatty acids in which cattle from NE finished on the low corn stalk diet had ($P \leq 0.050$) lower levels. Cattle from NE had ($P \leq 0.049$) greater i.m. adipose proportions of 13:0 and CLA. Dietary effects ($P \leq 0.050$) were observed for i.m. adipose tissue proportions of 16:0, 18:1(n-9), 18:2(n-6), 20:4(n-6), 22:5(n-3), MUFA, PUFA, and n-6 fatty acids. Sensory analysis revealed that cattle from NE were ($P \leq 0.023$) less juicy and had less bloody notes when compared with cattle from South Dakota. Cattle finished on the low alfalfa diet were ($P \leq 0.014$) more tender and juicy but had more bloody notes. No ($P \geq 0.670$) dietary or source effects were noted for liver-like off-flavor. Subcutaneous amounts of 18:2(n-6 *trans*) (r = –0.17) were inversely related to the incidence of liver-like off-flavor, whereas 20:1(n-9) (r = 0.21), CLA *cis*-9, *trans*-11 (r = 0.16) were directly related. Data from this study indicate that type and level of roughage inclusion and cattle source have minimal effects on fatty acid profiles and sensory properties of the musculus rectus femoris. However, individual fatty acids of s.c. and i.m. adipose tissue were significantly correlated with liver-like off-flavor.

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

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INTRODUCTION

Distillers grains have become very popular over the past 15 yr due to their energy value in relation to corn, price, flexibility in feeding, and reduction in incidence and duration in acidosis (Stock et al., 2000). Even with numerous feedlots in the Midwest finishing cattle on diets containing distillers grains, little research has been published on the effects of distillers grains on carcass quality. Shand et al. (1998) reported that cattle finished on wheat-based distillers grains or brewers grain were statistically similar to cattle finished on barley in regards to moisture, fat, pH, cooking losses, and sensory analysis. Likewise, Roeber et al. (2005) reported that finishing cattle on dried distillers grains had no effect on sensory attributes of strip loins. Recent research in our laboratory has investigated the effects of finishing cattle on wet distillers grains plus solubles (**WDGS**). Mello et al. (2007) reported that cattle finished on corn WDGS have greater levels of PUFA and lower levels of *cis*-vaccenic acid, which has been associated with off-flavor development in beef (Camfield et al., 1997).

Other research in our laboratory has concentrated on trying to identify the causes of liver-like off-flavor. Meisinger et al. (2006) reported that approximately

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Table 1. Composition of finishing diets and formulated nutrient analysis[1]

Treatments	Control	LALF	HALF	LSTALK	HSTALK	LSIL	HSIL
DRC[2]	32.50	30.50	28.50	30.98	29.46	29.44	26.37
HMC[3]	32.50	30.50	28.50	30.98	29.46	29.44	26.37
WDGS[4]	30.00	30.00	30.00	30.00	30.00	30.00	30.00
Alfalfa hay	0.00	4.00	8.00	0.00	0.00	0.00	0.00
Corn silage	0.00	0.00	0.00	0.00	0.00	6.13	12.26
Corn stalks	0.00	0.00	0.00	3.04	6.08	0.00	0.00
Supplement[5]	5.00	5.00	5.00	5.00	5.00	5.00	5.00
CP, %	16.40	16.70	17.00	16.30	16.10	16.30	16.30

[1]Values presented on a DM basis. LALF = low alfalfa; HALF = high alfalfa; LSTALK = low corn stalks; HSTALK = high corn stalks; LSIL = low corn silage; HSIL = high corn silage.
[2]Dry-rolled corn.
[3]High-moisture corn.
[4]Wet distillers grains plus solubles.
[5]All diets were formulated to contain a minimum of 0.65% Ca, 0.60% K, 360 mg/steer of Rumensin, 90 mg/steer daily of Tylan, and 130 mg/steer daily of thiamine.

55% of the variation in the liver-like off-flavor in the musculus rectus femoris was explained by pH and heme-Fe content. Hodgen (2006) used mass spectrometry to identify compounds present in samples that contained the liver-like off-flavor with a majority of these compounds being oxidation products of 18:2(n-6), 18:3(n-3), and 20:4(n-6). Although Jenschke et al. (2007) reported that WDGS did not affect liver-like off-flavor frequency, WDGS increased PUFA levels (Mello et al., 2007) and therefore could possibly increase compounds associated with the liver-like off-flavor.

Shahidi and Rubin (1986) reported that diet is the major environmental factor affecting beef flavor. The objectives of this research were to investigate effects of varying roughage sources and types, in addition to cattle source, on meat quality characteristics of the musculus rectus femoris with particular interest in liver-like off-flavor.

MATERIALS AND METHODS

The University of Nebraska-Lincoln Institutional Animal Care and Use Committee approved all procedures relating to live animals for this study.

Finishing Diets and Sample Procurement

Cattle from this study were a subset of the cattle described by Benton et al. (2007). Three hundred eighty-five crossbred steer calves of known source approximately 7 mo of age were purchased from sale barns in South Dakota (**SD**; n = 78) or Nebraska (**NE**; n = 82), implanted with Syonvex-C (Fort Dodge Animal Health, Fort Dodge, IA), and grazed on corn stalks for 45 d before being placed in their respective feeding diets. The steers were then weighed, implanted with Revalor-S (Intervet, Millsboro, DE), stratified to diet by weight, and randomly assigned a pen. Each pen (n = 35) contained 11 steers, and each pen was assigned 1 of 7 dietary treatments (Table 1). Cattle were on the finishing diets for 139 d. Dietary treatments consisted of a control with no roughage inclusion and 2 levels of alfalfa hay, corn silage, or corn stalks. Inclusion of alfalfa hay at 4 and 8% was used for the low and high inclusion level, respectively. Diets containing corn silage or corn stalks were then balanced to provide equal percentages of NDF from the roughage. This resulted in feeding approximately 6 or 12% corn silage and 3 or 6% corn stalks. All diets contained a mixture of dry-rolled and high-moisture corn fed at a 1:1 ratio and 30% WDGS (DM basis). All diets, regardless of dietary treatment, were formulated to provide a minimum of 0.65% Ca, 0.60% K, 360 mg/steer of Rumensin (Elanco Animal Health, Greenfield, IN), 90 mg/steer of Tylan (Elanco Animal Health), and 130 mg/steer of thiamine daily. For the final 28 d, all steers were supplemented (200 mg/steer) with Optaflexx (Elanco Animal Health). On d 140, cattle were slaughtered at a local commercial facility (Greater Omaha Packing Company Inc., Omaha, NE). Before fabrication, university personnel selected 160 carcasses (19 to 25 per treatment were randomly selected), regardless of grade. After grading, knuckles (IMPS #167; NAMP, 2007) were removed, vacuum-packaged, and shipped to the Loeffel Meat Laboratory at the University of Nebraska. After a 7-d aging period, the rectus femoris muscle (IMPS #167E; NAMP, 2007) was isolated, cut into 2.54-cm-thick steaks, vacuum-packaged, and frozen at –80°C until appropriate analyses could be conducted. The most proximal steak was minced, frozen in liquid N, pulverized (model 51BL32, Waring Commercial, Torrington, CT), and used for chemical analysis, whereas the most distal steak was used for trained sensory analysis.

