Genetic parameters for carnitine, creatine, creatinine, carnosine, and anserine concentration in longissimus muscle and their association with palatability traits in Angus cattle

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Genetic parameters for carnitine, creatine, creatinine, carnosine, and anserine concentration in longissimus muscle and their association with palatability traits in Angus cattle[1]

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ABSTRACT: The objective of this study was to estimate genetic parameters for carnitine, creatine, creatinine, carnosine, and anserine concentration in LM and to evaluate their associations with Warner-Bratzler shear force (WBSF) and beef palatability traits. Longissimus muscle samples from 2,285 Angus cattle were obtained and fabricated into steaks for analysis of carnitine, creatine, creatinine, carnosine, anserine, and other nutrients, and for trained sensory panel and WBSF assessments. Restricted maximum likelihood procedures were used to obtain estimates of variance and covariance components under a multiple-trait animal model. Estimates of heritability for carnitine, creatine, creatinine, carnosine, and anserine concentrations in LM from Angus cattle were 0.015, 0.434, 0.070, 0.383, and 0.531, respectively. Creatine, carnosine, and anserine were found to be moderately heritable, whereas almost no genetic variation was observed in carnitine and creatinine. Moderate positive genetic (0.25, $P < 0.05$) and phenotypic correlations (0.25, $P < 0.05$) were identified between carnosine and anserine. Medium negative genetic correlations were identified between creatine and both carnosine (-0.53, $P < 0.05$) and anserine (-0.46, $P < 0.05$). Beef and livery/metallic flavor were not associated with any of the 5 compounds analyzed ($P > 0.10$), and carnitine concentrations were not associated ($P > 0.10$) with any of the meat palatability traits analyzed. Carnosine was negatively associated with overall tenderness as assessed by trained sensory panelists. Similar negative associations with overall tenderness were identified for creatinine and anserine. Painty/fishy was the only flavor significantly and negatively associated with creatinine and carnosine. These results provide information regarding the concentration of these compounds, the amount of genetic variation, and evidence for negligible associations with beef palatability traits in LM of beef cattle.

Key words: beef, bioactive compounds, genetic parameters, palatability

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INTRODUCTION

Beef has a unique nutrient profile and is an important contributor of high-quality protein, essential micronutrients, and AA to the human diet (USDA, 2010). More information has recently become available on fatty acid composition and mineral and vitamin concentrations in different muscles from various breeds and under different production systems (Faucitano et al., 2008; Leheska et al., 2008; Purchas and Zou, 2008; Warren et al., 2008; De la Fuente et al., 2009; Duckett et al., 2009; Daley et al., 2010; Schonfeldt et al., 2010; Pordomingo et al., 2012; Sexten et al., 2012; Yuksel et al., 2012); however, little information is available regarding other components in beef that have been reported to be related to human health. Because of their potential protective effects, these components are generally referred to as bioactive compounds, or health-promoting active ingredients (Muller et al., 2002; Wyss et al., 2007; Hipkiss, 2009). These components, some of which are not generally recognized as nutrients, include carnitine, creatine, creatinine, carnosine, and anserine. With growing research interest in the health-protective mechanisms of these bioactive compounds and the potential effect of this research on

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meat consumption, it is important for the beef industry to evaluate these components with respect to content, variation, and association with meat quality traits. Evaluation of relationships between the concentrations of these compounds and sensory traits also is essential for understanding the effect of this natural variation on traits like tenderness, juiciness, and flavor, which represent critical aspects of consumer acceptance and satisfaction. Our objectives were to quantify the genetic and environmental components of the phenotypic variation of carnitine, creatine, creatinine, carnosine, and anserine concentrations in the LM of Angus beef cattle, to estimate genetic parameters associated with the concentrations, and to estimate associations of these compounds with Warner-Bratzler shear force (**WBSF**) and a wide portfolio of sensory traits.

