3-2013

Genetic parameters for concentrations of minerals in longissimus muscle and their associations with palatability traits in Angus cattle

R. G. Mateescu
Oklahoma State University

A. J. Garmyn
Oklahoma State University

Richard G. Tait Jr.
Iowa State University, rtait@iastate.edu

Qing Duan
Iowa State University

Q. Liu
Iowa State University

See next page for additional authors

Genetic parameters for concentrations of minerals in longissimus muscle and their associations with palatability traits in Angus cattle

Abstract

The objective of this study was to estimate genetic parameters for concentrations of minerals in LM and to evaluate their associations with beef palatability traits. Samples of LM from 2,285 Angus cattle were obtained and fabricated into steaks for analysis of mineral concentrations and for trained sensory panel assessments. Nine minerals, including calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, and zinc, were quantified. Restricted maximum likelihood procedures were used to obtain estimates of variance and covariance components under a multiple-trait animal model. Estimates of heritability for mineral concentrations in LM varied from 0.01 to 0.54. Iron and sodium were highly and moderately heritable, respectively, whereas the other minerals were lowly heritable except for calcium, copper, and manganese, which exhibited no genetic variation. Strong positive genetic correlations existed between iron and zinc (0.49, *P < 0.05), between magnesium and phosphorus (0.88, P < 0.05), between magnesium and sodium (0.68, P < 0.05), and between phosphorus and potassium (0.69, P < 0.05). Overall tenderness assessed by trained sensory panelists was positively associated with manganese, potassium, and sodium and negatively associated with phosphorus and zinc concentrations (P <0.05). Juiciness assessed by trained sensory panelists was negatively associated with magnesium and positively associated with manganese and sodium concentrations (P < 0.05). Livery or metallic flavor was not associated with any of the minerals (P > 0.05). Beefy flavor was positively associated with calcium, iron, and zinc and negatively associated with sodium concentration, whereas a painty or fishy flavor was positively associated with sodium and negatively associated with calcium and potassium concentrations (P < 0.05). Beef is a major contributor of iron and zinc in the human diet, and these results demonstrate sufficient genetic variation for these traits to be improved through marker-assisted selection programs without compromising beef palatability.*

Keywords

beef, genetic parameters, minerals concentration, palatability, Biochemistry Biophysics and Molecular Biology

Disciplines

Agriculture | Animal Sciences | Biochemistry | Biophysics | Genetics | Molecular Biology

Comments

This article is from Journal of Animal Science 91, no. 3 (March 2013): 1067–1075, doi:10.2527/jas.2012-5744.

Authors

R. G. Mateescu, A. J. Garmyn, Richard G. Tait Jr., Qing Duan, Q. Liu, Mary S. Mayes, Dorian J. Garrick, A. L. Van Eenennaam, D. L. VanOverbeke, G. G. Hilton, Donald C. Beitz, and James M. Reecy

JOURNAL OF ANIMAL SCIENCE
The Premier Journal and Leading Source of New Knowledge and Perspective in Animal Science

Genetic parameters for concentrations of minerals in longissimus muscle and their associations with palatability traits in Angus cattle

R. G. Mateescu, A. J. Garmyn, R. G. Tait, Jr., Q. Duan, Q. Liu, M. S. Mayes, D. J. Garrick, A. L. Van Eenennaam, D. L. VanOverbeke, G. G. Hilton, D. C. Beitz and J. M. Reecy

J ANIM SCI 2013, 91:1067-1075.
doi: 10.2527/jas.2012-5744 originally published online December 10, 2012

Genetic parameters for concentrations of minerals in longissimus muscle and their associations with palatability traits in Angus cattle[1]

R. G. Mateescu,*[2] A. J. Garmyn,* R. G. Tait Jr.,† Q. Duan,† Q. Liu,‡ M. S. Mayes,† D. J. Garrick,† A. L. Van Eenennaam,§ D. L. VanOverbeke,* G. G. Hilton,* D. C. Beitz,†‡ and J. M. Reecy†

*Department of Animal Science, Oklahoma State University, Stillwater 74078; †Department of Animal Science, Iowa State University, Ames 50011; ‡Department of Biochemistry, Biophysics and Molecular Biology, Iowa State University, Ames 50011; and §Department of Animal Science, University of California, Davis 95616

ABSTRACT: The objective of this study was to estimate genetic parameters for concentrations of minerals in LM and to evaluate their associations with beef palatability traits. Samples of LM from 2,285 Angus cattle were obtained and fabricated into steaks for analysis of mineral concentrations and for trained sensory panel assessments. Nine minerals, including calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, and zinc, were quantified. Restricted maximum likelihood procedures were used to obtain estimates of variance and covariance components under a multiple-trait animal model. Estimates of heritability for mineral concentrations in LM varied from 0.01 to 0.54. Iron and sodium were highly and moderately heritable, respectively, whereas the other minerals were lowly heritable except for calcium, copper, and manganese, which exhibited no genetic variation. Strong positive genetic correlations existed between iron and zinc (0.49, $P < 0.05$), between magnesium and phosphorus (0.88, $P < 0.05$), between magnesium and sodium (0.68, $P < 0.05$), and between phosphorus and potassium (0.69, $P < 0.05$). Overall tenderness assessed by trained sensory panelists was positively associated with manganese, potassium, and sodium and negatively associated with phosphorus and zinc concentrations ($P < 0.05$). Juiciness assessed by trained sensory panelists was negatively associated with magnesium and positively associated with manganese and sodium concentrations ($P < 0.05$). Livery or metallic flavor was not associated with any of the minerals ($P > 0.05$). Beefy flavor was positively associated with calcium, iron, and zinc and negatively associated with sodium concentration, whereas a painty or fishy flavor was positively associated with sodium and negatively associated with calcium and potassium concentrations ($P < 0.05$). Beef is a major contributor of iron and zinc in the human diet, and these results demonstrate sufficient genetic variation for these traits to be improved through marker-assisted selection programs without compromising beef palatability.

