Fatty acid profile, mineral content, and palatability of beef from a multibreed Angus–Brahman population[1]

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ABSTRACT: Consumers demand meat that is both healthy and palatable, 2 attributes of meat that are affected by lipid content. Many cattle in the southern United States are *Bos indicus* influenced, as this improves the ability to survive and thrive in these subtropical regions. However, these animals tend to have leaner carcasses and less marbled meat products. Thus, the objective of this study was to examine the effect of percent Brahman genetics on carcass characteristics, palatability, fatty acids profile, and minerals content in LM of steers from a multibreed population ranging from 100% Angus to 100% Brahman. Breed effect was significant for birth weight ($P = 0.0003$), weaning weight ($P < 0.0001$), HCW ($P < 0.0001$), dressing percentage ($P = 0.0008$), ribeye area ($P = 0.002$), quality grade ($P < 0.0001$), and marbling score ($P < 0.0001$), and all these traits except dressing percentage decreased as the percentage of Brahman increased. Among palatability traits, breed group had a significant effect only on tenderness (**TEND**) and connective tissue (CT) scores ($P < 0.0001$). Least squares means decreased from Angus (5.75 ± 0.13 TEND score and 6.29 ± 0.14 CT score, respectively) to Brahman (4.84 ± 0.10 TEND score and 5.49 ± 0.11 CT score, respectively) as indicated by a significant linear effect. Breed group significantly affected the percentage of several individual fatty acids, saturated fatty acids (SFA), and polyunsaturated fatty acids (PUFA), but not monounsaturated fatty acids (MUFA). The 100% Angus group had the highest percentage of SFA at 49.92%, which was significantly higher ($P < 0.05$) than the SFA percentage in the 50%, 75%, and 100% Brahman breed groups. Brangus animals also had an increased SFA percentage compared with the 100% Brahman animals ($P < 0.05$). No significant effect was identified for the concentration of PUFA across the 6 breed groups ($P = 0.14$). Least squares means decreased from 100% Angus to 100% Brahman for concentration of total fat, SFA, and MUFA (g/mg meat). The concentration of magnesium ($P < 0.0001$), phosphorus ($P = 0.06$), and potassium ($P = 0.06$) increased as the percentage of Brahman increased. Our study shows that breed has a significant effect on the fatty acid profile of beef. Cattle with high Brahman percentage, which are characterized by lower marbled meat, will present a more favorable healthfulness profile with reduced content of SFA and MUFA but the same content of PUFA as purebred Angus animals.

Key words: beef cattle, *Bos indicus*, healthfulness, mineral content

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INTRODUCTION

Brahman genetics are extensively used in crossbreeding programs in the southeastern regions of the United States (Cundiff et al., 2012; Lamy et al., 2012), characterized by hot and humid conditions typical of tropical and subtropical

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environments. Although Brahman cattle are well known for their adaptability in subtropical climates (Hansen, 2004), they tend to produce less marbling within the final beef product (Johnson et al., 1990; Pringle et al., 1997; Elzo et al., 2012). Several studies addressing relevant economic traits such as growth, carcass, and reproduction in *Bos indicus* influenced cattle prevalent in the southern United States have been published (Riley, 2002; Riley et al., 2012; Elzo et al., 2014; Elzo et al., 2016; Elzo et al., 2017; Leal-Gutiérrez et al., 2018), but information regarding fatty acid composition and mineral content is scarce.

A recent Beef Demand study identified 7 factors as consequential for driving beef demand (Schroeder et al., 2013). Ranked in the order of their relevance to consumers, these factors are beef price, food safety, product quality, health, nutrition, social aspects, and sustainability. Given that the industry cannot control price, the report identified food safety, product quality, nutritional value, and healthfulness as the key attributes that the industry can and should focus on. Beef consumption helps Americans fulfill their daily-recommended dietary intake of protein, by providing 20 g of protein per 100 g of beef consumed, while also providing many nutrients with positive effects on human health (monounsaturated fatty acids [MUFA] and polyunsaturated fatty acids [PUFA], such as omega-3 and conjugated linoleic acid [CLA], iron, zinc, and vitamin B6). However, beef is also associated with characteristics that are often perceived as negative, such as high levels of saturated fatty acids (SFA) and high caloric content. Knowledge of the role of *B. indicus*–influenced cattle concerning these areas is essential for the prosperity of the beef industry in the southern United States.

