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Estimation of relationships between mineral concentration and fatty acid composition of longissimus muscle and beef palatability traits[1]

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ABSTRACT: The objective of this study was to determine the influence of beef LM nutrient components on beef palatability traits and evaluate the impact of USDA quality grade on beef palatability. Longissimus muscle samples from related Angus cattle (n = 1,737) were obtained and fabricated into steaks for trained sensory panel, Warner-Bratzler shear force (WBSF), lipid oxidation measured by thiobarbituric acid reactive substances (TBARS), fatty acid, and mineral composition analysis. Pearson phenotypic correlations were obtained by the correlation procedure of SAS. Beef palatability data were analyzed by the GLM procedure of SAS with USDA quality grade as the main effect. Specific mineral concentrations did not demonstrate strong correlations with WBSF or sensory traits (r = −0.14 to 0.16). However, minerals appeared to have a stronger relationship with flavor; all minerals evaluated except Ca and Mn were positively correlated ($P < 0.05$) with beef flavor. Stearic acid (C18:0), C18:2, C20:4, and PUFA were negatively correlated ($P < 0.05$) with all 3 panelist tenderness traits (r = −0.09 to −0.22) and were positively correlated ($P < 0.05$) with WBSF (r = 0.09 to 0.15). The MUFA were positively correlated ($P < 0.05$) with panelist tenderness ratings (r = 0.07 to 0.10) and negatively associated ($P < 0.05$) with WBSF (r = −0.11). The strongest correlations with juiciness were negative relationships ($P < 0.05$) with C18:2, C18:3, C20:4, and PUFA (r = −0.08 to −0.20). Correlations with beef flavor were weak, but the strongest was a positive relationship with MUFA (r = 0.13). Quality grade affected ($P < 0.05$) WBSF, TBARS, and all trained sensory panel traits, except livery/metallic flavor. As quality grade increased, steaks were more tender ($P < 0.05$), as evidenced by both WBSF and sensory panel tenderness ratings. Prime steaks were rated juiciest ($P < 0.05$) by panelists, whereas Select and Low Choice were similarly rated below Top Choice for sustained juiciness. Quality grade influenced ($P < 0.05$) beef flavor, but not in a linear fashion. Although there were significant correlations, these results indicate tenderness, juiciness, and flavor are not strongly influenced by individual nutrient components in beef LM. Furthermore, the positive linear relationships between USDA quality grade and beef palatability traits suggest quality grade is still one of the most valuable tools available to predict beef tenderness.

Key words: beef, correlation, nutrient composition, palatability, quality grade, trained sensory panel

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INTRODUCTION

Today's typical consumers are health-conscious individuals that are becoming increasingly aware of the amount and type of fats they consume. Red meat is often perceived as a fatty protein source with certain health risks associated with its consumption. This stems from the total fat content, SFA composition, and cholesterol found in beef and their relationship with obesity, certain types of cancer, and cardiovascular diseases (Fernandez-Gines et al., 2005). Beef could be viewed more favorably from a human health standpoint if strategies could be applied to reduce SFA content while increasing the concentration of beneficial PUFA, especially n-3 PUFA and CLA (Scollan et al., 2006).

Beef producers strive to produce a high-quality product that meets consumer needs in a cost-effective manner. Fatty acid profiles can be altered through the diet to increase the concentration of PUFA (Realini et al., 2004; Faucitano et al., 2008). De Smet et al. (2004) showed genetic factors also influence fatty acid composition. Additionally, fats are not the only nutrients

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that affect the nutritional value of beef. Minerals such as iron are required in the human diet, and beef is an excellent source of iron, yet the consistency of iron content in beef products is highly variable (Duan et al., 2009). Therefore, identification of genetic markers that would allow producers to select beef for optimum nutritional values with respect to fatty acids, minerals, and vitamins, without sacrificing performance or product quality, could ultimately increase value and consumer satisfaction of beef.

Ideally, producers would like to select cattle with a greater propensity to marble, whereas some consumers favor decreased quantity of SFA due to their perceived negative effect on human health. However, researchers must first understand the relationship between fat content, fatty acid composition, and palatability to ensure tenderness, flavor, and juiciness are not compromised when selecting for cattle with enhanced nutritional composition. Most fatty acids have little or variable effect on beef palatability, but oleic acid (18:1) is consistently correlated with beef flavor in a positive manner (Dryden and Marchello, 1970; Westerling and Hedrick, 1979; Melton et al., 1982). Therefore, the goal of the present study was to characterize the relationship of individual fatty acids and minerals of beef LM with tenderness and sensory characteristics as well as lipid oxidation to understand how they affect product quality. In addition, the relationship of USDA quality grade on beef palatability was evaluated.

MATERIALS AND METHODS

The Oklahoma State University Institutional Review Board approved the experimental protocol used in this study.

Animal Resources

Three separate but related beef cattle resources were used in this study. The Iowa State University Research Herd has been selected for increased intramuscular fat (**IMF**) since 1996. Approximately 200 animals were slaughtered from each calf crop, and data were collected on a portion (n = 549) of these from 2007 through 2009. A related herd exists in California that has been selected for increased IMF. In 2008, 358 animals were slaughtered by Harris Ranch for use in this study. Another related herd exists in Oklahoma that has been selected for increased IMF, ribeye area, and retail product, and decreased backfat since 1993. In 2008, cattle (n = 451) were finished and slaughtered in Texas. In 2009, cattle from this herd (n = 389) were finished and slaughtered in Colorado.