Key words: beef, genetic parameters, minerals concentration, palatability

J. Anim. Sci. 2013.91:1067–1075
doi:10.2527/jas2012-5744

INTRODUCTION

Dietary minerals are essential components of human diets, and most dietitians recommend that these minerals be supplied from foods in which they occur naturally. Although the prevalence of obesity is rapidly increasing (Flegal et al., 2012) and has reached a 33.8% high among U.S. adults (Shields et al., 2011), many Americans are not meeting the recommended daily intake for many nutrients (ARS-USDA, 2011).

Of the commonly consumed protein foods, red meat is one of the best sources of readily absorbed iron and zinc. However, limited information is available regarding the content and natural variation in many nutrients in beef or the extent to which that variation is the result of genetic differences or associated with meat palatability traits. This information is necessary to evaluate the current and potential future role beef plays as a contributor of several essential minerals and trace elements to the human diet. Evaluation of relationships between the concentrations of these nutrients and sen-

[1]This research was supported by Pfizer Animal Genetics.
[2]Corresponding author: raluca@okstate.edu
Received August 11, 2012.
Accepted November 21, 2012.

sory traits is essential for understanding the impact of this natural variation on traits like tenderness, juiciness, and flavor, which represent critical aspects of consumer acceptance and satisfaction.

The objectives of this study were to quantify the genetic and environmental components of observed variation in the concentrations of minerals in LM of Angus beef cattle, to estimate genetic correlations among minerals, and to estimate associations of these minerals with a wide portfolio of beef palatability traits.

MATERIALS AND METHODS

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

Animals and Sample Collection

A total of 2,285 Angus-sired bulls (*n* = 540), steers (*n* = 1,311), and heifers (*n* = 434) sired by 155 sires were used in this study. All cattle were finished on concentrate diets in Iowa (*n* = 1,085), California (*n* = 360), Colorado (*n* = 388), or Texas (*n* = 452). Animals were harvested at commercial facilities when they reached typical U.S. market end points, with an average age of 457 ± 46 d. Production characteristics and additional details of the sample collection and preparation of these cattle were reported previously (Garmyn et al., 2011). After external fat and connective tissue were removed, the 1.27-cm steaks were analyzed for nutrient composition. Nutrient composition analysis was conducted at Iowa State University (Ames). In addition, 2.54-cm steaks were fabricated for sensory analysis. All steaks were vacuum packaged, aged at 2°C for 14 d from the harvest date, and then frozen at −20°C. Steaks were cooked and subjected to sensory analysis at Oklahoma State University Food and Agricultural Products Center (Stillwater).

Sensory Analysis

A detailed description of the selection and training of sensory panel members and procedures were described by Garmyn et al. (2011). Briefly, steaks were thawed at 4°C for 24 h before cooking, cooked to 68°C, sliced into approximately 2.54 × 1.27 × 1.27 cm samples, and served warm to panelists. Samples were evaluated using a standard ballot from the American Meat Science Association (AMSA, 1995). Panelists evaluated samples in duplicate for sustained juiciness and overall tenderness using an 8-point scale. The average score of all panelists for each animal was used in the analysis. Panelists evaluated cooked beef flavor, painty or fishy flavor, and livery or metallic flavor intensity using a 3-point scale. For juiciness, the scale was 1 = extremely dry and 8 = extremely juicy. The scale used for overall tenderness was 1 = extremely tough and 8 = extremely tender. The scale for connective tissue was 1 = abundant and 8 = none. The scale used for beef flavor and off-flavor intensity was 1 = not detectable, 2 = slightly detectable, and 3 = strong.

Mineral Concentrations

As previously described in Garmyn et al. (2011), the mineral content of LM samples was determined by inductively coupled plasma–optical emission spectroscopy (**ICP-OES**; SPECTRO Analytical Instruments, Mahwah, NJ). The samples were dried at 105°C for 18 to 20 h according to AOAC official method 934.01 (AOAC, 2000), and moisture content was calculated. Dried samples were subjected to a closed-vessel microwave digestion process (CEM, MDS-2000, Matthews, NC) with 5 mL concentrated nitric acid and 2 mL 30% hydrogen peroxide according to AOAC official method 999.10 (Jorhem and Engman, 2000). The microwave was programmed as follows: 250 W for 5 min, 630 W for 5 min, 500 W for 20 min, and 0 W for 15 min. Digested samples were transferred to 25-mL volumetric flasks and diluted with deionized water. The concentrations of calcium, copper, iron, manganese, phosphorus, potassium, sodium, magnesium, and zinc were then measured by ICP-OES.

Statistical Analysis

Trait means and standard deviations were calculated using the MEANS procedure (SAS Inst. Inc., Cary, NC). Sex (bull, cow, or steer) and feedlot location were confounded in this data set as California and Texas had only steers, bulls were only in Iowa, and cows were only in Colorado and Iowa. Least squares means estimating the effect of sex were obtained from the PROC GLM procedure of SAS using a fixed effects model that had sex, sex within feedlot location, and harvest day within sex by feedlot location and least squares means for feedlot location with a model that included feedlot, feedlot within sex, and harvest day within sex by feedlot location. Least squares means were separated using the PDIFF option of GLM in SAS.

For each mineral, restricted maximum likelihood procedures were used to estimate genetic and residual variances as well as heritability on the basis of a single-trait animal model fitted to the data using WOMBAT (Meyer, 2007).