MATERIALS AND METHODS

Animals and Sample Collection

A total of 2,285 Angus sired bulls (n = 540), steers (n = 1,311), and heifers (n = 434) was 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) and slaughtered at commercial facilities when they reached typical U.S. market endpoints with an average age of 457 ± 46 d. Production characteristics including detailed sample collection and preparation of these cattle were reported previously (Garmyn et al., 2011). Briefly, rib sections were obtained from each carcass, external fat and connective tissue were removed from 1.27-cm steaks for measurement of nutrient and other bioactive compounds, and 2.54-cm steaks were removed for WBSF and sensory analysis. All steaks were vacuum packaged, aged for 14 d from the slaughter date at 2°C and frozen at −20°C. Steaks were cooked and subjected to WBSF and sensory analysis at Oklahoma State University Food and Agricultural Products Center. Nutrient and bioactive compounds composition analysis was conducted at Iowa State University.

Warner-Bratzler Shear Force

Steak processing procedures have been described by Garmyn et al. (2011). Briefly, the frozen steaks were allowed to thaw at 4ºC for 24 h before cooking. Steaks were broiled in an impingement oven at 200ºC to an internal temperature of 68ºC monitored with an Atkins AccuTuff 340 thermometer (Atkins Temtes, Gainsville, FL). After cooking, steaks were cooled at 4ºC for 18 to 24 h as recommended by the AMSA (1995). Six cores, 1.27-cm in diameter, were removed parallel to muscle fiber orientation and sheared once by using a Warner-Bratzler head attached to an Instron Universal Testing Machine (Model 4502, Instron Corp., Canton, MS). The Warner-Bratzler head moved at a crosshead speed of 200 mm/min. Peak load (kilograms) of each core was recorded by an IBM PS2 (Model 55 SX) computer using software provided by Instron Corp. Mean peak load (kilograms) was analyzed for each sample.

Sensory Analysis

A detailed description of the 8-member, trained sensory panel and sensory analysis procedures were provided by Garmyn et al. (2011). Briefly, steaks were allowed to thaw at 4ºC for 24 h before cooking, cooked to 68°C as described above for WBSF, sliced into approximately 2.54-cm × 1.27-cm × 1.27-cm samples, and served warm to panelists. Sensory attributes of each steak were evaluated by the 8 trained panelists using a standard ballot from the AMSA (1995). Each sensory session contained 12 samples, and the 12 samples were in a randomized order according to panelist. Panelists evaluated samples in duplicate for 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/fishy flavor, and livery/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 used for beef flavor and off-flavor intensity was 1 = not detectable, 2 = slightly detectable, and 3 = strong.

Nutrient and Bioactive Compound Content Quantification

Creatine, creatinine, carnosine, and anserine were extracted from raw beef and analyzed by HPLC using methods adapted from Mora et al. (2008). Briefly, 6 mL of 0.01 *N* HCl were added to 2 g of ground, homogenized beef and vortexed for 15 s. These samples were placed on an orbital shaker for 15 min and centrifuged for 20 min at 12,000 × *g* and 4°C. The supernatant fraction was filtered through glass wool, and 250 µL were deproteinized by mixing with 750 µL of acetonitrile. Samples were held at 4° C for 20 min before centrifugation at 10,000 × *g* for 10 min.

Chromatography was performed using a Hewlett-Packard 1050 HPLC (Agilent Technologies, Palo Alto, CA) equipped with a quaternary pump, autosampler, and variable wavelength detector. An injection volume of 20 µL of deproteinized supernatant fluid was pumped through an Atlantis HILIC silica column (4.6 × 150 mm, 3 µm; Waters Corporation, Milford, MD). Solvent A consisted of 0.65 m*M* ammonium acetate in water/

Table 1. Statistics for carnitine, creatine, creatinine, carnosine, and anserine concentrations, Warner-Bratzler Shear force (WBSF), and trained panel sensory traits of longissimus muscle from Angus cattle