Proximate Analysis

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

pH

Ten grams of pulverized muscle tissue was homogenized with 90 mL of double-distilled, deionized water using a Polytron blender (Brinkman Instruments, New York, NY) set 10,800 rpm for 30 s. The pH of the resulting slurry was obtained using an Orion 4 Star Bench Top pH/ISE meter (Thermo Electron Corporation, Beverly, MA) equipped with a Ross ultra glass combination pH electrode (Thermo Electron Corporation) and a thermocouple. Each morning, the probe was calibrated using known standards (4.0 and 7.0). Each sample was done in duplicate, and duplicates were averaged to obtain the final pH for a particular sample.

Oxidation-Reduction Potential

Oxidation-reduction potential (**ORP**) was obtained in duplicate using the procedure outlined by Nam and Ahn (2003). Briefly, 5 g of pulverized muscle tissue, 15 mL of double-distilled, deionized water, and 50 μL of butylated hydroxytoluene in 7.2% ethanol was homogenized using a Polytron blender (Brinkman Instruments) at 10,800 rpm for 15 s. The ORP value was obtained using an Orion 4 Star Bench Top pH/ISE meter (Thermo Electron Corporation) equipped with an epoxy body, gel-filled ORP triode (model 9179BNMD, Thermo Electron Corporation) and thermocouple. Each morning, the probe was calibrated using a known standard.

Fatty Acid Analysis

One gram of muscle tissue or 0.1 g of s.c. adipose tissue was combined with 5 mL or 3 mL of chloroform:methanol (2:1, vol/vol), respectively, to extract the lipid fraction. Subsequent rinsing of the test tube brought the final volume up to 10 mL or 5 mL, respectively. The extract was then washed with 2 or 1 mL of a 0.74% KCl solution. The phases were separated by centrifugation at 1,000 × *g* for 5 min. The aqueous layer was aspirated, and the samples were dried under N at 60°C (Folch et al., 1957). The lipids were then saponified by adding 0.5 mL of 0.5 *M* NaOH in methanol, vortex-mixing, and heating for 5 min at 100°C under N. After saponification, fatty acids were methylated by adding 0.5 mL of boron trifluoride (acid catalyst) in 14% methanol and heating for 5 min at 100°C under N (Metcalfe et al., 1966). Finally, the fatty acid methyl esters (**FAME**) were washed using 1 mL of a saturated NaCl solution, dissolved in hexane, and centrifuged at 1,000 × *g* for 5 min to allow for phase solution. The hexane layer containing the FAME was transferred to vials, purged with N, and stored at –80°C until the fatty acid analysis was conducted (1 mo).

The FAME were analyzed using a Hewlett-Packard Gas Chromatograph (model 5890 SeriesII, Agilent Technologies, Santa Clara, CA) equipped with a Hewlett-Packard Autosampler (model 6890A series, Agilent Technologies). A fused silica column (100 m × 0.25 mm i.d., 0.2-μm film thickness, CP-Sil 88, Chrompack, Santa Clara, CA) with He (head pressure = 40 psi; flow rate = 1.0 mL/min) serving as the carrier gas was used to separate the FAME. Initially, the oven temperature was held for 10 min at 140°C. After the initial 10 min, the temperature increased 2°C/min until the temperature reached 220°C. Once at 220°C, the temperature was held for 20 min. Total run time was 70 min. The injector was set at 270°C, whereas the flame ionization detector was set at 300°C. Identification of individual fatty acids was made by a comparison of chromatograms of known standards. Fatty acids were expressed as a weight percentage of total FAME extracted.

Sensory Analysis

Steaks were cooked to an internal temperature of 70°C on an indoor-outdoor grill (model 31605A, Hamilton Beach Inc., Picton, Ontario, Canada). 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 steaks were turned once and cooked until the final temperature was reached. After cooking, 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.

During training, panelists (n = 8) were given samples with varying degrees of tenderness, juiciness, connective tissue, and off-flavor intensity to anchor them to the 8-point scale. Panelists were also instructed to identify either the presence or absence of specific off-flavors such as liver-like, metallic, sour, bitter, charred, oxidized, or bloody. For the liver-like off-flavor, steaks having the off-flavor were used for training. Panelists received approximately 40 h of training in addition to the previous 150 h of training received for other projects conducted in our laboratory. During testing sessions, panelists were seated in individual booths equipped with red fluorescent lights and partitioned to reduce collaboration between panelists and eliminate visual differences (Meilgaard et al., 1991). During testing, each panelist would enter a sensory rating of each steak in a laptop computer equipped with Compusense 5 (Release 4.4, Compusense Inc., Guelph, Ontario, Canada). Additionally, an exhaust fan with a negative pressure was used to remove aromas from the testing area. Each panelist was served double-distilled water and unsalted saltine crackers and given 3 min between samples to cleanse their palates. Seven samples, representing each dietary treatment and identified using 3-digit codes, were served on each day.