Intramuscular fat depot or "marbling" is a key factor in determining carcass value. Although *Bos taurus* breeds of cattle, such as Angus, are known for their superior marbling potential, *B. indicus* breeds have the tendency to produce less marbled beef products. The amount of intramuscular fat described by marbling and the fatty acid composition determines the healthfulness value of the beef product. PUFA and MUFA are known to have cholesterol-lowering properties and reduce the risk of coronary vascular disease among other healthful attributes. On the contrary, several short-chain SFA are associated with increased risk of coronary vascular disease (Bonanome and Grundy, 1988; Derr et al., 1993; Judd et al., 2002; Brouwer et al., 2010).

Breed, along with other factors such as sex, age, and diet (Wood et al., 2008; Mateescu, 2015), has an impact on both the amount of marbling and the fatty acid composition. Numerous recent reports are available regarding the fatty acid composition of *B. taurus* breeds (Nogi et al., 2011; Xu et al., 2013; Buchanan et al., 2015; Ekine-Dzivenu et al., 2017; Zhu et al., 2017), but information on the quality of fat and the healthfulness and nutritional value of beef from *B. indicus*–influenced cattle, in particular Brahman, is scarce (Dinh et al., 2010; Campbell et al., 2016).

The objective of this study was to characterize the carcass and palatability traits, fatty acid composition, and mineral content in a multibreed cattle population typical to the southern United States and estimate the effect of breed composition on nutritional and healthfulness value of beef.

MATERIALS AND METHODS

Animals and Management

The research protocol was approved by the University of Florida Institutional Animal Care and Use Committee number 201003744. Cattle used in this study were from the University of Florida multibreed Angus–Brahman herd (Elzo et al., 2014). A total of 230 steers across 6 breed groups based on the percentages of Angus breed composition were used from this herd: Angus = 100% to 80% (n = 39); 75% Angus = 79% to 65% (n = 33); Brangus = 62.5% (n = 30); 50% Angus = 59% to 40% (n = 42); 25% Angus = 39% to 20% (n = 27); and Brahman = 19% to 0% (n = 59). Steers born in 2014 and 2015 were transported to a contract feeder (Quincey Farms, Chiefland, FL) where they were provided a standard feedlot diet consisting of corn, protein, vitamins, and minerals until they reached a subcutaneous fat thickness over the ribeye of approximately 1.27 cm assessed through ultrasound. The concentrate diet had, on the average, 89.7% of DM, 14.4% of CP, 1.5 Mcal/kg DM of NEm, and 1.1 Mcal/kg DM of NEg. As cattle achieved appropriate degree of back fat thickness, they were transported to a commercial packing plant where they were harvested under USDA FSIS inspection. Steers were harvested in groups of 15 to 25 animals and the average slaughter age was 18.76 ± 1.13 mo.

Carcass Evaluation and Sample Collection

At 24-h postmortem, carcasses were ribbed between the 12th and 13th rib, per industry standard and carcass measurements were evaluated for each animal: HCW, dressing percentage (**DP**), marbling score (**MS**; 100 to 199 = practically devoid, 200 to 299 = traces, 300 to 399 = slight, 400 to 499 = small, 500 to 599 = modest, 600 to 699 = moderate, 700 to 799 = slightly abundant, 800 to 899 = moderately abundant, and 900 to 999 = abundant), ribeye area (**REA**), and fat over the eye (**FOE**). USDA quality grades (QG) and yield grades were calculated according to industry standards. Following carcass evaluation, two 2.54-cm thick steaks were removed from the anterior end of the carcass ribbing and transferred to the University of Florida Meat Processing Center (Gainesville, FL). Steaks were wet aged for 14 d and then frozen (−20 °C) until subsequent fatty acid, mineral, tenderness, and sensory analysis.