For minerals with nonzero estimated genetic variance (iron, magnesium, phosphorus, potassium, sodium, and zinc), restricted maximum likelihood procedures were used to estimate genetic and phenotypic covariances from a multitrait animal model simultaneously fitted to all 6 traits using WOMBAT (Meyer, 2007). In matrix notation, the basic model equation was

$$Y = X\beta + Zu + e,$$

where Y is a vector of the observations for 6 traits, X is an incidence matrix relating observations to fixed effects, β is a vector of the fixed effects for each trait, Z is an incidence matrix relating observations to random animal effects, u is a vector containing the random genetic effects for all animals and all 6 traits, and e is a vector of the random residual errors for all measured traits and animals. Contemporary groups were defined on the basis of gender at harvest (bull, heifer, or steer), finishing location (California, Colorado, Iowa, Texas), and harvest date for a total of 33 groups. Contemporary groups were fit as fixed effects in all analyses. It is assumed that the random effects u and e are independent and have multivariate normal distributions with mean 0 so that E[y] = Xb. Variance assumptions comprised Var(u) = A $\otimes \sum$a and Var(e) = I $\otimes \sum$e, where $\sum$a = matrix of additive genetic covariances between traits and $\sum$e = residual covariance matrix, A = relationship matrix, I = identity matrix, and $\otimes$ = direct product between matrices.

A pedigree file with 5,907 individuals including identification of all animal, sire, and dam trios for 5 generations was used to define relationships among animals in the data set. The significance of genetic correlations was obtained as $\theta \pm Z_{\alpha/2}$ (sampling error), assuming normality of the estimator, θ.

A single-trait animal model and a stepwise approach were used to construct a model to evaluate the association between each sensory trait and mineral content. We started with contemporary groups as a fixed effect and all minerals as covariates. Nonsignificant effects were deleted sequentially from the full model until a final model containing only significant terms was obtained. All significance tests were conducted at the 5% level.

Table 1. Simple statistics for calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, and zinc concentrations (µg/g muscle) and trained panel sensory traits of steaks from Angus cattle

Trait	No. of cattle	Mean	SD	CV
Calcium	2,260	38.71	19.79	0.51
Copper	1,980	0.78	0.85	1.09
Iron	2,259	14.44	3.03	0.21
Magnesium	2,274	254.54	43.06	0.17
Manganese	2,000	0.07	0.04	0.57
Phosphorus	2,271	1,968.02	278.36	0.14
Potassium	2,225	3,433.54	494.27	0.14
Sodium	2,273	489.44	92.92	0.19
Zinc	2,261	38.96	7.90	0.20
Panel tenderness[1]	1,720	5.79	0.59	0.10
Juiciness[1]	1,720	4.99	0.49	0.10
Beef flavor[2]	1,720	2.50	0.23	0.10
Painty/fishy flavor[2]	1,720	1.13	0.17	0.15
Livery/metallic flavor[2]	1,720	1.10	0.12	0.11

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

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

RESULTS AND DISCUSSION

In addition to its role as an excellent source of protein, beef is also an important source of minerals in the human diet. The number of observations and simple statistics for calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, and zinc concentrations (µg/g muscle) are presented in Table 1. Iron, magnesium, sodium, potassium, phosphorus, and zinc content were variable, with the CV ranging from 0.14 to 0.21, whereas calcium, copper, and manganese concentrations were highly variable, with the CV ranging from 0.51 to 1.09. Sex and feedlot location had a significant effect ($P < 0.05$) on all minerals. Least squares means and statistical significance for the effect of sex and feedlot location on the concentration of each mineral are presented in Tables 2 and 3, respectively. Although sex and feed location had a significant effect on all minerals, there was also considerable variation within each sex by feedlot location group, as shown in Table 4. Among all minerals, calcium, copper, and manganese were the most variable within sex by feedlot location, with CV ranging from 0.30 to 2.86, whereas iron, magnesium, sodium, potassium, phosphorus, and zinc content had a CV ranging from 0.07 to 0.27 across all sexes by feedlot location classes.

Heritabilities

Estimates of h^2 for calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, and zinc concentrations in LM from Angus cattle are presented in Table 5. The heritability for calcium, copper, and manganese was essentially 0, whereas magnesium, phosphorus, potassium, and zinc had low heritability (h^2 = 0.009–0.09) and sodium was moderately heritable (h^2 = 0.12). Iron was the only mineral with high heritability (h^2 = 0.54). This is the first report to our knowledge of heritability estimates for these minerals in skeletal muscles from beef cattle.

Correlations

Genetic and phenotypic correlations, calculated by using a multiple-trait animal model, are shown in Table 6. All minerals analyzed in this study showed positive phenotypic correlations. There was a weak positive phenotypic correlation between iron and zinc, and each of these 2 minerals had weak positive phenotypic correlations with magnesium, phosphorus, potassium, and sodium (ranging from 0.20 to 0.35). Sodium was positively and moderately correlated with magnesium, phosphorus, and potassium (phenotypic correlations ranging from 0.52 to 0.65). Strong and positive phenotypic correlations were observed between phosphorus and magnesium (0.819), between potassium and magnesium (0.72), and between potassium and phosphorus (0.75).

Only a few significant genetic correlations existed between the minerals in our study. Strong and positive genetic correlations were found between magnesium and phosphorus (0.88), magnesium and potassium (0.68), and phosphorus and potassium (0.69). A moderate positive genetic correlation was identified between iron and zinc (0.49). All significant genetic correlations identified in this study were positive, indicating that selection would tend to change the beef content for these minerals in the same direction. Although selection programs for increasing the content of all these minerals in beef is possible, it would very likely be impractical. However, heritability for iron and moderate heritability for zinc along with their positive genetic correlation indicate that a selection program with emphasis on increasing the beef content for these 2 minerals is feasible and genetic improvement should be successful. Given the difficulty of collecting records for these traits in selection candidates, implementation would require identification of genetic markers associated with iron and zinc content for use in marker-assisted selection programs.

Relationships with Sensory Traits

Regression estimates and SE are shown in Table 7 for sensory traits with statistically significant genetic associations with LM mineral concentrations.

Overall tenderness was significantly associated with manganese, phosphorus, potassium, sodium, and zinc. Overall tenderness increased 1.17, 0.0002, and 0.001 points per 1 μg increase per gram of muscle in manganese, potassium, and sodium, respectively. In contrast, overall tenderness decreased by 0.0007 and 0.005 points for every 1 μg increase per gram of muscle in phosphorus and zinc, respectively. The only significant correlation with the tenderness score reported by Nour et al. (1983) was with cobalt (Co), a mineral not analyzed in our study, but the correlation was relatively low.