Statistical Analysis

An ANOVA using the MIXED procedure of SAS Inst. Inc. (Cary, NC) was used to analyze the data. Chemical data were analyzed as a split plot. Diet was in the whole

Table 2. Least squares means for main effects for moisture, ash, pH, percentage of fat, and oxidation-reduction potential (ORP)

Item	Moisture	Ash	pH	Fat, %	ORP
Treatment[1]					
Control	73.41	1.18	5.58[e]	5.02	538.79
LALF	73.41	1.20	5.65[bcd]	5.47	534.84
HALF	73.27	1.16	5.66[bc]	5.19	523.63
LSTALK	73.80	1.17	5.62[cde]	5.52	528.82
HSTALK	74.09	1.18	5.68[b]	4.76	533.82
LSIL	73.65	1.22	5.61[cde]	4.52	532.55
HSIL	73.66	1.21	5.59[de]	5.22	531.55
SEM	0.29	0.02	0.02	0.31	3.42
$P > F$	0.516	0.320	0.012	0.198	0.157
Location					
Nebraska	73.57	1.20	5.63	5.12	533.26
South Dakota	73.74	1.18	5.62	5.08	530.74
SEM	0.15	0.01	0.01	0.16	2.08
$P > F$	0.382	0.129	0.729	0.852	0.435

[b–e]Mean values within a column and followed by the same letter are not significantly different ($P > 0.050$).
[1]LALF = low alfalfa; HALF = high alfalfa; LSTALK = low corn stalks; HSTALK = high corn stalks; LSIL = low corn silage; HSIL = high corn silage.

plot, whereas source was in the split plot. Main effects of diet, source, and their interaction were considered fixed effects. Pen within diet (whole-plot error term) and source by pen within diet were considered random effects. Sensory data were analyzed as a split-split plot. Diet was in the whole plot, source was in the split plot, and panelist was in the split-spilt plot. Main effects of diet, source, and their interaction were considered fixed along with session, panelist, panelist by diet, and panelist by source which served as blocking factors. Pen within diet (whole-plot error term), panelist by pen within diet, source by pen within diet, and panelist by source by pen within diet (split-plot error term) were all considered random effects. For both analyses, the Kenward-Roger denominator degree of freedom approximation was used. When indicated significant ($P \leq 0.050$) by ANOVA, main effects (diet and source) were separated using the LSMEANS and DIFF (LSD test) functions, whereas simple effects of interactions were generated using the LSMEANS and SLICE functions, respectively. The CORR procedure was used to quantify the relationship and the liver-like off-flavor and chemical data.

RESULTS

Chemical Data

Proximate Analysis, pH, and ORP. Main effects for proximate analysis, ORP, and the source effect for pH were not statistically significant ($P \geq 0.129$), but a significant ($P = 0.012$) dietary effect for pH was observed (Table 2). The pH values were in the range of what would be expected of 7-d aged beef (5.59 to 5.68). The control treatment was similar to the silage treatment (regardless of level) and to the low corn stalk treatment ($P \geq 0.253$). Cattle finished on alfalfa (regardless of level) had a significantly ($P \leq 0.033$) greater pH when compared with the control diet.

Subcutaneous Fatty Acids. Saturated fatty acid content of s.c. adipose tissue (Table 3) did not differ among diets or sources for 10:0, 12:0, 13:0, 14:0, 16:0, 18:0, 19:0, 20:0, and SFA ($P \geq 0.084$). The s.c. adipose tissue of cattle from SD (45.74%) tended ($P = 0.065$) to contain greater proportions of SFA when compared with cattle from NE (44.77%; Table 3). A significant ($P = 0.046$) diet × source interaction for 15:0 was observed (data not shown). There were no significant diet effects ($P \geq 0.185$) within either source. The s.c. fat on cattle from SD and finished on the low amount of corn stalks had significantly ($P = 0.001$) greater proportions of 15:0 when compared with cattle from NE finished on the same diet. A similar trend was noted for 17:0 (data not shown). Cattle from SD that were finished on low amounts of corn stalks had s.c. adipose tissue with significantly ($P = 0.003$) greater amounts of 17:0 when compared with cattle from NE finished on the same diet.

Minimal differences were noted for unsaturated fatty acid profiles (Table 4). No significant ($P \geq 0.128$) dietary or source effects were noted for 14:1(n-5), 16:1(n-7), 17:1(n-7), 18:1(n-9), *cis* 18:1(n-7), 20:1(n-9), 20:2(n-6), 20:3(n-6), or 20:4(n-6). Diet tended ($P = 0.100$) to affect 18:2(n-6) in which s.c. from cattle finished on corn silage (regardless of level) had numerically greater levels when compared with cattle finished on the control, alfalfa, or corn stalks diets. No significant source effect was observed for 18:2(n-6) ($P = 0.439$). *Trans* fatty acids, CLA (regardless of isomer), PUFA, and n-6 fatty acid content were not affected ($P \geq 0.112$) by diet or source (Table 5). Additionally, diet effects for MUFA and PUFA were not different ($P \geq 0.304$). However, cattle from NE contained more MUFA ($P = 0.048$) in the s.c. adipose tissue and tended to contain more unsaturated fatty acids ($P = 0.068$). The n-6:n-3 ratio was ap-

Table 3. Least squares means for main effects of SFA for s.c. fat[1]

Effect	10:0	12:0	13:0	14:0	16:0	18:0	19:0	20:0	SFA
Treatment[2]									
Control	0.05	0.08	0.02	4.01	25.07	14.79	0.17	0.11	46.50
LALF	0.05	0.09	0.01	3.86	24.64	13.96	0.17	0.10	45.18
HALF	0.05	0.08	0.01	3.72	24.40	14.49	0.17	0.11	45.31
LSTALK	0.04	0.08	0.01	3.70	24.52	13.90	0.18	0.11	44.99
HSTALK	0.05	0.08	0.01	3.64	23.96	14.41	0.17	0.11	44.84
LSIL	0.05	0.08	0.01	3.75	24.05	14.06	0.16	0.11	44.49
HSIL	0.06	0.09	0.01	3.90	24.53	14.61	0.17	0.11	45.46
SEM	0.003	0.006	0.004	0.16	0.37	0.06	0.006	0.006	0.73
$P > F$	0.084	0.577	0.921	0.407	0.200	0.863	0.784	0.948	0.348
Location									
Nebraska	0.05	0.08	0.01	3.72	24.28	14.13	0.17	0.10	44.77
South Dakota	0.05	0.08	0.01	3.88	24.62	14.51	0.17	0.11	45.74
SEM	0.002	0.003	0.002	0.09	0.22	0.31	0.003	0.003	0.39
$P > F$	0.413	0.082	0.700	0.174	0.260	0.367	0.611	0.117	0.065