Slaughter and Data Collection

Cattle were slaughtered at commercial facilities in Iowa, California, Texas, or Colorado. Trained personnel obtained carcass measurements, including HCW, ribeye area, marbling score (**MS**), percentage KPH, fat thickness, USDA calculated yield grade, and USDA quality grade based primarily on MS (USDA, 1997). The scale used for data entry of MS was 3.0 = traces, 4.0 = slight, 5.0 = small, 6.0 = modest, 7.0 = moderate, 8.0 = slightly abundant, and 9.0 = moderately abundant.

Sample Collection and Preparation

Sample collection was unique in each plant. Carcasses were fabricated according to Institutional Meat Purchasing Specifications (**IMPS**; USDA, 1996). Rib sections were obtained from each carcass in Iowa, California, and Colorado. In Texas, strip loins (IMPS #180) were collected from each carcass. Samples were collected, vacuum-packaged, boxed, and transported to the Iowa State University Meat Laboratory, Ames, or the Oklahoma State University (**OSU**) Food and Agricultural Products Center, Stillwater, for fabrication. Two 1.27-cm steaks were removed for nutrient composition and thiobarbituric acid reactive substances (**TBARS**). External fat and connective tissue were removed for the nutrient composition and TBARS steaks. Two 2.54-cm steaks were then removed for Warner-Bratzler shear force (**WBSF**) and sensory analysis. All steaks were vacuum packaged, aged for 14 d from the slaughter date at 2°C, and then frozen at −20°C for subsequent analysis. After samples were frozen, WBSF, sensory, and TBARS steaks fabricated in Iowa were transported to the OSU Food and Agricultural Products Center. Nutrient composition steaks were shipped frozen to the Iowa State University Meat Lab for analysis.

WBSF

The frozen steaks were allowed to thaw at 4°C for 24 h before cooking. Steaks were broiled in an impingement oven (XLT Impinger, model 3240-TS, BOFI Inc., Wichita, KS or Lincoln Impinger, model 1132-000-A, Lincoln Foodservice Products, Fort Wayne, IN) at 200°C to an internal temperature of 68°C. An Atkins AccuTuff 340 thermometer (Atkins Temtec, Gainesville, FL) was used to monitor temperature of steaks as they exited the oven. If they had not yet reached 68°C, they were returned to the conveyor until they reached 68°C. After cooking, steaks were cooled at 4°C for 18 to 24 h as recommended by the American Meat Science Association (AMSA, 1995). Six cores, 1.27-cm in diameter, were removed parallel to muscle fiber orientation and sheared once using a Warner-Bratzler head attached to an Instron Universal Testing Machine (model 4502, Instron Corporation, Canton, MS). The Warner-Bratzler head moved at a crosshead speed of 200 mm/min. Peak load (kg) of each core was recorded by an IBM PS2 (model 55 SX) using software provided by the Instron Corporation. Mean peak load (kg) was analyzed for each sample.

Sensory Analysis

Steaks were assigned a randomized number for sensory sessions and assigned to sensory panel session based on the randomized number. Steaks were allowed to thaw at 4°C for 24 h before cooking, cooked to 68°C as described above for WBSF, sliced into approximately 2.54 × 1.27 × 1.27 cm samples, and served warm to panelists.

Sensory attributes of each steak were evaluated by an 8-member trained panel consisting of OSU personnel. Panelists were trained for tenderness, juiciness, and 3 specific flavor attributes (Cross et al., 1978). Sensory sessions were conducted once or twice per day and contained 12 samples each. Samples were evaluated using a standard ballot from the American Meat Science Association (AMSA, 1995). Panelists evaluated samples in duplicate for initial (**IJ**) and sustained juiciness (**SJ**), initial (**IT**) and overall tenderness (**OT**), and amount of connective tissue (**CT**) using an 8-point scale. Panelists evaluated cooked beef flavor (**BF**), painty/fishy flavor (**PFF**), and livery/metallic flavor (**LMF**) intensity using a 3-point scale. For juiciness, the scale was 1 = extremely dry and 8 = extremely juicy. The scale used for IT and OT was 1 = extremely tough and 8 = extremely tender. The scale used for CT was 1 = abundant and 8 = none. The scale used for BF and off-flavor intensity was 1 = not detectable, 2 = slightly detectable, and 3 = strong.

During sessions, panelists were randomly seated in individual booths in a temperature and light controlled room. While being served, the panelists were under red filtered lights as suggested by the American Meat Science Association (AMSA, 1995). The 12 samples were served in a randomized order according to panelist. The panelists were provided distilled, deionized water, and unsalted crackers to cleanse their palate.

TBARS

Lipid oxidation was evaluated by TBARS using the modified method of Buege and Aust (1978). A 10-g sample was placed in a blender (model 51BL31, Waring Products Inc., Torrington, CT) and homogenized with 30 mL of cold deionized water. The mixture was transferred to a disposable tube and centrifuged for 10 min at 1,850 × *g*. Two milliliters of supernatant was extracted from the tube and placed in a disposable glass tube with 4 mL of thiobarbituric acid/trichloroacetic acid and 100 μL of butylated hydroxyanisol. Tubes were vortexed and then incubated in a boiling water bath (100°C) for 15 min, followed by 10 min in a cold water bath (15 to 20°C). After cooling, samples were centrifuged for 10 min at 1,850 × *g*. The absorbance was read at 531 nm using a Beckman spectrophotometer (model DU 7500, Beckman Instruments Inc., Brea, CA). A standard curve was generated for each day of analysis using 1,1,3,3-tetra-ethoxypropane. Lipid oxidation was measured in duplicate for each steak, and the average absorbance reading was used for each sample. Results were expressed as milligrams of malonaldehyde per kilogram of sample.