Warner–Bratzler Shear Force and Sensory Panel Analysis

One of the two frozen steaks from each animal was thawed at 3 °C for 24 h and cooked on an open-top, electric grill. Steaks were cooked to an internal temperature of 71 °C, equivalent to a medium degree of doneness. Internal temperature was monitored using copper-constant thermocouples (Omega Engineering Inc., Stamford, CT) located in the geometric center of each steak. Temperature was recorded by a 1100 Labtech Notebook Pro Software version 12.1 (Computer Boards Inc., Middleboro, MA). Once cooked, steaks were chilled at 3 °C for 24 h. After chilling, six 1.27-cm cores were removed from each steak parallel to the muscle fibers. Each of the 6 cores were sheared through the center (crosshead speed of 200 mm/min) with a Warner–Bratzler shear force (**WBSF**) head attached to a 490-N load cell using an Instron Universal Testing Machine (Instron Corporation, Canton, Massachusetts, USA).

The other frozen steak from each animal was handled and cooked in the same manner as the WBSF samples. Once cooked, steaks were cut into 1.27-cm cubes and served warm to trained sensory panelists. The sensory panel consisted of 7 to 11 trained members (AMSA, 1995) who evaluated each sample for various meat palatability traits. Sensory panel measurements analyzed by the sensory panelists included tenderness score (**TEND**; 1 = extremely tough to 8=extremely tender), connective tissue score (**CT**; 1 = abundant amount to 8 = none detected), juiciness score (**JUIC**; 1 = extremely dry to 8 = extremely juicy), beef flavor score (**FLAV**; 1 = extremely bland to 8 = extremely intense), and off-flavor score (**OFLAV**; 1 = extreme off-flavor to 6 = none detected).

Fatty Acid Extraction and Gas Chromatography Analysis

After trimming external fat and connective tissue, a thin shaving across the entire steak surface was removed from each steak sample and powdered in liquid nitrogen to obtain a homogenized sample of the steak. Fatty acid extraction and analysis was performed at the W. M. Keck Metabolomics Research Laboratory, Iowa State University (Ames, IA). About 200 mg of finely ground steak samples were extracted into 1 mL of 2:1 chloroform:methanol mixture. The extracted fats were transesterified with 25% sodium methoxide in methanol. The resulting fatty acid methyl esters (**FAMES**) were extracted into hexane and detected on Agilent 7890A GC-FID instrument. One microliter of the sample was injected into an Agilent 7890. A gas chromatograph equipped with a flame ionization detector was used for separation and quantification of the FAMEs. The analysis was performed on Agilent CP-Wax 52CB column (15 m, 0.32 mm, 0.5 μm). The oven temperature program was as follows. Initial temperature of 100 °C increased to 170 °C with a ramp of 2 °C/min, increased to 180 °C with a ramp of 0.5 °C/min, and to a final temperature of 250 °C with a ramp of 1 °C/min and held for 3 min. The inlet temperature was 250 °C and detector temperatures were 220 °C. Helium was used as the carrier gas. Supelco 37 FAME mix (Catalog # CRM47885 SUPELCO) was used to generate the calibration curve for identification and quantification of FAMES.

Twenty-eight individual fatty acids and 3 groups of fatty acids based on the saturation level (SFA, MUFA, and PUFA) were calculated and expressed as percentage of the total fatty acids and as mg/g of tissue.

Mineral Concentrations

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 (Davis and Lin, 2005), 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 methods 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 watts for 15 min. Digested samples were transferred to 25-mL volumetric flasks and diluted with deionized water. The concentrations of iron, phosphorus, potassium, sodium, magnesium, and zinc were then measured by ICP-OES.