Juiciness in the present study was negatively associated with magnesium content and positively associated with manganese and sodium concentration. A decrease of 1 μg magnesium per gram of muscle and an increase of 1 μg manganese and sodium per gram of muscle was associated with 0.004, 1.29 and 0.001 points, respectively, increased juiciness as evaluated by the panelists on the sensory panel (on an 8-point scale). A similar negative association between juiciness and magnesium content was found by Nour et al. (1983).

Beefy flavor was associated significantly with calcium, iron, sodium, and zinc. An increase of 1 microgram calcium, iron, and zinc per gram muscle was associated with a 0.0006-, 0.006-, and 0.002-point (on the 3-point scale) increase in beefy flavor, respectively. A decrease of 1 μg sodium per gram of muscle was associated with an increase of 0.0004 points in beefy flavor. Iron and zinc were reported previously (Nour et al., 1983) to have significant positive phenotypic correlations with beefy flavor (r = 0.33 and 0.34), respectively, although weaker

Table 2. Least squares means for calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, and zinc concentrations (μg/g muscle) in LM from Angus cattle by sex

	Sex		
Mineral	Bull	Cow	Steer
Calcium	39.56[a]	34.94[b]	41.94[c]
Copper	1.29[a]	0.87[b]	0.68[b]
Iron	14.17[a]	14.93[b]	14.65[b]
Magnesium	233.57[a]	254.98[b]	270.09[c]
Manganese	0.059[a]	0.079[b]	0.074[c]
Phosphorus	1,850.36[a]	1,945.47[b]	2,059.11[c]
Potassium	3,194.22[a]	3,497.38[b]	3,595.73[c]
Sodium	439.25[a]	530.03[b]	517.04[c]
Zinc	40.60[a]	39.71[a]	38.13[b]

[a–c]Within a row, least squares without a common superscript were significantly different ($P < 0.05$).

Table 3. Least squares means for calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, and zinc concentrations (μg/g muscle) in LM from Angus cattle by feedlot location

	Feedlot location			
Mineral	California	Colorado	Iowa	Texas
Calcium	40.35	42.46	37.02[a]	40.93
Copper	0.62	0.88	0.88	0.74
Iron	12.02[a]	16.63[b]	14.01[c]	15.32[d]
Magnesium	237.78[a]	303.45[b]	232.05[c]	283.08[d]
Manganese	0.057[a]	0.076	0.075	0.080[b]
Phosphorus	1,930.62[a]	2,253.16[b]	1,802.76[c]	2,132.52[d]
Potassium	3,434.27[a]	3,947.54[b]	3,214.08[c]	3,600.31[d]
Sodium	481.76[a]	627.49[b]	446.84[c]	490.20[d]
Zinc	37.87	42.19[a]	37.75	37.00

[a–d]Within a row, least squares without a common superscript were significantly different ($P < 0.05$).

phenotypic correlations were previously reported on the present data set ($r = 0.14$ and 0.06, respectively; Garmyn et al., 2011). Meisinger et al. (2006) examined the relationship of heme iron to off-flavor in different muscles from the chuck and round and a significant correlation (−0.51) was identified only between heme iron and off-flavor intensity for just 1 (vastus lateralis) of 7 muscles used in their study. The possibility exists for heme iron, by producing radicals capable of inducing lipid oxidation (Kanner and Harel, 1985; Batifoulier et al., 2002), to act as a pro-oxidant and influence meat flavor. However, the mechanism of iron involvement in lipid peroxidation in meat is still under debate.

The only other flavor significantly associated with any of the minerals analyzed in this study was a painty or fishy flavor, which decreased by 0.0004 and 0.00003 points and increased by 0.0003 points (on the 3-point scale) with a 1-µg increase in calcium, potassium, and sodium per gram of muscle, respectively. Jenschke et al. (2007) found sodium had a significant effect on the liverlike off-flavor, but similar to results presented in this study, the contribution was minimal.

Livery or metallic flavor was not significantly associated with any of the minerals analyzed ($P > 0.05$; data not shown). Copper concentration was not significantly associated ($P > 0.05$) with any of the meat quality traits analyzed.

It is important to point out that all the associations between mineral content and palatability traits identified in this study, although statistically significant, are negligible from a practical standpoint when taking into consideration the average content of these minerals and the range for their natural variation presented in this study. The associations identified indicate that if it is desired to improve the nutritional value of beef by increasing the iron and zinc content, no negative effects on palatability traits are expected.

Nutritional Value of Beef

Calcium, an essential nutrient with an important role in bone health, is required for vascular contraction and vasodilation, muscle function, nerve transmission, intracellular signaling, and hormonal secretion (Anderson et al., 1993; Ambudkar, 2011; Fearnley et al., 2011; Rosenberg and Spitzer, 2011). The health benefits of calcium are related to bone health and osteoporosis, cardiovascular disease, blood pressure regulation and hypertension, kid-

Table 4. Number of records (*n*), mean, SD and CV for calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium and zinc concentrations (µg/g muscle) in LM from Angus cattle by sex and feed location