Nutrient Phenotype Collection

Nutrient composition samples were frozen and ground before fatty acid and mineral assays. An approximately 4-g sample was dried at 105°C for 18 to 20 h (AOAC, 2000). Longissimus muscle samples were prepared for mineral analyses using microwave digestion (MDS-2000, CEM, Matthews, NC). For LM digestion, 0.35 to 0.40 g of dry material was added to 5 mL of concentrated HNO_3 and 2 mL of 30% H_2O_2. Vessels were then placed in the microwave digestor, and power was applied for 45 min. Digested samples were transferred to volumetric flasks and diluted with deionized water. Samples were analyzed for mineral content using inductively coupled plasma-optical emission spectroscopy (Spectro Analytical Instruments, Fitchburg, MA) as outlined by AOAC (2000). Concentrations of phosphorus, potassium, sodium, calcium, copper, iron, magnesium, manganese, and zinc were calculated. To calculate the sample mineral concentration (mg/kg), the measured mineral concentration (mg/kg) was multiplied by the number of dilutions and divided by the sample weight (g). Phosphorus and potassium were diluted 250 times, and all other minerals were diluted 25 times. A standard was used for calibration between different groups, which consisted of 10 samples.

Total lipids were esterified from the LM samples with acetyl chloride/methanol for 1 h at 100°C (Christie, 1972). The solution was allowed to cool and neutralized with 6% potassium carbonate. Methyl esters were subsequently extracted in hexane. Fatty acid methyl esters were analyzed using a gas chromatograph (model 3900, Varian Analytical Instruments, Walnut Creek, CA) fitted with a fused silica capillary column (Supelco, Bellefonte, PA). The initial column temperature was 70°C and increased to 175°C at a rate of 13°C/min, followed by an increase to 215°C at a rate of 4°C/min. The total running time was 59 min. The initial injector temperature was 70°C and was programmed to increase to a final temperature of 220°C at a rate of 220°C/min. The detector was maintained at 220°C. Fatty acids were identified by evaluating the retention time against the GLC 461 standard obtained from Nu-Chek-Prep (Elysian, MN). Fatty acid composition was calculated using the peak areas on a percentage basis. The index of atherogenicity (**IA**) was calculated according to Ulbricht and Southgate (1991). The IA was designed to rank mixtures of fatty acids by their propensity to cause atherogenesis, as predicted from concentrations of individual fatty acids in the lipid. The IA is calculated as $[(C12{:}0 + 4(C14{:}0) + C16{:}0) \div (\Sigma MUFA + \Sigma PUFA)]$.

Table 1. Simple statistics for carcass traits of Angus cattle (n = 1,737)

Item	Mean	SD
HCW, kg	332.76	32.86
Fat thickness, mm	13.44	4.75
LM area, cm^2	80.19	7.58
KPH, %	2.01	0.35
USDA calculated yield grade	3.03	0.66
Marbling score[1]	6.05	0.98

[1]Marbling score: 3.0 = traces; 4.0 = slight; 5.0 = small; 6.0 = modest; 7.0 = moderate; 8.0 = slightly abundant; 9.0 = moderately abundant.

Statistical Analysis

All statistical analyses were performed using SAS (SAS Inst. Inc., Cary, NC). The MEANS procedure was used to produce descriptive statistics for carcass data. The correlation procedure was used to generate Pearson phenotypic correlations to determine the relationship between MS, WBSF, trained sensory panel traits, TBARS, mineral concentration, and fatty acid composition. Unadjusted means and SD were obtained through PROC CORR of SAS. Significance was determined at $P < 0.05$ for analyses.

Finally, data were analyzed to determine the relationship between USDA quality grade and instrumental tenderness and trained sensory panel traits. Data were edited by removing USDA Standard carcasses because sample size was insufficient for this quality grade. Dependent variables were tested for significance by ANOVA using PROC GLM. Least squares means were computed and separated ($P < 0.05$) using the PDIFF option of GLM. The statistical model included a fixed effect of USDA quality grade.

RESULTS AND DISCUSSION

Carcass traits are reported in Table 1. The average MS was 6.05 (range 3.60 to 9.20), which corresponds to modest marbling. This range corresponds with traces to moderately abundant marbling. As noted previously, cattle were slaughtered at multiple facilities, and therefore, various trained personnel collected the carcass data for each facility. This could potentially affect results, particularly MS; however, only highly trained evaluators were responsible for subjectively assigning MS at each facility.

Descriptive statistics for WBSF, sensory traits, and TBARS are shown in Table 2. The average WBSF value was 3.67 (range 2.12 to 8.47). From the initial rating of juiciness, SJ dropped from 5.38 to 5.00. The average panelist rating for IT (5.82; range 3.37 to 7.63) and OT (5.79; range 3.00 to 7.38) was slightly tender, whereas panelists detected a slight amount (5.88; range 3.13 to 7.25) of CT on average. The BF intensity average was 2.50. The average PFF and LMF were 1.13 and 1.04, respectively.