Trait	n[1]	Mean	SD	CV, %
Carnitine, mg/g muscle[2]	2,248	3.16	0.94	29.9
Creatine, mg/g muscle[2]	1,835	5.26	0.53	10.1
Creatinine, mg/g muscle[2]	2,161	0.21	0.11	52.4
Carnosine, mg/g muscle[2]	2,140	3.72	0.46	12.4
Anserine, mg/g muscle[2]	2,139	0.67	0.13	19.4
WBSF, kg	2,251	3.53	0.77	21.8
Panel tenderness[3]	1,720	5.79	0.59	10.2
Juiciness[3]	1,720	4.99	0.49	9.8
Beef flavor[4]	1,720	2.50	0.23	9.2
Painty/fishy flavor[4]	1,720	1.13	0.17	15.0
Livery/metallic flavor[4]	1,720	1.10	0.12	10.9

[1]Number of cattle.
[2]Fresh weight basis.
[3]1 = extremely dry/tough; 8 = extremely juicy/tender
[4]1 = not detectable; 3 = strong.

acetonitrile (25:75, vol/vol) with the pH at 5.5. Solvent B consisted of 4.55 m*M* ammonium acetate in water/acetonitrile (70:30, vol/vol) with the same pH as Solvent A. The solvent gradient was linear from 0% solvent B to 100% solvent B in 13 min, with a return to 0% solvent B in 2 min followed by re-equilibration at initial conditions for 5 min. Solvent flow rate was set at 1.4 mL/min. The variable wavelength detector was initially set at 236 nm and was changed to 214 nm after 4 min. Sample peak areas were correlated to standard curves of creatinine, creatine, carnosine, and anserine for quantification. Carnitine was analyzed by an enzymatic radioisotope method (McGarry and Foster, 1976).

Statistical Analyses

Trait means and standard deviations were calculated using the MEANS procedure (SAS Inst. Inc., Cary, NC). Least squares means by sex for the 5 meat compounds were obtained using the GLM procedure of SAS.

Restricted maximum likelihood procedures were used to estimate genetic and phenotypic (co)variances from a 5-trait animal model using the WOMBAT program (Meyer, 2007). In matrix notation, the basic model was:

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

where Y is a vector of the observations for 5 traits; X is an incidence matrix relating observations of 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 of the multiple-trait random effects and; e is a vector of the random residual errors for all measured traits and animals.

Contemporary groups were defined as gender at slaughter (bull, heifer, and steer) nested within slaughter date, with slaughter date nested within each finishing location (Iowa, Texas, and Colorado), for a total of 33 groups. Contemporary groups were fit as fixed effects in all analyses. It is assumed that E[y] = Xb, and that the random effects u and e are independent and have multivariate normal distributions with mean 0 and variances Var(u) = A Ä Σa and Var(e) = I Ä Σe, where Σa = matrix of additive genetic covariances between traits, Σe = residual covariance matrix; A = relationship matrix; I = identity matrix; and Ä = direct product between matrices.

A 5- generation pedigree file with 5,907 individuals containing the identification of the animal, sire, and dam was used to define relationships among animals in the data set. The pedigree included 2,282 animals with records and 2,070 animals without records (parents, grandparents, etc.). There were 537 sires, out of which 155 sires had progeny with phenotypic data in the data set, and 1,533 dams, out of which 564 had progeny phenotypic data in the data set. A multi-trait analysis for all 5 traits (carnitine, creatine, creatinine, carnosine, and anserine) was conducted to estimate heritabilities and the genetic correlations between pairs of traits. A bivariate analysis for WBSF and each of the 5 compounds was conducted to estimate the genetic correlations between pairs of traits. Significance of genetic correlations was obtained as $\theta \pm Z_{\alpha}/2$ (sampling error), assuming normality of the estimator, θ.

To evaluate the association between each compound and WBSF and sensory traits, a single-trait animal model and a stepwise approach was used to construct the final model. We started with contemporary groups as a fixed effect, and added 1 measure of palatability at a time as a covariate with the most significant effect in the model being included until no more significant effects could be added, using $P < 0.10$ as a threshold.