[1]Fatty acids are expressed as a percentage of total fatty acid methyl esters; iso 16:0, iso 18:0, and 24:0 were not detected.
[2]LALF = low alfalfa; HALF = high alfalfa; LSTALK = low corn stalks; HSTALK = high corn stalks; LSIL = low corn silage; HSIL = high corn silage.

proaching significance ($P = 0.067$). The s.c. fat of cattle finished on silage (regardless of level) had a greater n-6:n-3 ratio when compared with the other diets. A significant ($P = 0.034$) diet × source interaction was observed (data not shown) for 18:3(n-3). Cattle from NE that were finished on the control diet had s.c. fat with greater ($P = 0.004$) proportions of 18:3(n-3) when compared with cattle from SD finished on the control diet. Moreover, cattle from SD and finished on the low corn stalk diet tended ($P = 0.081$) to contain greater proportions of 18:3(n-3) when compared with cattle from NE finished on the low corn stalk diet. A significant ($P = 0.011$) diet × source interaction was also noted for n-3 fatty acid content (data not shown). As with 18:3(n-3), s.c. adipose tissue from cattle from NE finished on the control diet contained more n-3 fatty acids when compared with cattle from SD finished on the control diet ($P = 0.001$). Cattle from SD and finished on the low corn stalk diet contain more n-3 fatty acids in the s.c. fat when compared with cattle from NE finished on the same diet.

Intramuscular Fatty Acids. No significant ($P \geq 0.153$) dietary or source effects were observed for 10:0, 12:0, 14:0, 15:0, iso 16:0, iso 18:0, 18:0, 19:0, 20:0, or SFA (Tables 6 and 7). Cattle from NE had more ($P = 0.049$) 13:0 in the i.m. fat, but the dietary effect for 13:0 was not significant ($P = 0.477$). Source had no effect on 16:0 concentration ($P = 0.160$), but diet significantly ($P = 0.011$) affected 16:0 levels in i.m. fat. Cattle finished on corn silage (regardless of level) and a high amount

Table 4. Least squares means for main effects of unsaturated fatty acids for s.c. fat[1]

Item	14:1 (n-5)	16:1 (n-7)	17:1 (n-7)	18:1 (n-9)	*cis* 18:1 (n-7)	18:2 (n-6)	20:1 (n-9)	20:2 (n-6)	20:3 (n-6)	20:4 (n-6)
Treatment[2]										
Control	0.83	3.18	0.91	32.78	1.89	3.61	0.24	0.06	0.09	0.05
LALF	0.90	3.42	0.99	33.93	2.06	3.38	0.23	0.06	0.09	0.05
HALF	0.80	3.33	0.94	34.90	2.02	3.41	0.22	0.07	0.09	0.05
LSTALK	0.79	3.39	1.02	35.02	2.05	3.38	0.25	0.07	0.09	0.05
HSTALK	0.85	3.38	1.02	34.35	2.11	3.45	0.23	0.06	0.08	0.05
LSIL	0.88	3.36	0.97	34.02	2.04	3.88	0.25	0.07	0.08	0.05
HSIL	0.83	3.12	0.89	32.97	1.99	4.27	0.26	0.07	0.09	0.05
SEM	0.06	0.17	0.05	0.96	0.07	0.25	0.01	0.004	0.006	0.004
$P > F$	0.870	0.741	0.300	0.395	0.230	0.100	0.384	0.684	0.538	0.785
Location										
Nebraska	0.84	3.35	0.99	34.46	2.06	3.55	0.24	0.07	0.09	0.05
South Dakota	0.84	3.28	0.94	33.53	1.99	3.70	0.24	0.07	0.09	0.05
SEM	0.03	0.09	0.03	0.49	0.04	0.13	0.01	0.003	0.003	0.002
$P > F$	0.943	0.552	0.128	0.159	0.151	0.439	0.497	0.901	0.167	0.363

[1]Fatty acids are expressed as a percentage of total fatty acid methyl esters; 18:3(n-6), 20:5(n-3), 22:4(n-6), and 22:5(n-3) were not detected.
[2]LALF = low alfalfa; HALF = high alfalfa; LSTALK = low corn stalks; HSTALK = high corn stalks; LSIL = low corn silage; HSIL = high corn silage.

Table 5. Least squares means for main effects of unsaturated, *trans*, polyunsaturated, and n-6 fatty acids for s.c. fat[1]

Item	18:1 *trans*	18:2 (n-6 *trans*)	CLA *cis*-9, *trans*-11	CLA *trans*-10, *cis*-12	CLA[2]	MUFA	PUFA	UFA[3]	n-6	n-6:3[4]
Treatment[5]										
Control	8.86	0.17	0.57	0.09	0.07	48.58	4.83	53.49	3.81	37.25
LALF	8.82	0.17	0.56	0.09	0.07	50.35	4.58	54.82	3.58	32.96
HALF	8.54	0.18	0.60	0.09	0.07	49.98	4.68	54.68	3.62	34.20
LSTALK	7.93	0.17	0.63	0.09	0.08	50.32	4.70	54.99	3.62	33.56
HSTALK	8.54	0.17	0.60	0.09	0.08	50.51	4.70	55.14	3.65	36.62
LSIL	8.87	0.17	0.59	0.10	0.07	50.37	5.14	55.49	4.09	41.03
HSIL	8.79	0.17	0.59	0.11	0.07	49.16	5.49	54.53	4.48	45.76
SEM	0.67	0.01	0.03	0.01	0.01	0.77	0.26	0.73	0.26	3.27
$P > F$	0.917	0.947	0.558	0.209	0.602	0.304	0.148	0.350	0.112	0.067
Location										
Nebraska	8.40	0.17	0.61	0.09	0.07	50.43[y]	4.82	55.22	3.76	37.41
South Dakota	8.84	0.17	0.58	0.10	0.07	49.37[z]	4.93	54.25	3.91	37.27
SEM	0.38	0.005	0.01	0.004	0.003	0.40	0.14	0.39	0.14	1.78
$P > F$	0.422	0.261	0.151	0.321	0.613	0.048	0.559	0.068	0.430	0.951