Table 2. Simple statistics for Warner-Bratzler shear force (WBSF), trained sensory panel traits, and thiobarbituric acid reactive substances (TBARS) of beef LM (n = 1,706)

Trait	Mean	SD
WBSF, kg	3.67	0.69
Initial juiciness[1]	5.38	0.51
Sustained juiciness[1]	5.00	0.50
Initial tenderness[1]	5.82	0.58
Overall tenderness[1]	5.79	0.59
Connective tissue[2]	5.88	0.59
Beef flavor[3]	2.50	0.23
Painty/fishy flavor[3]	1.13	0.17
Livery/metallic flavor[3]	1.10	0.12
TBARS,[4] mg/kg	0.14	0.04

[1]Scale: 1 = extremely dry, extremely tough; 8 = extremely juicy, extremely tender.

[2]Scale: 1 = abundant; 8 = none.

[3]Scale: 1 = not detectable; 3 = strong.

[4]Expressed as milligrams of malonaldehyde per kilogram of sample.

Unadjusted means for mineral concentration are provided in Table 3. Potassium was the most abundant mineral, followed by phosphorus, sodium, magnesium, zinc, calcium, and iron. Copper and manganese make up only a small proportion of the total mineral content. According to USDA (2010), the average beef top loin steak is composed of 3,540 μg of potassium, 2,110 μg of phosphorus, 570 μg of sodium, 240 μg of magnesium, 250 μg of calcium, 41 μg of zinc, 16.4 μg of iron, 0.8 μg of copper, and 0.1 μg of manganese per gram of meat. This population appears to have less than average phosphorus and calcium concentrations.

Descriptive statistics for fatty acid composition are presented in Table 4. Oleic acid (C18:1 *cis*-9) was the most abundant single fatty acid, constituting most of the MUFA concentration. Palmitic acid (C16:0) and stearic acid (C18:0) were the next most abundant fatty acids, followed by linoleic acid (C18:2), palmitoleic acid (C16:1), and myristic acid (C14:0). According to USDA (2010), C18:1 accounts for 45.5% of total fatty acids of beef top loin. Palmitic acid ranges between 27 to 28%, and stearic typically averages 15% of the total concen-

Table 3. Simple statistics for mineral concentration (micrograms of mineral per gram of wet meat) of beef LM

Trait, μg	n	Mean	SD
Calcium	1,737	37.19	20.55
Copper	1,478	0.73	0.70
Iron	1,725	14.46	3.18
Magnesium	1,738	265.40	42.47
Manganese	1,472	0.08	0.04
Phosphorus	1,738	2,022.00	285.39
Potassium	1,691	3,559.00	457.68
Sodium	1,737	509.77	92.70
Zinc	1,726	38.36	7.40

Table 4. Simple statistics for fatty acid composition (g/100 g of fatty acid) of beef LM (n = 1,592)

Trait[1]	Mean, %	SD
C14:0	2.66	0.68
C16:0	25.91	3.33
C16:1	3.35	0.79
C17:0	1.43	0.42
C17:1	1.14	0.39
C18:0	13.34	2.40
C18:1 *cis*-9	38.09	5.01
C18:1 *trans*-10/11	3.68	1.46
C18:1 *trans*-15	1.01	0.55
C18:2	3.94	1.27
C18:3[2]	0.19	0.17
C20:4	0.81	0.36
Other[3]	3.20	1.56
SFA	44.46	5.45
MUFA	48.57	6.03
PUFA	5.78	2.01
PUFA:SFA	0.13	0.05
MCFA (<C15:1)	3.95	0.93
LCFA	94.86	10.46
Σ n-3 fatty acids	0.63	1.01
Σ n-6 fatty acids	5.16	1.62
n-3:n-6 ratio	0.13	0.39
IA[4]	0.67	0.12

[1]MCFA = medium-chain fatty acids; LCFA = long-chain fatty acids.

[2]n-3 fatty acids.

[3]Other includes C10:0, C12:0, C13:0, C14:1, C15:0, C18:1*c*-11, C18:1*c*-12, C18:1*c*-13, C18:1*t*-6/9, C18:1*t*-12, CLA*c*-9/*t*-11, CLA*t*-10/*c*-12, C18:3n-6, C20:0, C20:1, C20:2, C20:3n-3, C20:3n-6, C20:5, C22:0, C22:1, C22:5, C22:6, C23:0, C24:0. *c* = *cis*; *t* = *trans*.

[4]Index of atherogenicity {[C12:0 + 4(C14:0) + C16:0] ÷ (ΣMUFA + ΣPUFA)}.

tration of fatty acids in beef top loin. The remaining fatty acids are present anywhere from <1 to 4%, with C18:2 representing 4.3%, C16:1 at 3.8%, C14:0 at 3.1%, and C18:3 accounting for 0.3% of the total proportion of fatty acids in beef top loin (USDA, 2010). The average SFA concentration was 44.46%. The average MUFA concentration was 48.57%, whereas PUFA averaged 5.78%. The USDA (2010) reported the average beef top loin steak consists of 45.3% SFA, 49.3% MUFA, and 5.3% PUFA. This population appears to have less SFA and greater PUFA concentrations than the national average, which is nutritionally desirable.