Sex	Feed location	Variable	Calcium	Copper	Iron	Magnesium	Manganese	Phosphorus	Potassium	Sodium	Zinc
Bull	IA	*n*	537	507	537	539	520	539	532	539	537
		mean	38.10	1.49	14.23	233.07	0.06	1,856.80	3,240.38	440.21	40.68
		SD	18.17	4.26	2.54	31.04	0.03	206.09	472.41	68.14	7.45
		CV	0.48	2.86	0.18	0.13	0.42	0.11	0.15	0.15	0.18
Cow	CO	*n*	198	151	198	198	169	198	196	198	197
		mean	37.75	1.07	15.65	276.77	0.07	2,086.26	3,761.03	593.37	43.04
		SD	11.14	1.34	3.26	22.17	0.02	151.02	409.82	62.08	7.44
		CV	0.30	1.25	0.21	0.08	0.34	0.07	0.11	0.10	0.17
	IA	*n*	231	227	230	231	218	231	230	231	229
		mean	35.76	0.65	14.03	226.37	0.08	1,759.46	3,132.26	450.95	38.06
		SD	19.93	0.47	2.42	32.21	0.05	278.68	462.33	68.92	9.88
		CV	0.56	0.71	0.17	0.14	0.65	0.16	0.15	0.15	0.26
Steer	CA	*n*	357	247	357	358	234	358	358	358	358
		mean	37.13	0.63	11.95	238.33	0.06	1,931.35	3,419.63	481.27	37.82
		SD	35.88	0.52	2.51	21.76	0.03	139.60	299.79	45.06	5.39
		CV	0.97	0.82	0.21	0.09	0.59	0.07	0.09	0.09	0.14
	CO	*n*	190	180	187	190	185	190	154	190	190
		mean	47.16	0.69	17.61	330.13	0.08	2,420.06	4,134.06	661.61	41.35
		SD	16.96	0.26	3.17	46.39	0.03	281.20	472.43	81.17	7.78
		CV	0.36	0.38	0.18	0.14	0.39	0.12	0.11	0.12	0.19
	IA	*n*	309	252	305	309	244	309	306	309	309
		mean	36.17	0.68	13.72	227.53	0.06	1,742.83	3,194.36	432.66	35.53
		SD	18.85	1.42	2.53	25.71	0.04	249.30	489.10	59.66	7.59
		CV	0.52	2.09	0.18	0.11	0.56	0.14	0.15	0.14	0.21
	TX	*n*	449	449	445	449	430	449	449	448	441
		mean	41.63	0.74	15.54	284.54	0.08	2,137.13	3,607.60	495.27	37.81
		SD	10.80	0.67	2.45	23.27	0.03	169.68	281.24	62.50	7.95
		CV	0.26	0.90	0.16	0.08	0.36	0.08	0.08	0.13	0.21

ney stones, and weight management (Burtis et al., 1993; Flynn, 2003; Tylavsky et al., 2008; Astrup, 2011; Meier and Kranzlin, 2011;). In our study, the average calcium concentration was 38.71 μg/g muscle; therefore, the contribution to the daily human requirements is relatively minor, providing, on average, 3.87 mg calcium per 100 g serving of beef for the 1,000- to 1,300-mg daily need by the average adult.

Copper is a trace element essential in most animals, including humans, and a critical functional component of a number of essential enzymes used by most cells. In particular, copper is required for cytochrome oxidase and superoxidase dismutase, enzymes involved in energy production and protection of cells from free radical damage, respectively (Yim et al., 1993; Gezer et al., 1998; Jimenez and Speisky, 2000). The average copper concentration in our study was 0.78 μg/g muscle; therefore, a 100 g serving of beef contributes, on average, 0.08 mg of copper, which represents between 4% and 8% of the recommended dietary allowance. Probably more important than the actual amount of copper provided is the role played in iron metabolism through ferroxidase I and II, 2 copper-dependent enzymes with the capacity to oxidize ferrous iron to ferric iron, which can be loaded onto the transferrin for transport to the site of red cell formation (Osaki et al., 1971; Garnier et al., 1981).

Iron is an important dietary mineral involved in various bodily functions, including the transport of oxygen in the blood. The iron concentration in the present data set was 14.44 μg/g muscle, representing, on average, 1.44 mg iron per 100 g serving of beef. The current recommended daily allowance varies depending on gender and age from 8 to 18 mg per day. In this context, a 100 g serving of beef would provide between 8% and 18% of the recommended daily allowance. The amount of iron absorbed compared with the amount ingested is typically low, and the source of iron is an important factor determining the efficiency of absorption (Kapsokefalou and Miller, 1993; Andrews, 2005; West and Oates, 2008; Han, 2011). Iron in animal and some plant products is mostly in the form of heme iron, which is more efficiently absorbed. Heme iron in meat is from blood and heme-containing proteins in muscle cells including mitochondria, whereas in plants heme iron is present in mitochondria in all cells that use oxygen for respiration. The importance of iron in human diet, the high heritability of this mineral in beef (0.54), and the natural variation that was present in our study indicate the iron content in beef could be successfully improved through selection. The maximum iron concentration in this study was 27.43 μg/g muscle, representing between 15% and 34% of the recommended daily allowance depending on gender and age.

Table 5. Genetic (σ^2_a) and residual (σ^2_e) variance and heritability (h^2) estimates with SE for calcium, copper, iron, magnesium, manganese, phosphorus, potassium, sodium, and zinc concentrations (μg/g muscle) in LM from Angus cattle obtained by single trait REML analysis

Trait[1]	σ^2_a	σ^2_e	$h^2 \pm$ SE
Calcium	0.00003	277.74	0.000 ± 0.03
Copper	0.00025	0.49	0.000 ± 0.04
Iron	3.69	3.09	0.544 ± 0.09
Magnesium	36.78	530.83	0.065 ± 0.04
Manganese	0.00006	0.007	0.009 ± 0.03
Phosphorus	1,105.10	29,630.5	0.036 ± 0.03
Potassium	3,989.63	104,989.0	0.037 ± 0.03
Sodium	591.32	2574.71	0.187 ± 0.06
Zinc	4.73	47.10	0.091 ± 0.04

Magnesium is essential to good human health as it helps maintain normal muscle and nerve function, keeps heart rhythm steady, supports a healthy immune system, and keeps bones strong (Clarkson and Haymes, 1995; Saris et al., 2000; Tam et al., 2003; Spiegel, 2011; Genuis and Bouchard, 2012). Magnesium also helps regulate blood glucose concentrations, promotes normal blood pressure, and is involved in ATP metabolism and protein synthesis (Wester, 1987; Saris et al., 2000). There is an increased interest in the role of magnesium in preventing and managing disorders such as hypertension, cardiovascular disease, and diabetes (Bo and Pisu, 2008; Champagne, 2008; Houston, 2011). In our study, the magnesium concentration was 254.5 μg/g muscle;