[y,z]Values containing the same superscript within a column do not differ statistically ($P > 0.050$).
[1]Fatty acids are expressed as a percentage of total fatty acid methyl esters.
[2]Unidentified CLA isomer.
[3]Unsaturated fatty acids.
[4]n-6:n-3 ratio.
[5]LALF = low alfalfa; HALF = high alfalfa; LSTALK = low corn stalks; HSTALK = high corn stalks; LSIL = low corn silage; HSIL = high corn silage.

of corn stalks had significantly lower levels of 16:0 when compared with the control. However, cattle finished on low amounts of corn stalks and alfalfa hay (regardless of level) were similar to the control. A significant ($P = 0.030$) diet × source interaction was noted for 17:0. For cattle finished on low amounts of corn stalks, the i.m. fat of cattle within this diet from SD had significantly ($P = 0.005$) greater amount of 17:0 compared with cattle from NE. Conversely, cattle finished on high amounts of corn silage from NE had more ($P = 0.031$) 17:0 when compared with cattle from SD finished on high amounts of corn silage (data not shown). Significant ($P \leq 0.046$) dietary effects were observed for 18:1(n-9) and 18:2(n-6). Cattle finished on the low amounts of alfalfa and corn stalks had greater amounts of 18:1(n-9) in the i.m. fat when compared with the control but had smaller amounts of 18:2(n-6) (Table 8). Additionally, cattle finished on low amounts of alfalfa had significantly ($P \leq 0.050$) lower levels of 20:4(n-6) and 22:5(n-3) when compared with the other diets (Table 9). Cattle from

Table 6. Least squares means for main effects of SFA for i.m. fat[1]

Item	10:0	12:0	13:0	14:0	15:0	iso 16:0	16:0
Treatment[2]							
Control	0.04	0.07	0.017	3.23	0.58	0.95	25.12[c]
LALF	0.04	0.07	0.015	3.11	0.57	0.74	24.59[c]
HALF	0.04	0.07	0.005	3.05	0.53	0.88	24.41[cde]
LSTALK	0.04	0.07	0.001	3.04	0.57	0.79	24.59[c]
HSTALK	0.03	0.06	0.016	2.93	0.55	0.93	23.83[e]
LSIL	0.03	0.06	0.002	3.03	0.54	1.04	24.08[de]
HSIL	0.04	0.06	0.009	3.01	0.57	0.95	24.10[de]
SEM	0.01	0.01	0.007	0.11	0.02	0.07	0.28
$P > F$	0.600	0.577	0.477	0.423	0.535	0.062	0.011
Location							
Nebraska	0.04	0.07	0.02[y]	3.01	0.56	0.88	24.24
South Dakota	0.03	0.07	0.01[z]	3.11	0.57	0.92	24.54
SEM	0.004	0.004	0.003	0.05	0.01	0.04	0.15
$P > F$	0.837	0.981	0.049	0.187	0.405	0.474	0.160

[c–e]Values containing the same superscript within a column do not differ statistically ($P > 0.050$).
[y,z]Values containing the same superscript within a column do not differ statistically ($P > 0.050$).
[1]Fatty acids are expressed as a percentage of total fatty acid methyl esters.
[2]LALF = low alfalfa; HALF = high alfalfa; LSTALK = low corn stalks; HSTALK = high corn stalks; LSIL = low corn silage; HSIL = high corn silage.

Table 7. Least squares means for main effects of saturated fatty acids for i.m. fat[1]

Item	iso 18:0	18:0	19:0	20:0	SFA
Treatment[2]					
Control	0.57	12.74	0.12	0.10	44.82
LALF	0.45	12.94	0.12	0.09	44.37
HALF	0.58	12.73	0.12	0.09	43.78
LSTALK	0.48	12.81	0.11	0.12	44.08
HSTALK	0.60	13.36	0.13	0.09	44.04
LSIL	0.56	12.89	0.11	0.08	43.71
HSIL	0.61	12.98	0.12	0.09	44.06
SEM	0.05	0.31	0.01	0.01	0.25
$P > F$	0.258	0.691	0.784	0.428	0.390
Location					
Nebraska	0.52	13.04	0.12	0.09	44.04
South Dakota	0.58	12.81	0.12	0.09	44.21
SEM	0.03	0.18	0.01	0.01	0.04
$P > F$	0.153	0.374	0.970	0.680	0.616

[1]Fatty acids are expressed as a percentage of total fatty acid methyl esters; 24:0 was not detected.
[2]LALF = low alfalfa; HALF = high alfalfa; LSTALK = low corn stalks; HSTALK = high corn stalks; LSIL = low corn silage; HSIL = high corn silage.

NE had significantly ($P = 0.020$) greater amounts of CLA in the i.m. fat when compared with SD cattle (Table 10). Cattle finished on low amounts of alfalfa and corn stalks had the greatest amounts ($P < 0.050$) of MUFA, whereas cattle finished on corn silage (regardless of level) had the greatest amount ($P < 0.050$) of PUFA and n-6 fatty acids (Table 10). For unsaturated fatty acids, a significant ($P = 0.033$) diet × source interaction was observed (data not shown). Cattle finished on low amounts of corn silage from NE had greater ($P = 0.046$) amounts of unsaturated fatty acids in i.m. fat compared with cattle finished on the same diet from SD. However, cattle finished on high amounts of corn silage from SD had more ($P = 0.012$) unsaturated fatty acids compared with cattle finished on the same diet from NE.