RESULTS AND DISCUSSION

The number of observations and simple statistics for the traits evaluated in this study are shown in Table 1. Beef is one of the most widely consumed protein sources in the world and an excellent source of vitamins and minerals (Biesalski, 2005; Zanovec et al., 2010; O'Neil et al., 2011). In recent years, growing interest of consumers for nutritional composition of food has resulted in numerous studies related to meat quality, including both visual and sensory traits. Relatively fewer studies exist on meat constituents like the 5 we measured. There is growing evidence, however, regarding potential implications for human health and well-being for some of these meat compounds.

Carnitine, sometimes regarded as a vitamin-like substance (Pekala et al., 2011), is an essential molecule in

fatty acid oxidation, mediating the transport of medium-/long-chain fatty acids into the mithocondrial matrix (Demarquoy et al., 2004) and preventing accumulation of toxic intermediate compounds by facilitating their transport out of the mitochondria. Oral L-carnitine supplementation has been reported to have beneficial effects on exercise capacity in clinical populations and is considered a potential ergogenic aid for endurance athletes (Muller et al., 2002). Although dietary reference intakes for L-carnitine have not been established, beef is one of the best dietary sources of L-carnitine (Demarquoy, 2011; Pekala et al., 2011). L-carnitine content of beef steaks in our study averaged 316 mg/serving (100 g).

Creatine is important to muscle energy metabolism and, under certain circumstances, creatine supplements can enhance muscle performance (Demant and Rhodes, 1999; McKenna et al., 1999). Based on data presented in the present study, a typical serving (100 g) of beef would provide an average of 526 mg of creatine. Creatine has been reported to improve short-term, intense exercise performance. Currently, some athletes try to consume between 2 and 5 g/d during training (Kraemer and Volek, 1998). Our data indicate that what is normally considered a serving of beef (100 g) can provide approximately ¼ of the lowest desired amount.

Creatine and its phosphorylated form irreversibly become creatinine in muscle as a result of a non-enzymatic conversion that involves the removal of water and the formation of a ring structure. This conversion takes place easily under elevated temperatures such as those observed while cooking meat (Skog et al., 1998). The presence of creatine and creatinine in meat has been implicated as a negative aspect of beef consumption because they can constitute important precursors of heterocyclic amines, which can be formed on the surface of meat when cooked at high temperatures using dry-heat such as in roasting, frying, and grilling (Pais et al., 1999).

Carnosine, a dipepetide with buffering capability in skeletal and other mammalian tissues (Decker et al., 2000), has significant antioxidant properties (Zhou and Decker, 1999). The amount of carnosine present in 100 g of beef in our study was 372 mg, which is similar to the commercially available daily supplements of 200 to 500 mg of carnosine. Mora et al. (2008) reported carnosine, creatine, and creatinine content in several different muscles in swine and showed that muscle type had a significant effect on the content of these 3 compounds, with greater content in glycolytic muscles. Our study was conducted on LM muscle (glycolytic), so we expect the content of these compounds in more oxidative muscle types to be less. Purchas and Busboom (2005) measured the concentration of carnosine, creatine, and creatinine in beef muscle from Angus-crossbred heifers finished on high-concentrate and pasture-based diets. The feedlot-finished beef, similar to that used in this study, had lower concentrations of carnosine and creatinine, but similar concentrations of creatine. The concentration values noted by Purchas and Busboom (2005) for these compounds should be interpreted with care given the small sample size in their study. The amount of carnosine reported in the present study is in line with values reported by Purchas and Zou (2008), who found more variation in the level of carnosine in different muscles than between pasture- and grain-finished cattle.

Anserine is a dipeptide present in skeletal muscle and brain (Kohen et al., 1988). Although the precise metabolic function of anserine is not known, a possible antioxidant function has been proposed. Given the proven efficiency of anserine to act as a Cu-chelating agent (Brown, 1981), a potential role in Cu metabolism in vivo also has been suggested. Anserine content of beef steaks in our study averaged 67 mg/serving (100 g), but no dietary reference intakes for anserine have been established.