Correlations

Pearson correlations between MS, WBSF, sensory traits, and TBARS are provided in Table 5. Marbling score was correlated ($P < 0.05$) with WBSF, but that correlation was rather weak (r = −0.25). There were strong positive correlations ($P < 0.05$) between IT, OT, and CT, with the largest between IT and OT (r = 0.95). The sensory tenderness traits (IT, OT, and CT) had moderately strong associations ($P < 0.05$) with WBSF in the negative direction. This is in accordance with Shackelford et al. (1995), who found a strong relationship between peak load and OT for the LM when they compared instrumental tenderness and trained sensory panel tenderness scores. Furthermore, Shackelford et al. (1999) reported a strong negative correlation between WBSF and trained sensory panel (r = −0.72), and Rhee et al. (2004) reported strong negative correlations between WBSF and overall sensory panel tenderness (r = −0.74) and CT (r = −0.65). There was a strong positive correlation ($P < 0.05$) between IJ and SJ (r = 0.89). Beef flavor was correlated ($P < 0.05$) with PFF (r = −0.46) and LMF (r = −0.16), but the relationship with LMF was relatively weak. Thiobarbituric acid reactive substances were associated ($P < 0.05$) with BF (r = −0.07), PFF (r = −0.13), and LMF (r = −0.05), but those correlations were all weak.

The current findings agree with Smith et al. (1985), who found steaks from carcasses with greater MS had lesser shear force values and greater sensory panel ratings than steaks with decreased MS. Wheeler et al. (1994) found a similar relationship between MS, WBSF, and tenderness ratings, but did not find a relationship between BF and MS. In the current study, BF was not related ($P > 0.05$) to MS. Also, MS was correlated ($P < 0.05$) with IJ and SJ, but those relationships were relatively weak. However, Wheeler et al. (1994) found steaks with modest or moderate marbling were juicier than steaks with traces or slight marbling.

Table 5. Pearson correlations between marbling score (MS), Warner-Bratzler shear force (WBSF), trained sensory panel traits, and thiobarbituric acid reactive substances (TBARS) of beef LM (n = 1,706)

Item	WBSF	IJ	SJ	IT	OT	CT	BF	PFF	LMF	TBARS
MS	−0.25*	0.20*	0.23*	0.22*	0.23*	0.19*	−0.02	0.08*	0.02	0.01
WBSF, kg		−0.15*	−0.12*	−0.63*	−0.64*	−0.61*	−0.05*	0.01	−0.08*	−0.02
Initial juiciness (IJ)			0.89*	0.37*	0.30*	0.19*	−0.04	0.12*	0.11*	−0.12*
Sustained juiciness (SJ)				0.35*	0.31*	0.22*	−0.07*	0.09*	0.10*	−0.09*
Initial tenderness (IT)					0.95*	0.86*	−0.01	0.03	0.09*	−0.03
Overall tenderness (OT)						0.92*	0.00	−0.02	0.09*	0.01
Connective tissue (CT)							0.02	−0.08*	0.08*	0.03
Beef flavor (BF)								−0.46*	−0.16*	−0.07*
Painty/fishy flavor (PFF)									−0.06*	−0.13*
Livery/metallic flavor (LMF)										−0.05*

*Significant correlations ($P < 0.05$).

Campo et al. (2006) found significant correlations (r = 0.84) between TBARS and rancid (r = 0.84), beef (r = −0.80), metallic (r = −0.36), and livery flavors (r = −0.60), as well as overall liking (r = −0.84). The correlations in the present study between TBARS and flavor intensities were much weaker than those reported by Campo et al. (2006), and the relationship between PFF and TBARS was negative, which contradicts previous work. Whereas Campo et al. (2006) determined that a TBARS value of approximately 2 (expressed as milligrams of malonaldehyde per kilogram of lean muscle) could be set as a threshold for acceptability of oxidized beef, it should be noted that the TBARS values were well below 2 in this study, averaging 0.14 (Table 2). Samples in this study were aged until 14 d postmortem in a vacuum package and frozen immediately, leaving little opportunity for lipid oxidation. Overall, decreased TBARS values could explain why weak relationships were seen between TBARS and flavor intensities.

Table 6 summarizes the Pearson correlations between mineral concentrations and MS, WBSF, sensory traits, and TBARS. In general, specific mineral concentrations did not demonstrate strong relationships with WBSF, trained sensory panel traits, or TBARS. The strongest correlations were seen between minerals and TBARS, with the strongest between magnesium, phosphorus, potassium, and sodium. Although minerals can act as catalysts for lipid oxidation because antioxidant enzyme activities rely on certain trace minerals as cofactors (Al-Qudah et al., 2010), this may explain the favorable relationship observed between mineral concentration and TBARS in the current study. As the concentration of each mineral increased, TBARS values would decrease. All minerals, except calcium and manganese, were positively correlated ($P < 0.05$) with BF; however, these were all weak relationships. Cooper, manganese, and zinc were the only minerals that were not related to LMF, but again these were weak relationships. Every mineral except iron and zinc was negatively associated with ($P < 0.05$) WBSF; however, only sodium, manganese, and potassium were related to overall sensory tenderness.

Nour et al. (1983) found relationships between minerals and trained sensory panel traits; however, they are not consistent with the current results. Zinc and iron were positively related to flavor intensity and juiciness, but magnesium was negatively correlated with both traits. There were no significant relationships between tenderness and mineral concentration (Nour et al., 1983). In the current study, zinc and iron were positively associated with BF, although the relationships were weaker than those found by Nour et al. (1983). Moreover, there was no significant correlation between zinc and juiciness in the present study. Although Yancey et al. (2006) did not examine the LM, they did find liver flavor intensity increased and BF intensity decreased in the gluteus medius as iron content increased. However, livery flavor decreased as iron concentration increased in the psoas major. In the present study, both BF and LMF were positively correlated with iron. This discrepancy demonstrates the inconsistent relationship between iron content and beef, livery, or metallic flavors.