Table 6. Estimates of genetic (above the diagonal) and phenotypic (below the diagonal) correlations with approximate SE (in parentheses) between iron, magnesium, phosphorus, potassium, sodium, and zinc concentrations (μg/g muscle) in LM from Angus cattle obtained by multiple-trait REML analysis

Trait	Iron	Magnesium	Phosphorus	Potassium	Sodium	Zinc
Iron		−0.31(.27)	−0.58 (.32)	−0.29 (.27)	−0.08 (.19)	0.49 (.17)
Magnesium	0.35 (.02)		0.88 (.11)	0.68 (.22)	0.29 (.28)	−0.47 (.42)
Phosphorus	0.26 (.02)	0.82(.01)		0.69 (.23)	0.23 (.33)	−0.34 (.44)
Potassium	0.20 (.02)	0.72 (.01)	0.75 (.01)		0.32 (.28)	−0.52 (.42)
Sodium	0.26 (.02)	0.65(.01)	0.52 (.02)	0.65 (.01)		−0.16(.29)
Zinc	0.31 (.02)	0.30(.02)	0.26 (.02)	0.21 (.02)	0.23 (.02)	

therefore, a 100 g serving of beef would provide, on average, between 6.4% and 8.5% of the 300- to 400-mg daily recommended allowance for magnesium intake for adults. Given the high variability for magnesium concentration, the same serving of beef could provide as much as 14% of the daily recommended allowance.

Manganese is a trace mineral found mostly in the bones, liver, kidneys, and pancreas. Manganese helps the body form connective tissue, bones, blood clotting factors, and sex hormones (Santamaria and Sulsky, 2010). It also plays a role in lipid and carbohydrate metabolism, calcium absorption, and blood glucose regulation (Kehl-Fie and Skaar, 2010; Bae et al., 2011). Manganese is also necessary for normal brain and nerve function. In addition, manganese is a component of the enzyme superoxide dismutase, 1 of the key antioxidants in the body (Miriyala et al., 2012). The manganese concentration in our study was highly variable, with an average of 0.07 µg/g muscle. The 0.007 mg provided by a 100 g serving of beef is a negligible amount toward the daily adequate intake of 1.8 to 2.3 mg per day.

Phosphorus, a mineral that makes up 1% of the total BW of a person, is present in every cell of the body. The main use of phosphorus is in the formation of bones and teeth. It plays an important role in the use of carbohydrates and lipids by the body and in the synthesis of protein for the growth, maintenance, and repair of cells and tissues (van den Broek and Beynen, 1998; Civitelli and Ziambaras, 2011). It is also crucial for the production of ATP, a molecule used by the body to transfer energy. Phosphorus is a constituent of the coenzyme form of most B vitamins. It also assists in the contraction of muscles, in the functioning of kidneys, in maintaining the regularity of the heartbeat, and in nerve conduction (Horl et al., 1983; Clarkson and Haymes, 1995; van den Broek and Beynen, 1998). The main food sources of phosphorus are the protein food groups of meat and milk. A meal plan that provides adequate amounts of calcium and protein also provides an adequate amount of phosphorus. In our study, the phosphorus concentration was 1,968 µg/g muscle, with a 100 g serving of beef providing, on average, 196.8 mg of phosphorus, or 28% of the 700-mg daily recommended allowance for phosphorus intake for adults. Although highly variable, with a serving of beef in this study contributing a maximum of 45% (3,163 µg/g muscle) of the daily recommended allowance for phosphorus intake, phosphorus had a low heritability (0.04), which makes this mineral an unlikely candidate for selection.

Potassium, a very important mineral in the human body, is mostly involved in electrical and cellular body functions. It has various roles in metabolism and body functions and is essential for the proper function of all cells, tissues, and organs (Tylavsky et al., 2008). Beef is one of the top sources of potassium in the human diet (O'Neil et al., 2011; Nicklas et al., 2012). In our study, the potassium concentration was 3,433 µg/g muscle, with 1 serving of beef providing, on average, 343.3 mg of potassium, which is equivalent to almost 10% of the daily recommended value.

Zinc is essential for growth and development and is involved in DNA and RNA synthesis and the catabolism of carbohydrates, lipids, and proteins for ATP generation (Saper and Rash, 2009). Zinc boosts immunity and also helps the body heal wounds and maintain normal blood glucose concentrations (Jansen et al., 2009; John et al., 2010; Kehl-Fie and Skaar, 2010; Morgan et al., 2011; Mocchegiani et al., 2012). Animal and plant foods supply zinc, but as with iron, zinc is more efficiently absorbed from beef, which makes it an excellent source of dietary zinc. In our study, the zinc concentration was 38.9 µg/g muscle. Therefore, a 100 g serving of beef contains an average of 3.89 mg, or 26% of the recommended daily intake. High CV (0.20) and moderate heritability (0.10) indicate a potentially successful increase of zinc content through selection, if desired.

Our results on concentrations of measured minerals agree with those of several other studies (Biesalski, 2005; Zanovec et al., 2010; O'Neil et al., 2011) documenting the role of beef in providing essential minerals to the human diet, particularly iron, magnesium, phosphorus, potassium, and zinc. When availability from other food sources, however, is considered, the amount of iron and zinc provided through consumption of lean beef has a critical role toward meeting the nutritional requirements

Table 7. Estimates of the changes in palatability traits associated with mineral concentrations (µg/g muscle) in LM from Angus cattle (regression coefficient and respective SE in parentheses)

Trait	Calcium	Iron	Magnesium	Manganese	Phosphorus	Potassium	Sodium	Zinc
Overall tenderness[1]				1.17 (0.53)	−0.0007 (0.0002)	0.0002 (0.0001)	0.001 (0.0003)	−0.005 (0.002)
Juiciness[1]			−0.004 (0.0006)	1.29 (0.44)			0.001 (0.0003)	
Beefy flavor	0.0006 (0.0003)	0.006 (0.002)					−0.0004 (0.00009)	0.002 (0.001)
Painty/fishy flavor[2]	−0.0004 (0.0002)					−0.00003 (0.00001)	0.0003 (0.00008)	

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

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

of these 2 nutrients and may provide major health benefits.