In addition to health-promoting properties, all 5 of the compounds we evaluated are potential markers of dietary meat intake. Quantitative measures of meat intake have been of interest (Dragsted, 2010) because meat intake is associated with many different health outcomes, and assessment through food questionnaires is generally imprecise. The CV (Table 1) observed in this study suggest that carnitine followed by carnosine could be regarded as potentially useful biomarkers for meat intake because of their lower variability compared with the other beef compounds investigated in this study. Nonetheless, other factors that need further investigation might affect the utility of these compounds as dietary biomarkers, including specificity and sensitivity. More information on the amount of natural variation for carnitine, creatine, creatinine, carnosine, and anserine in different muscles and in different production systems is necessary before these compounds can be used reliably as biomarkers for meat intake.

The mean squares and statistical significance obtained for the effect of sex on the concentration of the 5 compounds in LM from Angus cattle are presented in Table 2. The carnitine concentration was greater in steers than in bulls and cows, whereas the concentrations of creatine and creatinine were greater in cows than in bulls and steers. No differences were among the sex classes were found in the carnosine and anserine concentrations. It should be noted that although statistically significant, the difference found among sexes for carnitine, creatine, and creatinine were small in magnitude and therefore likely of limited practical importance.

Heritabilities

Estimates of heritability for carnitine, creatine, cre-

Table 2. Number of records (n) and least squares means (LSM) by sex for carnitine, creatine, creatinine, carnosine, and anserine concentrations in longissimus muscle from Angus cattle

Meat compound, mg/g of muscle[1]		Sex		
		Male	Female	Steer
Carnitine	n	525	433	1,290
	LSM	2.94[a]	2.94[a]	3.23[b]
Creatine	n	473	314	1,041
	LSM	5.49[a]	5.23[b]	5.30[b]
Creatinine	n	527	345	1,289
	LSM	0.21[a]	0.22[b]	0.23[b]
Carnosine	n	527	358	1,255
	LSM	3.66[a]	3.67[a]	3.70[a]
Anserine	n	527	358	1,254
	LSM	0.67[a]	0.66[a]	0.67[a]

[1]Fresh weight basis.

[a,b]Within a row, least squares that do not have a common superscript differ, $P < 0.10$.

atinine, carnosine, and anserine concentrations in LM from Angus cattle varied from 0.02 to 0.53 (Table 3). Almost no genetic variation was observed in carnitine and creatinine, whereas creatine, carnosine, and anserine were moderately heritable. To our knowledge, this is the first report of heritability estimates for these compounds in muscles from beef cattle. Heritabilities for creatine, carnosine, and anserine are sufficiently large that their content in beef could be changed through selection. Carnosine in particular might have important health benefits that warrant its use in selection. Carnosine has been observed to exert anti-aging activity at cellular and whole-animal levels and it might provide protective action against neurodegeneration, secondary diabetic complications, and other age-related pathologies (Reddy et al., 2005). Possible biological activities of carnosine include scavenging of reactive O_2 and reactive N species, chelating Zn and Cu ions, in addition to its antiglycating activities (Wu et al., 2003). The ability of carnosine to react with deleterious aldehydes such as malondialdehyde, methylglyoxal, hydroxynonenal, and acetaldehyde (products of oxidative stress) could contribute to its protective functions (Hipkiss and Chana, 1998; Brownson and Hipkiss, 2000). A selection program aimed at increasing carnosine content in beef can be effective using mass selection with heritability of almost 40%. A substantial negative genetic correlation with creatine (−0.53), which may have some negative health effect, should heighten the attractiveness of increasing carnosine content in beef.