To estimate the extent to which lipid composition influenced beef palatability, correlations between fatty acid profiles and MS, WBSF, sensory traits, and TBARS were determined (Table 7). Marbling score was correlated ($P < 0.05$) with several individual fatty acids; however, the strongest relationships were observed with PUFA (r = −0.38). Specifically, linoleic acid (C18:2) and arachidonic acid (C20:4) exhibited moderately strong negative relationships with MS. Kazala et al. (1999) reported similar negative relationships between the concentration of C18:2 with MS, as well as C18:0.

Warner-Bratzler shear force was significantly correlated with several individual fatty acids, as well as MUFA (r = −0.11) and PUFA (r = 0.14). Saturated fatty acids, including C14:0, C17:0, and C18:0, had weak negative relationships ($P < 0.05$) with WBSF. A similar trend was observed for MUFA; C16:1, C17:1, C18:1 *cis*-9, and C18:1 *trans*-10/11 also exhibited weak negative correlations ($P < 0.05$) with WBSF. Polyunsaturated fatty acids, specifically C18:2 and C20:4, were positively related ($P < 0.05$) to WBSF, but these were weak correlations. Stearic acid (C18:0), linoleic

Table 6. Pearson correlations between mineral concentrations and marbling score, Warner-Bratzler shear force (WBSF), trained sensory panel traits, and thiobarbituric acid reactive substances (TBARS) of beef LM (n = 1,472)

Mineral	Marbling score	WBSF	Initial juiciness	Sustained juiciness	Initial tenderness	Overall tenderness	Connective tissue	Beef flavor	Painty/ fishy flavor	Livery/ metallic flavor	TBARS
Calcium	−0.01	−0.06*	0.03	0.02	0.03	0.04	0.07*	0.00	−0.04	0.05*	−0.08*
Copper	0.02	−0.06*	0.06*	0.02	0.06*	0.04	0.03	0.05*	0.01	0.02	−0.05
Iron	0.06*	−0.03	0.15*	0.11*	0.06*	0.04	0.03	0.14*	0.02	0.09*	−0.23*
Magnesium	−0.05*	−0.07*	0.13*	0.06*	0.06*	0.02	0.01	0.11*	0.09*	0.09*	−0.47*
Manganese	0.13*	−0.06*	0.06*	0.04	0.08*	0.06*	0.04	0.05	0.04	0.00	−0.16*
Phosphorus	−0.06*	−0.09*	0.09*	0.02	0.07*	0.04	0.05*	0.10*	0.04	0.09*	−0.39*
Potassium	−0.03	−0.14*	0.06*	−0.01	0.10*	0.05*	0.05*	0.13*	0.07*	0.07*	−0.36*
Sodium	0.04	−0.14*	0.16*	0.07*	0.17*	0.13*	0.10*	0.12*	0.08*	0.13*	−0.32*
Zinc	−0.03	0.02	0.08*	0.04	0.02	−0.01	−0.01	0.06*	0.02	0.04	−0.07*

*Significant correlations ($P < 0.05$).

Table 7. Pearson correlations between fatty acid concentration and marbling score, Warner-Bratzler shear force (WBSF), trained sensory panel traits, and thiobarbituric acid reactive substances (TBARS) of beef LM (n = 1,592)

Fatty acid	Marbling score	WBSF	Initial juiciness	Sustained juiciness	Initial tenderness	Overall tenderness	Connective tissue	Beef flavor	Painty/ fishy flavor	Livery/ metallic flavor	TBARS
C14:0	0.11*	−0.06*	−0.02	−0.02	0.04	0.07*	0.07*	0.05*	−0.07*	−0.01	0.04
C16:0	0.09*	−0.02	0.05*	0.06*	−0.01	0.00	−0.03	0.06*	0.00	−0.03	0.04
C16:1	0.15*	−0.09*	0.10*	0.10*	0.07*	0.06*	0.03	0.09*	−0.03	0.00	−0.06*
C17:0	0.00	−0.18*	0.03	0.03	0.11*	0.16*	0.18*	0.06*	0.11*	0.01	−0.17*
C17:1	−0.05*	−0.16*	−0.06*	−0.03	0.10*	0.16*	0.20*	0.01	−0.18*	−0.03	−0.10*
C18:0	−0.15*	0.09*	0.09*	0.07*	−0.09*	−0.13*	−0.18*	0.04	0.15*	−0.01	−0.06*
C18:1 *cis*-9	0.11*	−0.06*	0.11*	0.12*	0.05	0.06*	0.04	0.11*	−0.05	−0.04	0.00
C18:1 *trans*-10/11	−0.04	−0.14*	0.11*	0.04	0.13*	0.11*	0.07*	0.08*	0.04	0.11*	−0.25*
C18:1 *trans*-15	0.04	−0.03	0.17*	0.17*	0.07*	0.04	0.00	0.03	0.09*	0.02	−0.05
C18:2	−0.40*	0.15*	−0.12*	−0.14*	−0.20*	−0.22*	−0.21*	−0.07*	0.11*	0.01	−0.05*
C18:3[1]	0.05	0.03	−0.11*	−0.08*	−0.06*	−0.02	−0.01	−0.01	−0.10*	−0.06*	0.19*
C20:4	−0.46*	0.15*	−0.17*	−0.16*	−0.20*	−0.20*	−0.18*	−0.08*	0.00	−0.01	−0.01
Other[2]	−0.14*	0.00	−0.18*	−0.18*	−0.08*	−0.04	−0.01	−0.06*	−0.05*	0.02	0.07
SFA	−0.03	0.01	0.04	0.03	−0.05	−0.05	−0.07*	0.06*	0.05	−0.03	0.00
MUFA	0.14*	−0.11*	0.15*	0.14*	0.09*	0.10*	0.07*	0.13*	−0.04	0.00	−0.08*
PUFA	−0.38*	0.14*	−0.18*	−0.19*	−0.19*	−0.19*	−0.17*	−0.08*	−0.04	0.00	0.01
Σ n-3 fatty acids	−0.07*	0.02	−0.12*	−0.11*	−0.05*	−0.03	0.00	−0.06*	−0.07*	−0.03	0.07*
Σ n-6 fatty acids	−0.43*	0.15*	−0.14*	−0.17*	−0.21*	−0.22*	−0.21*	−0.07*	0.09*	0.02	−0.05