Conclusion

This study found that several mineral concentrations are heritable, and several favorable genetic correlations exist between these minerals. These results indicate manipulation of the mineral content of meat is possible through selection, with practically no alterations in beef palatability traits. Because of the lack of phenotypic data on mineral content, further studies are needed to identify genetic markers to be used in marker-assisted selection if manipulation of mineral content is desired.

LITERATURE CITED

Ambudkar, I. S. 2011. Dissection of calcium signaling events in exocrine secretion. Neurochem. Res. 36:1212–1221.

AMSA. 1995. Research Guidelines for cookery, sensory evaluation, and instrumental tenderness measurements of fresh meat. National Live Stock and Meat Board, Chicago, IL.

ARS-USDA. 2011. Continuing survey of food intakes by individuals 1994–96, 1998. ARS-USDA, Beltsville Hum. Nut. Res. Cent., Food Surv. Res. Group, Beltsville, MD.

Anderson, J. J., F. A. Tylavsky, L. Halioua, and J. A. Metz. 1993. Determinants of peak bone mass in young adult women: A review. Osteoporos. Int. 3(Suppl. 1):32–36.

Andrews, N. C. 2005. Understanding heme transport. N. Engl. J. Med. 353:2508–2509.

AOAC. 2000. Official methods of analysis. 17th ed. Assoc. Off. Anal. Chem., Gaithersburg, MD.

Astrup, A. 2011. Calcium for prevention of weight gain, cardiovascular disease, and cancer. Am. J. Clin. Nutr. 94:1159–1160.

Bae, Y. J., M. K. Choi, and M. H. Kim. 2011. Manganese supplementation reduces the blood cholesterol levels in Ca-deficient ovariectomized rats. Biol. Trace Elem. Res. 141:224–231.

Batifoulier, F., Y. Mercier, P. Gatellier, and M. Renerre. 2002. Influence of vitamin E on lipid and protein oxidation induced by H_2O_2-activated MetMb in microsomal membranes from turkey muscle. Meat Sci. 61:389–395.

Biesalski, H. K. 2005. Meat as a component of a healthy diet—Are there any risks or benefits if meat is avoided in the diet? Meat Sci. 70:509–524.

Bo, S., and E. Pisu. 2008. Role of dietary magnesium in cardiovascular disease prevention, insulin sensitivity and diabetes. Curr. Opin. Lipidol. 19:50–56.

Burtis, W. J., A. E. Broadus, and K. L. Insogna. 1993. Calcium and kidney stones. N. Engl. J. Med. 329:508–509.

Champagne, C. M. 2008. Magnesium in hypertension, cardiovascular disease, metabolic syndrome, and other conditions: A review. Nutr. Clin. Pract. 23:142–151.

Civitelli, R., and K. Ziambaras. 2011. Calcium and phosphate homeostasis: Concerted interplay of new regulators. J. Endocrinol. Invest. 34:3–7.

Clarkson, P. M., and E. M. Haymes. 1995. Exercise and mineral status of athletes: Calcium, magnesium, phosphorus, and iron. Med. Sci. Sports Exerc. 27:831–843.

Fearnley, C. J., H. L. Roderick, and M. D. Bootman. 2011. Calcium signaling in cardiac myocytes. Cold Spring Harb. Perspect. Biol. 3:a004242.

Flegal, K. M., M. D. Carroll, B. K. Kit, and C. L. Ogden. 2012. Prevalence of obesity and trends in the distribution of body mass index among US adults, 1999–2010. JAMA 307:491–497.

Flynn, A. 2003. The role of dietary calcium in bone health. Proc. Nutr. Soc. 62:851–858.

Garmyn, A. J., G. G. Hilton, R. G. Mateescu, J. B. Morgan, J. M. Reecy, R. G. Tait Jr., D. C. Beitz, Q. Duan, J. P. Schoonmaker, M. S. Mayes, M. E. Drewnoski, Q. Lui, and D. L. Vanoverbeke. 2011. Estimation of relationships between mineral concentration and fatty acid composition of longissimus muscle and beef palatability traits. J. Anim. Sci. 89:2849–2858.

Garnier, A., L. Tosi, and M. Steinbuch. 1981. Ferroxidase II. The essential role of copper in enzymatic activity. Biochem. Biophys. Res. Commun. 98:66–71.

Genuis, S. J., and T. P. Bouchard. 2012. Combination of micronutrients for bone (COMB) study: Bone density after micronutrient intervention. J. Environ. Public Health 2012:354151.

Gezer, S., G. Kirkali, C. Pekcetin, and A. Gure. 1998. The effects of pre- and post natal copper depletion on mitochondrial cytochrome oxidase activities of newborn rats. Biochem. Soc. Trans. 26:S350.

Han, O. 2011. Molecular mechanism of intestinal iron absorption. Metallomics 3:103–109.

Horl, W. H., W. Kreusser, M. Rambausek, A. Heidland, and E. Ritz. 1983. Glycogen metabolism in phosphorus-depleted rats. Miner. Electrolyte Metab. 9:113–118.

Houston, M. 2011. The role of magnesium in hypertension and cardiovascular disease. J. Clin. Hypertens. (Greenwich) 13:843–847.

Jansen, J., W. Karges, and L. Rink. 2009. Zinc and diabetes—Clinical links and molecular mechanisms. J. Nutr. Biochem. 20:399–417.

Jenschke, B. E., J. M. Hodgen, J. L. Meisinger, A. E. Hamling, D. A. Moss, A. M. Lundesjo, K. M. Eskridge, and C. R. Calkins. 2007. Unsaturated fatty acids and sodium affect the liver-like off-flavor in cooked beef. J. Anim. Sci. 85:3072–3078.