Statistical Analysis

All statistical analyses were performed using SAS 9.4 (SAS Institute Inc., Cary, NC). The MEANS procedure was used to produce descriptive statistics for fatty acid composition data. Traits were analyzed using the MIXED procedure of SAS. Models for all traits included year of birth as a random effect and breed as fixed effects. Breed-group least squares means were separated using LSMEANS with the PDIFF option. To estimate the linear and quadratic effects of percent Brahman genetics, the breed groups were recoded as 0, 1, 1.5, 2, 3, and 4 indicating 0%, 25%, 37.25%, 50%, 75%, and 100% Brahman genetics, respectively. The model included year of birth as a random effect and the linear and quadratic breed as a covariate. When the quadratic effect was not significant, it was dropped and a model including just the linear effect was used. The intercept from this model estimates the effect of 100% Angus genes (adjusted for random year of birth effect) and the estimated regression coefficients represent the effect of replacing 25% of Angus genes by Brahman genes.

RESULTS AND DISCUSSION

Table 1 presents summary statistics for traits evaluated in this study in a population of 230 animals with breed composition ranging from 100% Angus to 100% Brahman.

Carcass Characteristics

Least squares means of carcass measurements for the 6 breed groups in this study are presented in Table 2. The carcass data for the total 230 animals are representative of industry average quality and yield grades (Shackelford et al., 2012) and similar to previously reported data on this multibreed population (Elzo et al., 2012; Elzo et al., 2014; Elzo et al., 2016). Breed effect was significant for BW ($P = 0.0003$), WW ($P < 0.0001$), HCW ($P < 0.0001$), DP ($P = 0.0008$), REA ($P = 0.002$), QG ($P < 0.0001$), and MS ($P < 0.0001$). No breed differences were identified for FOE which was expected as a direct consequence of animals slaughtered at a similar fat thickness end point. Cattle with the highest percent Brahman (Brahman breed group) had the lowest HCW and REA compared with all other breed groups. This is in agreement with previous studies which reported that Angus cattle had heavier HCW and greater REA than Brahman (Peacock et al., 1979; Lunt et al., 1985; Williams et al., 2010, Elzo et al., 2012).

Marbling score decreased from Angus (464.12 ± 13.12 units) to Brahman (352.85 ± 10.34 units), with the highest percentage Brahman animals having statistically lower marbling scores than all the other breed groups ($P < 0.0001$). This was also reflected in the QG which followed the same trend across breed groups with Brahman having the lowest QG (547.37 ± 5.6) compared with all other breed compositions. It is important to point out that the Angus, 75% Angus, and Brangus breed groups had a marbling score higher than the industry average (449 ± 94.8), and the Brahman breed group was within one standard deviation of this average (Shackelford et al., 2012).

Table 2 also contains least squares means for the 6 breed groups for meat palatability traits. No significant differences were found for beef flavor or off flavor across the breed groups. Breed group had a significant effect only on TEND and CT traits recorded during the trained sensory panel ($P < 0.0001$). A negative linear effect was significant with least squares means decreasing from Angus (5.75 ± 0.13 TEND score and 6.29 ± 0.14 CT score, respectively) to Brahman (4.84 ± 0.10 TEND score and 5.49 ± 0.11 CT score, respectively). Previous reports consistently identified animals with high Brahman influence to have lower sensory tenderness scores and higher connective tissue scores (Johnson et al., 1990; Pringle et al., 1997; Elzo et al., 2012). The lower tenderness of Brahman cattle has been attributed to increased postmortem calpastatin activity (Wheeler et al., 1990; Shackelford et al., 1991; Pringle et al., 1997) which results in a reduction in desmin and troponin-T degradation (Phelps et al., 2017). There are two important points related to the tenderness qualities of steaks from Angus, Brahman, and their crossbreds evaluated by WBSF or through the sensory panel. When using the WBSF, considered an objective measure of tenderness, no significant differences were detected along the breed composition continuum from purebred Angus to purebred Brahman. The coefficient of variation obtained from a regression analysis of

Table 1. Summary statistics for carcass quality, meat quality, mineral content, and fatty acid composition of animals available for this study