Table 3. Genetic (s^2a) and residual (s^2e) variance and heritability (h^2) estimates with sampling errors (SE) for carnitine, creatine, creatinine, carnosine, and anserine concentrations in LM from Angus cattle obtained by REML multiple-trait analysis

Trait, mg/g of muscle[1]	n^2	s^2_a	s^2_e	$h^2 \pm$ SE
Carnitine	2,248	0.0055	0.350	0.015 ± 0.032
Creatine	1,835	0.0974	0.127	0.434 ± 0.097
Creatinine	2,161	0.0001	0.002	0.070 ± 0.045
Carnosine	2,140	0.0557	0.089	0.383± 0.068
Anserine	2,139	0.0076	0.007	0.531 ± 0.075

[1]Fresh weight basis.

[2]Number of cattle.

Correlations

Genetic and phenotypic correlations, calculated using a multiple-trait animal model, are shown in Table 4. A significant moderate positive genetic and phenotypic correlation was identified between carnosine and anserine, and negative and medium genetic correlations were identified between creatine and both carnosine and anserine. The phenotypic correlations among all other components, even when statistically significant (creatinine with creatine, carnosine with anserine) were all very small and, therefore, most likely inconsequential.

Several relationships existed among the 5 compounds analyzed in this study. The negative phenotypic correlation between creatine and creatinine could be explained by the relationship between these 2 compounds. Creatine is converted in muscle tissue to creatinine through water removal and formation of a cyclic structure, and this non-enzymatic conversion is irreversible and takes place at a constant rate (Wyss and Kaddurah-Daouk, 2000). Creatinine also is generated from creatine phosphate after dephosphorylation and cyclisation. Carnosine is a dipeptide that is synthesized from β-alanine and L-histidine, whereas anserine is an N-methylated derivative of carnosine (Quinn et al., 1992). Moderate positive correlations, both genetic and phenotypic, identified between carnosine and anserine in the present study are likely to be beneficial if one considers that both carnosine and anserine have anti-oxidant properties. Moreover, carnosine and anserine block the formation of advanced glycosylation end-products that are produced at greater rates in pathological circumstances such as diabetes, cataracts, arteriosclerosis, and Alzheimer's disease (Reddy et al., 2005). Furthermore, addition of carnosine was shown to inhibit fatty acid oxidation and formation of metmyoglobin in meat, which results in improved storability through stabilization of meat color and flavor (Sanchez-Escalante et al., 2001; Djenane et al., 2004; Das et al., 2006; Badr, 2007).

Several of the genetic correlations identified in this study could be regarded as beneficial, which indicates that these traits could be improved simultaneously, if desired. It is important however, to note the extremely low genetic variation especially in carnitine, creatinine, and

Table 4. Estimates of genetic (above the diagonal) and phenotypic (below the diagonal) correlations with approximate sampling errors (in parentheses) between carnitine, creatine, creatinine, carnosine, and anserine concentrations in LM from Angus cattle obtained by REML multiple-trait analysis (genetic and phenotypic correlations for WBSF were obtained by REML bivariate analyses)

Trait, mg/g of muscle[1]	Carnitine	Creatine	Creatinine	Carnosine	Anserine	WBSF
Carnitine	-	-0.769 (0.801)	-0.368 (0.907)	-0.076 (0.488)	0.565 (0.651)	NE[2]
Creatine	-0.032 (.024)	-	0.449 (0.280)	-0.530* (0.136)	-0.459* (0.127)	0.022 (0.201)
Creatinine	-0.002 (0.022)	0.056* (0.025)	-	-0.299 (0.259)	-0.115 (0.242)	-0.385 (0.291)
Carnosine	-0.003 (0.022)	0.010 (0.029)	0.076* (0.023)	-	0.249* (0.120)	0.176 (0.169)
Anserine	0.020 (0.023)	-0.001 (0.029)	0.057* (0.023)	0.254* (0.024)	-	-0.013 (0.161)
WBSF	-0.004 (0.022)	0.023 (0.025)	0.037 (0.022)	0.139* (0.023)	0.042 (0.024)	-

[1]Fresh weight basis.
[2]Not estimable.
*Significant correlation, $P < 0.05$.

anserine concentrations. Although most of the genetic correlations between the meat compounds analyzed in this study were rather large (although most not significant), the phenotypic correlations were minimal as a result of rather large and of opposite sign residual or environmental correlations (data not shown).