Jimenez, I., and H. Speisky. 2000. Effects of copper ions on the free radical-scavenging properties of reduced gluthathione: Implications of a complex formation. J. Trace Elem. Med. Biol. 14:161–167.

John, E., T. C. Laskow, W. J. Buchser, B. R. Pitt, P. H. Basse, L. H. Butterfield, P. Kalinski, and M. T. Lotze. 2010. Zinc in innate and adaptive tumor immunity. J. Transl. Med. 8:118.

Jorhem, L., and J. Engman. 2000. Determination of lead, cadmium, zinc, copper, and iron in foods by atomic absorption spectrometry after microwave digestion: NMKL Collaborative Study. J. AOAC Int. 83:1189–1203.

Kanner, J., and S. Harel. 1985. Initiation of membranal lipid peroxidation by activated metmyoglobin and methemoglobin. Arch. Biochem. Biophys. 237:314–321.

Kapsokefalou, M., and D. D. Miller. 1993. Lean beef and beef fat interact to enhance nonheme iron absorption in rats. J. Nutr. 123:1429–1434.

Kehl-Fie, T. E., and E. P. Skaar. 2010. Nutritional immunity beyond iron: A role for manganese and zinc. Curr. Opin. Chem. Biol. 14:218–224.

Meier, C., and M. E. Kranzlin. 2011. Calcium supplementation, osteoporosis and cardiovascular disease. Swiss. Med. Wkly. 141:w13260.

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.

Meyer, K. 2007. WOMBAT: A tool for mixed model analyses in quantitative genetics by restricted maximum likelihood (REML). J. Zhejiang Univ. Sci. B 8:815–821.

Miriyala, S., I. Spasojevic, A. Tovmasyan, D. Salvemini, Z. Vujaskovic, D. St Clair, and I. Batinic-Haberle. 2012. Manganese superoxide dismutase, MnSOD and its mimics. Biochim. Biophys. Acta.1822:794–814.

Mocchegiani, E., J. Romeo, M. Malavolta, L. Costarelli, R. Giacconi, L. E. Diaz, and A. Marcos. 2012. Zinc: Dietary intake and impact of supplementation on immune function in elderly. Age (Dordr.). Doi: 10.1007/s11357-011-9377-3.

Morgan, C. I., J. R. Ledford, P. Zhou, and K. Page. 2011. Zinc supplementation alters airway inflammation and airway hyperresponsiveness to a common allergen. J. Inflamm. (Lond.) 8:36.

Nicklas, T. A., C. E. O'Neil, M. Zanovec, D. R. Keast, and V. L. Fulgoni III. 2012. Contribution of beef consumption to nutrient intake, diet quality, and food patterns in the diets of the US population. Meat Sci. 90:152–158.

Nour, A. Y., M. L. Thonney, G. Armbruster, and J. R. Stouffer. 1983. Muscle mineral concentrations as predictors of taste panel sensory attributes of beef. J. Food Sci. 48:1170–1171.

O'Neil, C. E., M. Zanovec, D. R. Keast, V. L. Fulgoni III, and T. A. Nicklas. 2011. Nutrient contribution of total and lean beef in diets of US children and adolescents: National Health and Nutrition Examination Survey 1999–2004. Meat Sci. 87:250–256.

Osaki, S., D. A. Johnson, and E. Frieden. 1971. The mobilization of iron from the perfused mammalian liver by a serum copper enzyme, ferroxidase I. J. Biol. Chem. 246:3018–3023.

Rosenberg, S. S., and N. C. Spitzer. 2011. Calcium signaling in neuronal development. Cold Spring Harb. Perspect. Biol. 3:a004259.

Santamaria, A. B., and S. I. Sulsky. 2010. Risk assessment of an essential element: Manganese. J. Toxicol. Environ. Health A 73:128–155.

Saper, R. B., and R. Rash. 2009. Zinc: An essential micronutrient. Am. Fam. Physician 79:768–772.

Saris, N. E., E. Mervaala, H. Karppanen, J. A. Khawaja, and A. Lewenstam. 2000. Magnesium. An update on physiological, clinical and analytical aspects. Clin. Chim. Acta 294:1–26.

Shields, M., M. D. Carroll, and C. L. Ogden. 2011. Adult obesity prevalence in Canada and the United States. NCHS Data Brief No. 56. Natl. Cent. Health Stat., Hyattsville, MD.

Spiegel, D. M. 2011. Magnesium in chronic kidney disease: Unanswered questions. Blood Purif. 31:172–176.

Tam, M., S. Gomez, M. Gonzalez-Gross, and A. Marcos. 2003. Possible roles of magnesium on the immune system. Eur. J. Clin. Nutr. 57:1193–1197.

Tylavsky, F. A., L. A. Spence, and L. Harkness. 2008. The importance of calcium, potassium, and acid-base homeostasis in bone health and osteoporosis prevention. J. Nutr. 138:164S–165S.

van den Broek, F. A., and A. C. Beynen. 1998. The influence of dietary phosphorus and magnesium concentrations on the calcium content of heart and kidneys of DBA/2 and NMRI mice. Lab. Anim. 32:483–491.

West, A. R., and P. S. Oates. 2008. Mechanisms of heme iron absorption: Current questions and controversies. World J. Gastroenterol. 14:4101–4110.

Wester, P. O. 1987. Magnesium. Am. J. Clin. Nutr. 45:1305–1312.

Yim, M. B., P. B. Chock, and E. R. Stadtman. 1993. Enzyme function of copper, zinc superoxide dismutase as a free radical generator. J. Biol. Chem. 268:4099–4105.

Zanovec, M., C. E. O'Neil, D. R. Keast, V. L. Fulgoni, and T. A. Nicklas. 2010. Lean beef contributes significant amounts of key nutrients to the diets of US adults: National Health and Nutrition Examination Survey 1999 -2004. Nutr. Res. 30:375–381.