Sensory Analysis. Significant diet effects were observed (Table 11) for muscle fiber tenderness ($P = 0.014$) and juiciness ($P = 0.002$) while connective tissue amount was approaching significance ($P = 0.068$). Cattle finished on low amounts of alfalfa and corn stalks were the most tender and most juicy when compared with the other diets. Additionally, these diets tended to have the least amount of detectable connective tissue, which probably contributed to the increased tenderness of these dietary treatments. No dietary effect was noted for off-flavor intensity ($P = 0.819$). Source effects for muscle fiber tenderness, connective tissue amount, and off-flavor inten-

Table 8. Least square means for main effects of unsaturated fatty acids for i.m. fat[1]

Item	14:1 (n-5)	16:1 (n-7)	17:1 (n-7)	18:1 (n-9)	*cis* 18:1 (n-7)	18:2 (n-6)	18:3)n-3)	20:1 (n-9)	20:2 (n-6)	20:3 (n-6)
Treatment[2]										
Control	0.70	2.86	0.98	29.85^{ef}	1.93	6.19^{de}	0.09	0.33	0.08	0.36
LALF	0.70	3.04	0.95	31.52^{d}	1.96	5.50^{e}	0.10	0.31	0.07	0.32
HALF	0.70	3.06	0.90	31.07^{de}	2.09	6.14^{de}	0.11	0.29	0.08	0.38
LSTALK	0.63	3.02	1.03	31.67^{d}	2.02	5.66^{e}	0.10	0.34	0.08	0.33
HSTALK	0.65	2.82	0.98	30.65^{def}	2.02	6.26^{de}	0.10	0.31	0.05	0.37
LSIL	0.71	2.93	1.02	30.33^{def}	2.05	7.00^{d}	0.11	0.30	0.07	0.36
HSIL	0.69	2.82	0.93	29.46^{f}	1.99	6.95^{de}	0.10	0.31	0.07	0.39
SEM	0.04	0.11	0.05	0.58	0.05	0.39	0.01	0.02	0.01	0.02
$P > F$	0.722	0.419	0.370	0.044	0.193	0.046	0.679	0.672	0.422	0.417
Location										
Nebraska	0.66	2.89	0.97	30.83	1.99	6.16	0.10	0.31	0.07	0.35
South Dakota	0.70	2.98	0.97	30.47	2.03	6.32	0.10	0.31	0.07	0.37
SEM	0.02	0.06	0.02	0.29	0.02	0.20	0.01	0.01	0.01	0.01
$P > F$	0.138	0.269	0.793	0.374	0.184	0.571	0.663	0.937	0.899	0.244

[d–f]Values containing the same superscript within a column do not differ statistically ($P > 0.050$).
[1]Fatty acids are expressed as a percentage of total fatty acid methyl esters; 18:3(n-6) was not detected.
[2]LALF = low alfalfa; HALF = high alfalfa; LSTALK = low corn stalks; HSTALK = high corn stalks; LSIL = low corn silage; HSIL = high corn silage.

Table 9. Least squares means for main effects of unsaturated fatty acids for i.m. fat[1]

Item	20:4 (n-6)	20:5 (n-3)	22:4 (n-6)	22:5 (n-3)
Treatment[2]				
Control	1.18[c]	0.13	0.16	0.28[cd]
LALF	0.86[d]	0.10	0.12	0.21[e]
HALF	1.12[cd]	0.11	0.18	0.28[cd]
LSTALK	0.95[cd]	0.12	0.14	0.24[de]
HSTALK	1.23[c]	0.12	0.17	0.28[cd]
LSIL	1.23[c]	0.11	0.17	0.31[c]
HSIL	1.23[c]	0.13	0.18	0.28[cd]
SEM	0.10	0.02	0.02	0.02
$P > F$	0.050	0.749	0.131	0.018
Location				
Nebraska	1.06	0.11	0.15	0.26
South Dakota	1.16	0.12	0.17	0.27
SEM	0.06	0.01	0.01	0.01
$P > F$	0.215	0.633	0.301	0.339

[c–e]Values containing the same superscript within a column do not differ statistically ($P > 0.050$).
[1]Fatty acids are expressed as a percentage of total fatty acid methyl esters.
[2]LALF = low alfalfa; HALF = high alfalfa; LSTALK = low corn stalks; HSTALK = high corn stalks; LSIL = low corn silage; HSIL = high corn silage.

sity were not significant ($P \geq 0.241$). However, steaks of cattle from SD were significantly juicer than steaks of cattle from NE ($P = 0.019$; Table 11). No significant dietary or source effects were observed for the liver-like, metallic, sour, charred, or oxidized off-flavors ($P \geq 0.169$), but significant dietary ($P = 0.006$) and source ($P = 0.023$) effects were reported for bloody notes (Table 12). However, cattle finished on low amounts of corn stalks had 3 times as many panelists indicate liver-like off-flavor when compared with the other diets. Cattle finished on the low amounts of alfalfa had the most bloody notes, whereas cattle finished on the control, high amounts of alfalfa and corn stalks, and silage diets had the lowest bloody notes. Additionally, cattle from SD had greater bloody notes than cattle from NE. A significant ($P < 0.001$) diet × source interaction was observed for bitter

Table 10. Least squares means for main effects of unsaturated, *trans*, polyunsaturated, n-6, and n-3 fatty acids for i.m. fat[1]

Item	18:1 *trans*	18:2 (n-6 *trans*)	CLA *cis*-9, *trans*-11	CLA *trans*-10, *cis*-12	CLA[2]	MUFA	PUFA	n-6	n-3	n-6:3[3]
Treatment[4]										
Control	6.65	0.12	0.47	0.07	0.06	43.30[g]	9.17[ef]	7.96[ef]	0.49	16.55
LALF	6.88	0.11	0.49	0.07	0.04	45.20[e]	7.98[f]	6.86[f]	0.41	17.26
HALF	6.56	0.13	0.43	0.04	0.04	44.45[efg]	9.00[f]	7.87[ef]	0.50	16.88
LSTALK	6.30	0.13	0.46	0.05	0.05	45.04[ef]	8.33[f]	7.17[f]	0.45	16.38
HSTALK	6.45	0.12	0.44	0.03	0.06	43.85[fg]	9.16[ef]	8.04[ef]	0.50	16.93
LSIL	6.53	0.10	0.44	0.05	0.04	43.89[efg]	9.98[e]	8.81[e]	0.54	18.28
HSIL	7.08	0.11	0.47	0.07	0.06	43.61[g]	10.04[e]	8.82[e]	0.51	18.79
SEM	0.40	0.01	0.03	0.01	0.01	0.51	0.51	0.50	0.04	1.42
$P > F$	0.818	0.332	0.760	0.218	0.917	0.040	0.034	0.039	0.218	0.826
Location										
Nebraska	6.60	0.11	0.45	0.06	0.06[y]	44.30	8.95	7.79	0.48	17.16
South Dakota	6.67	0.12	0.46	0.05	0.04[z]	44.08	9.23	8.07	0.49	17.43
SEM	0.23	0.01	0.01	0.01	0.01	0.26	0.25	0.25	0.02	0.73
$P > F$	0.837	0.638	0.580	0.793	0.020	0.536	0.415	0.410	0.603	0.786