Relationships With Sensory Traits

Regression estimates and standard errors for sensory traits with statistically significant associations with meat compounds are shown in Table 5. Beef and livery/metallic flavor were not significantly associated with any of the 5 compounds analyzed ($P > 0.10$). Conversely, carnitine concentrations were not significantly associated ($P > 0.10$) with any of the meat quality traits analyzed.

Carnosine was negatively associated with overall tenderness as assessed by the panelist on the sensory analyses. Similar associations with the overall tenderness were identified for creatinine and anserine. Increased tenderness as evaluated by the panelists on the sensory panel (1 point on the 8-point scale) was associated with a decrease of 0.005 mg creatine, 0.083 mg carnosine, and 0.01 mg anserine/g of meat. The associations identified between the concentrations of these compounds and tenderness, assessed by panelists, might be related to the intramuscular fat content as well as the proportion of different muscle fiber types. Carnitine, creatine, creatinine, carnosine, and anserine are distributed only in muscle tissue (Wyss and Kaddurah-Daouk, 2000; Hipkiss, 2009). Therefore, steaks with less muscle tissue per mass of steak will have reduced creatinine, carnosine, and anserine concentrations. Smith et al. (1985) reported that steaks from carcasses with greater marbling scores had lower ($P < 0.05$) shear force values and increased ($P < 0.05$) sensory panel ratings than steaks with lower marbling scores, findings that were supported by results on the present data presented by Garmyn et al. (2011).

Positive associations were identified between juiciness and creatine, creatinine, and anserine concentrations. Increased juiciness (1 point on the 8-point scale) was associated with an increase of 0.06 mg creatine, 0.005 mg creatinine, and 0.013 mg anserine/g of meat.

The undesirable painty/fishy flavor was the only flavor significantly associated with creatinine and carnosine. The association was advantageously negative, with increased painty/fishy flavor (1 point on the 3-point scale) associated with a decrease of 0.026 mg creatinine and 0.182 mg carnosine/g of meat. This relationship could be explained by the fact that, at physiological concentrations in muscle, carnosine can scavenge reactive O_2 species and have anti-oxidant effects (Hipkiss, 2009), decreasing products of lipid peroxidation in edible beef (Derave et al., 2010) that could be perceived by the trained sensory panel members as painty/fishy flavor.

In conclusion, results of this study indicate that muscle concentrations of creatine, carnosine, and anserine were moderately heritable, whereas almost no ge-

Table 5. Estimates of regression and their respective SE (in parentheses) for sensory traits with statistically significant associations with creatine, creatinine, carnosine, and anserine concentrations in LM from Angus cattle[1]

Trait	Creatine	Creatinine	Carnosine	Anserine
Overall tenderness[2]		-0.005(0.002)	-0.083(0.018)	-0.010(0.006)
Juiciness[2]	0.06(0.03)	0.005(0.002)		0.013(0.007)
Painty/fishy flavor[3]		-0.026(.008)	-0.182(0.063)	

[1]Sensory traits analyzed included: panel tenderness, juiciness, beef flavor, painty/fishy flavor, and livery/metallic flavor.
[2]1 = extremely dry/tough; 8 = extremely juicy/tender.
[3]1 = not detectable; 3 = strong.

netic variation was observed in carnitine and creatinine. The additive genetic variation for some of these traits is sufficiently large to be exploited in specific breeding programs. The estimated genetic correlations were low or moderate in magnitude and, in general, favorable or weak, indicating that simultaneous improvement is feasible. Few associations between these compounds and WBSF or meat quality assessed by sensory panels were detected, and these associations were favorable, suggesting that palatability would not be compromised if the nutritional profile of beef would be improved by increasing the concentration of these compounds. In addition, the lower CV for carnitine and carnosine exhibited in this study could be a desirable attribute if these compounds are to be used as biomarkers for meat intake.

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