[1]n-3 fatty acids.

[2]Other includes C10:0, C12:0, C13:0, C14:1, C15:0, C18:1 *cis*-11, C18:1 *cis*-12, C18:1 *cis*-13, C18:1 *trans*-6/9, C18:1 *trans*-12, CLA *cis*-9/*trans*-11, CLA *trans*-10/*cis*-12, C18:3n-6, C20:0, C20:1, C20:2, C20:3n-3, C20:3n-6, C20:5, C22:0, C22:1, C22:5, C22:6, C23:0, C24:0.

*Significant correlations ($P < 0.05$).

acid (C18:2), arachidonic acid (C20:4), and PUFA were negatively correlated ($P < 0.05$) with all 3 sensory tenderness traits (IT, OT, and CT); however, MUFA were positively correlated ($P < 0.05$) with IT and OT as well as CT. The strongest correlation ($P < 0.05$) between IJ and SJ occurred with PUFA (r = 0.18 and −0.19, respectively), whereas several of the individual fatty acids were significantly related to juiciness. The individual PUFA were negatively related to juiciness, whereas individual SFA and MUFA were positively correlated with IJ and SJ. Although correlations were weak, BF was positively associated ($P < 0.05$) with C14:0, C16:0, C16:1, C18:1 *cis*-9, and C18:1 *trans*-10/11, SFA, and MUFA. Linoleic acid (C18:2), C20:4, and PUFA were negatively correlated ($P < 0.05$) with BF, but these were weak relationships (r ≤ −0.08). The strongest correlation with PFF occurred with stearic acid (C18:0), whereas C17:0, C18:2, C18:1 *trans*-10/11, and the sum of n-6 fatty acids were also positively related to PFF. Myristic acid (C14:0), C18:1, C18:3, and the sum of n-3 fatty acids were negatively associated with PFF. Only 2 individual fatty acids were associated with LMF; however, these relationships were relatively weak.

Dryden and Marchello (1970) found C18:1 was positively correlated with flavor when LM was presented to a semi-trained sensory panel; however, a larger correlation coefficient was reported (r = 0.66) and significantly fewer steaks were tested. Only 10 samples were compared, in contrast to almost 1,600 in the current study. Even so, their findings align with the current results because C18:1 *cis*-9 was positively related to BF. However, we were able to detect weak relationships between BF and C14:0, C16:0, C16:1, C17:0, and C18:2 that Dryden and Marchello (1970) did not. Westerling and Hedrick (1979) determined flavor was negatively correlated with C16:0, C18:0, C18:2, and SFA, which contradicts the weak positive correlations of the current study with C16:0, C18:2, and SFA. Furthermore, the present study failed to detect a relationship between C18:0 and BF.

Thiobarbituric acid reactive substances were correlated ($P < 0.05$) with several individual fatty acids, with the strongest relationship occurring with C18:1 *trans*-10/11 (r = −0.25). There was a weak negative relationship ($P < 0.05$) with total MUFA, but there were no associations with total SFA or PUFA. The susceptibility of a fatty acid to oxidize is related primarily to the degree of unsaturation; however, the fatty acid composition of the lipid, the presence and activity and pro- and antioxidants, oxygen content, and storage conditions (e.g., temperature, light intensity/exposure, moisture content) will all affect the rate of autoxidation of meat products (Belitz et al., 2004). Although it is desirable to increase PUFA in meat for its benefit to human health, off-flavors are more likely to develop during cooking when PUFA concentrations become too great (Elmore et al., 2002). However, as noted previously, samples in this study were aged until 14 d postmortem in a vacuum package and frozen immediately, leaving little opportunity for lipid oxidation. Therefore, decreased TBARS values could explain why no relationships were observed between TBARS and PUFA.