[e–g]Values containing the same superscript within a column do not differ statistically ($P > 0.050$).
[y,z]Values containing the same superscript within a column do not differ statistically ($P > 0.050$).
[1]Fatty acids are expressed as a percentage of total fatty acid methyl esters.
[2]Unidentified isomer of CLA.
[3]n-6:n-3 ratio.
[4]LALF = low alfalfa; HALF = high alfalfa; LSTALK = low corn stalks; HSTALK = high corn stalks; LSIL = low corn silage; HSIL = high corn silage.

Table 11. Least squares means for main effects for muscle fiber tenderness, connective tissue amount, juiciness, and off-flavor intensity

Item	Muscle fiber tenderness[1]	Connective tissue amount[2]	Juiciness[3]	Off-flavor intensity[4]
Treatment[5]				
Control	5.14^{g}	5.05	4.71^{gh}	2.27
LALF	5.61^{f}	5.40	5.64^{f}	2.36
HALF	5.04^{g}	4.91	4.52^{h}	2.29
LSTALK	5.59^{f}	5.41	5.04^{g}	2.41
HSTALK	5.11^{g}	5.05	4.72^{gh}	2.36
LSIL	5.22^{g}	5.25	4.81^{g}	2.30
HSIL	5.21^{g}	5.06	4.68^{gh}	2.27
SEM	0.15	0.14	0.13	0.09
$P > F$	0.014	0.068	0.002	0.819
Location				
Nebraska	5.23	5.23	4.74^{z}	2.31
South Dakota	5.31	5.10	5.01^{y}	2.34
SEM	0.08	0.08	0.09	0.05
$P > F$	0.465	0.241	0.019	0.675

$^{f–h}$Mean values within a column and followed by the same letter are not significantly different ($P > 0.050$).
^{y,z}Mean values within a column and followed by the same letter are not significantly different ($P > 0.050$).
[1]Muscle fiber tenderness: 1 = extremely tough; 8 = extremely tender.
[2]Connective tissue amount: 1 = abundant amount; 8 = no connective tissue.
[3]Juiciness: 1 = extremely dry; 8 = extremely juicy.
[4]Off-flavor intensity: 1 = no off-flavor; 8 = extreme off-flavor.
[5]LALF = low alfalfa; HALF = high alfalfa; LSTALK = low corn stalks; HSTALK = high corn stalks; LSIL = low corn silage; HSIL = high corn silage.

notes (data not shown). Within the control diet, cattle from SD had greater bitterness notes than cattle from NE ($P = 0.002$). Conversely, within the low alfalfa and high corn stalks diets, cattle from NE were more bitter than cattle from NE ($P \leq 0.005$).

Correlation coefficients between chemical attributes and the liver-like off-flavor were calculated (Table 13). Subcutaneous adipose tissue of 18:2(n-6 *trans*) were inversely ($P = 0.037$; r = –0.17) related with liver-like off-flavor, whereas s.c. proportions of 20:1(n-9) ($P = 0.001$; r = 0.21) and CLA *cis*-9, *trans*-11 ($P = 0.046$; r = 0.16) were directly related. Also, pH ($P = 0.076$; r = 0.14) tended to be directly related, whereas s.c. proportions of 20:4(n-6) ($P = 0.088$; r = –0.14) and i.m. proportions 22:4(n-6) ($P = 0.066$; r = –0.15) were inversely related to the liver-like off-flavor.

Table 12. Least squares means for main effects for livery-like, metallic, sour, charred, oxidized, and bloody

Item	Liver-like[1]	Metallic[1]	Sour[1]	Charred[1]	Oxidized[1]	Bloody[1]
Treatment[2]						
Control	2.10	61.62	43.87	9.79	21.19	14.98^{e}
LALF	3.13	63.40	41.68	6.12	19.42	34.88^{c}
HALF	2.09	64.50	38.10	9.72	19.39	19.69^{de}
LSTALK	9.14	58.52	35.39	5.35	19.93	25.32^{cd}
HSTALK	2.52	50.85	42.64	10.46	27.16	14.41^{e}
LSIL	2.98	58.79	43.54	11.14	24.13	19.88^{de}
HSIL	1.99	52.21	42.04	5.05	21.45	18.22^{de}
SEM	3.61	4.54	4.36	3.93	3.99	4.15
$P > F$	0.670	0.169	0.720	0.745	0.651	0.006
Location						
Nebraska	3.52	56.67	42.63	9.94	23.03	17.63^{z}
South Dakota	3.32	60.44	39.44	6.53	20.59	24.48^{y}
SEM	1.85	2.51	2.37	2.02	2.09	2.13
$P > F$	0.940	0.274	0.341	0.224	0.397	0.023

$^{c–e}$Mean values within a column and followed by the same letter are not significantly different ($P > 0.050$).
^{y,z}Mean values within a column and followed by the same letter are not significantly different ($P > 0.050$).
[1]Off-flavors are expressed as a percentage of panelists that identified the off-flavor.
[2]LALF = low alfalfa; HALF = high alfalfa; LSTALK = low corn stalks; HSTALK = high corn stalks; LSIL = low corn silage; HSIL = high corn silage.

Table 13. Correlation coefficients between chemical attributes and the liver-like off-flavor

Item	r	$P > F$
18:2 (n-6*t*)[1]	–0.17	0.037
20:1 (n-9)[1]	0.21	0.001
CLA *cis*-9, *trans*-11[1]	0.16	0.046
20:4 (n-6)[1]	–0.14	0.088
22:4 (n-6)[2]	–0.15	0.066
pH	0.14	0.076

[1]Subcutaneous adipose tissue.
[2]Intramuscular adipose tissue.

DISCUSSION

Evaluation of geographical source as a possible source of variation in chemical and sensory attributes of beef has received little attention in the literature. Results from this study indicate that fatty acid profiles were affected more than the sensory profile of beef, because cattle source only affected bloody and bitter notes. Cattle were purchased in sale barns; therefore, it is difficult to hypothesize what might be causing these differences. Possible differences in forage types during weaning could play a role; however, those effects most likely would have been negligible due to being on a finishing diet for 139 d and thus probably occurred before entering the trial. Melton et al. (1982) noted that fatty acid profiles also change as days on corn increase. Specifically, 14:0, 14:1, 15:0, 16:1, 17:0, 17:1, 18:0, and 18:1 significantly increase from 0 d to 112 d on corn, whereas 18:0 and 18:2 decrease.

Others have conducted research on distillers grains and roughage. Although analyses were conducted on the musculus longissimus lumborum, Shand et al. (1998) reported that cattle finished on wheat-based distillers grains had similar moisture and pH values as reported here, but percentage fat values reported here were approximately 24% greater, which could be due to the source of distillers grains (corn vs. wheat) or muscle differences. Mills et al. (1992) reported no statistical differences of i.m. fatty acid levels from cattle finished on diets containing shelled corn with either 40% corn silage or 40% alfalfa haylage. This could be due to muscle differences, because Mills et al. (1992) used the LM. Additionally, levels of roughage in the diet and differences in quantification of fatty acids could have also played a role. Mills et al. (1992) only quantified 14:0, 16:0, 16:1(n-7), 18:0, 18:1(n-9), and 18:2(n-6), whereas we quantified many more. Baublits et al. (2006) reported that cattle finished on fescue or orchard grass in addition to pelleted soy had significantly greater amounts of 16:0 and 18:1(n-9) but smaller amounts of 15:0, 16:1(n-7), 18:3(n-3), and 20:4(n-6) when compared the control diet, which consisted of only tall fescue. However, results from the current study indicate minor changes in the aforementioned fatty acids, which are probably due to lower levels of roughage inclusion. Although cattle from this study were fed a constant amount of WDGS (30%), Mello et al. (2007) reported that cattle finished on 30% WDGS had significantly greater amounts of 18:0, 18:2(n-6), 20:0, CLA *cis*-9, *trans*-11, *trans* fatty acids, n-6 fatty acids, and greater n-6:n-3 ratio but smaller amounts of 16:1(n-7), 18:1(n-9), and *cis* 18:1(n-7) when compared with cattle not finished on WDGS.

Cattle finished on corn silage also had greater amounts of PUFA, which can increase lipid oxidation and decrease consumer acceptability (Kanner, 1994). The current study did not include retail display, so oxidation in the form of malonaldehyde was not measured. However, ORP was measured, but no significant diet or source effects were noted. Oxidation-reduction potential is a measure of the total oxidative or reducing capacity of the meat system, whereas the thiobarbituric acid assay is a measure of malonaldehyde. Because cattle finished on silage (regardless of level) had greater levels of PUFA, muscle tissue from these animals would be expected to have greater susceptibility to lipid oxidation; therefore, vitamin E in the ration would likely be beneficial.

Results from this study indicate that cattle finished on low levels of alfalfa and corn stalks were significantly more tender and juicier when compared the other diets. Mills et al. (1992) found no statistical differences in hardness, juiciness, number of chews, sustained juiciness, or resistance of the bolus. Baublits et al. (2006) reported that cattle finished on fescue or orchard grass with soyhull supplementation had significantly lower grassy aromatics when compared with cattle finished solely on fescue grass. Juiciness, tenderness, connective tissue, or other aromatics, including livery or aftertastes, did not differ. In the current study, cattle finished on low levels of alfalfa and corn stalks had significantly greater bloody notes. Miller (2001) reported that beef with a pH above 5.6, lower degrees of doneness, and beef from older animals tend to have greater bloody notes. The pH values ranged from 5.58 to 5.68, were cooked to the same degree of doneness, and were the same relative age. Therefore, the increase in bloody notes from beef finished on low amounts of alfalfa or corn stalks may be due to pH. Others have noted no differences in flavor with corn silage or alfalfa addition to the diet (Prior et al., 1977; Harrison et al., 1978).

The current study reveals that pH tends to have a positive correlation with liver-like off-flavor. Meisinger et al. (2006) reported that 55% of the variation of the liver-like off-flavor in the musculus rectus femoris was due to heme-Fe content and pH. 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. Our results indicate that individual s.c. fatty acids play a significant role in the development of the liver-like off-flavor. Specifically, 18:2(n-6 *trans*) might have played an important role due to its negative association with liver-like off-flavor in relation to the trend reported by Belk et al. (1993). Others have also

indicated that fatty acids play an important role in the development of the liver-like off-flavor. Camfield et al. (1997) reported 18:1(n-7) and 20:2(n-6) were related to the liver-like off-flavor, whereas Yancey et al. (2006) reported that 18:1(n-9 *trans*), 16:1, and 17:1 were negatively related in the musculus gluteus medius and individually explained approximately 20% of the variation in the liver-like off-flavor, whereas 18:1(n-9) 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 musculus psoas major. In the current study, all fatty acids related to the liver-like off-flavor were polyunsaturated, which leads us to hypothesize that lipid oxidation may play a pertinent role in the development of the liver-like off-flavor. However, Yancey et al. (2006) reported that lipid oxidation, as quantified by the presence of malonaldehyde, had minimal effects on the liver-like off-flavor, whereas Hodgen (2006) indicated a strong relationship between liver-like off-flavor notes and primary oxidation by-products of oleic, linoleic, and arachidonic acids as identified by mass spectrometry. Additionally, ORP was not significantly correlated with the liver-like off-flavor (P = 0.121; r = 0.12). Perhaps the thiobarbituric acid and ORP procedures are not sensitive enough to measure oxidation. Future aging studies that utilize mass spectrometry might prove beneficial in advancing our understanding of the cause of liver-like off-flavor.

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