Quality Grade and Palatability

Quality grade affected ($P < 0.05$) WBSF, TBARS, and all trained sensory panel traits except LMF (Table 8). Although correlations were not particularly strong with MS, when classified into quality grade categories (as carcasses are merchandized), panelists were capable of detecting differences within quality grade categories. As USDA quality grade increased, steaks were more tender ($P < 0.05$). Warner-Bratzler shear force values were least for USDA Prime steaks. Low Choice steaks were tougher than Top Choice (upper two-thirds USDA Choice) steaks, which were both more tender than Select. A similar pattern was observed for trained sensory panel tenderness traits, as Prime steaks were rated greater than all other grades for IT, OT, and CT ($P < 0.05$). Panelists did not initially detect a difference ($P > 0.05$) in tenderness between Low Choice and Select; they were both rated least for IT. However, panelists detected the greatest CT in Select steaks, resulting in the least OT ratings. Smith et al. (1985) reported steaks from carcasses with greater MS had decreased ($P < 0.05$) shear force values and greater ($P < 0.05$) sensory panel ratings than steaks with decreased MS, which supports the current results. Wheeler et al. (1994) determined steaks decreased in shear force as marbling increased from traces to small; however, there was no difference in shear force values for steaks within the USDA Choice grade (small, modest, and moderate), which contradicts the present findings. Furthermore, Lorenzen et al. (2003) examined the effect of quality grade on trained and consumer sensory panel ratings, but did not include USDA Prime in that evaluation. Nonetheless, Lorenzen et al. (2003) reported USDA Select were less tender than USDA Choice, but did not detect differences in WBSF, muscle fiber tenderness, or CT amount between Top Choice and Low Choice top loin steaks, which contradicts the current findings.

Prime steaks were rated the juiciest ($P < 0.05$) both initially and overall by trained sensory panelists. Panelists initially rated Top Choice and Select steaks as the least juicy ($P < 0.05$), below Low Choice; however, when panelists evaluated SJ, they rated Select and Low Choice below Top Choice for SJ. The results for SJ are in accordance with Lorenzen et al. (2003) that reported that trained sensory panelist rated Top Choice steaks juicier than Low Choice or Select steaks.

Quality grade significantly ($P < 0.05$) affected LM BF and PFF; however, there was no clear pattern based on USDA quality grade. Panelists rated Low Choice steaks greater ($P < 0.05$) than all other grades for BF and less ($P < 0.05$) than all other grades for PFF, with no other differences between quality grades. Finally, LMF was not influenced ($P > 0.05$) by USDA quality grade. Lorenzen et al. (2003) reported less cooked BF

Table 8. Least squares means for USDA quality grade effect on Warner-Bratzler shear force (WBSF), trained sensory panel traits, and thiobarbituric acid reactive substances (TBARS) of beef LM

	USDA quality grade				
Item	Select	Low Choice	Top Choice[1]	Prime	SEM[2]
n	160	772	683	123	
WBSF, kg	3.92[a]	3.75[b]	3.58[c]	3.27[d]	0.042
Initial juiciness[3]	5.41[b]	5.27[c]	5.45[b]	5.65[a]	0.071
Sustained juiciness[3]	4.97[c]	4.89[c]	5.06[b]	5.30[a]	0.030
Initial tenderness[3]	5.66[c]	5.74[c]	5.90[b]	6.09[a]	0.035
Overall tenderness[3]	5.56[d]	5.73[c]	5.87[b]	6.07[a]	0.036
Connective tissue amount[4]	5.63[d]	5.86[c]	5.93[b]	6.10[a]	0.036
Beef flavor[5]	2.47[b]	2.52[a]	2.49[b]	2.45[b]	0.014
Painty/fishy flavor[5]	1.17[a]	1.10[b]	1.15[a]	1.17[a]	0.010
Livery/metallic flavor[5]	1.12	1.10	1.10	1.11	0.008
TBARS,[6] mg/kg	0.127[b]	0.137[a]	0.139[a]	0.134[ab]	0.0025

[a–d]Within a row, means without a common superscript differ ($P < 0.05$).

[1]Top Choice = upper two-thirds USDA Choice.

[2]Pooled SE of the treatment means.

[3]Scale: 1 = extremely dry, extremely tough; 8 = extremely juicy, extremely tender.

[4]Scale: 1 = abundant; 8 = none.

[5]Scale: 1 = not detectable; 3 = strong.

[6]Expressed as milligrams of malonaldehyde per kilogram of sample.

intensity in Low Choice steaks when compared with Top Choice, which both had greater BF intensity than Select. This does not support the current findings because there was no linear trend for any of the sensory flavor attributes.

Thiobarbituric acid reactive substances were affected ($P < 0.05$) by USDA quality grade; however, there was no clear pattern based on quality grade. Select steaks had the least numerical TBARS values, but were statistically similar to Prime. Overall, these values were much less than previously cited work (Campo et al., 2006). Samples in the current study were aged until 14 d postmortem in a vacuum package and frozen immediately, leaving little opportunity for lipid oxidation.

Conclusions

Several significant correlations existed between specific minerals, fatty acids, and beef palatability; however, these relationships were not strong. All minerals except calcium and manganese were positively related to BF. Furthermore, every mineral except cooper, manganese, and zinc was positively associated with the LMF. Total PUFA and specifically C18:2 and C20:4 were negatively related to juiciness and tenderness, whereas MUFA had a positive relationship with juiciness and tenderness. Total MUFA had the strongest correlation with BF, whereas C17:1 had the strongest correlation with PFF. Although there were significant correlations, these results indicate tenderness, juiciness, and flavor are not strongly influenced by the nutrient components in beef LM in Angus cattle. Therefore, it does not appear that palatability would be compromised if cattle were selected to enhance the nutritional profile of beef by altering the fatty acid or mineral composition.

Finally, USDA quality grade influenced beef palatability traits, including WBSF and trained sensory panel ratings for tenderness, juiciness, and flavor. Several studies have shown similar results; however, results from this study showed differences within USDA Choice for tenderness and juiciness that other researchers have failed to detect. The positive linear relationships between quality grade and tenderness and juiciness may suggest USDA quality grade is still one of the most valuable tools available to predict beef palatability.

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