Trait	*N*	Mean	SD	Min	Max
Carcass quality					
BW, kg	230	34.07	6.04	18.14	50.80
WW, kg	230	238.36	40.73	120.20	353.80
HCW, kg	230	333.58	42.15	215.00	467.65
Dressing percentage, %	230	60.15	2.94	53.30	70.90
Fat thickness, cm	230	1.46	0.64	0.28	4.06
Yield grade	230	3.43	0.80	0.60	8.10
Quality grade	230	587.77	50.00	490.00	700.00
Meat quality					
LM area, cm^2	230	77.81	12.09	47.74	129.03
Marbling score[1]	230	416.78	89.54	280.00	700.00
WBSF, kg	230	4.52	1.18	2.10	7.90
Tenderness[2]	230	5.25	0.83	3.00	7.50
Juiciness[2]	230	4.99	0.66	3.40	6.60
Connective tissue[2]	230	5.80	0.88	3.50	7.60
Flavor[2]	230	5.54	0.46	4.20	6.70
Off flavor[2]	230	5.69	0.26	4.60	60.00
Mineral content					
Ca, µg/g	230	88.26	43.91	33.14	215.95
Fe, µg/g	230	14.57	3.75	4.76	27.44
K, µg/g	230	3158.86	513.79	1033.66	4658.84
Mg, µg/g	230	210.39	36.13	81.98	347.71
Na, µg/g	230	351.81	59.72	127.35	520.30
P, µg/g	230	1727.31	282.75	559.59	2796.58
Zn, µg/g	230	32.69	7.42	9.19	64.08
Fatty acid composition					
SFA, %	230	48.51	3.85	38.66	64.77
MUFA,%	230	45.79	5.08	36.27	54.66
PUFA, %	230	5.70	2.58	2.69	17.39
SFA, mg/100g meat	230	4.91	3.39	0.46	15.65
MUFA, mg/100g meat	230	4.64	3.13	0.09	13.93
PUFA, mg/100g meat	230	0.49	0.25	0.05	1.85
Total fat	230	10.04	6.71	1.34	38.26

[1]Marbling score: 100 to 199 = Devoid, 200 to 299 = traces, 300 to 399 = Slight, 400 to 499 = Small, 500 to 599 = Modest, 600 to 699=Moderate, 700 to 799 = Slightly abundant.

[2]Sensory traits: tenderness, connective tissue, beef flavor intensity, and juiciness on scales form 1 to 8 (1 = extremely tough, abundant amount, extremely bland, extremely dry; 8 = extremely tender, none detected, extremely intense, extremely juicy). Off flavor was evaluated on a scale from 1 to 6 (1 = extreme off-flavor to 6 = none detected).

sensory tenderness using WBSF values was 13.34 indicating variation in the sensory tenderness which is not captured by the WBSF. However, a statistically significant difference was found when tenderness was evaluated either by the TEND or CT score during the trained sensory panel. Among other factors, tenderness as perceived by consumers is determined by the amount and solubility of the connective tissue and the amount of marbling. Marbling has a major effect on the perceived juiciness and a high correlation was reported between tenderness and juiciness (Mateescu et al., 2015), where steaks with high marbling score have superior juiciness and overall liking (Killinger et al., 2004; Okumura et al., 2007; Legako et al., 2015). It is however important to highlight the fact that although statistically significant, these differences are insignificant in terms of changes in tenderness that can be perceived by regular, untrained consumers (Watson et al., 2008). These results indicate that meat from *B. indicus*–influenced cattle tends to be less tender compared with meat from Angus animals, but these differences, when measured objectively using WBSF, are not statistically significant. Moreover, when considering that the minimum difference the average consumer can detect is a 0.5-kg difference in WBSF when consuming meat at home (Miller et al., 1995), the differences found in

Table 2. Least squares means and SE for carcass and meat quality characteristics in Angus (n = 39), 75% Angus (n = 33), Brangus (n = 30), 50% Angus (n = 42), 25% Angus (n = 27), and Brahman (n = 59) cattle

	Breed group									
Trait	Angus	75% A	Brangus	50% A	25% A	Brahman	SE[1]	I[2]	b_1[2]	b_2[2]
Birth weight, kg	33.40[bc]	33.79[bc]	35.99[ab]	34.69[ab]	37.52[a]	31.51[c]	0.97	32.96	3.174[S]	−0.852[S]
Weaning weight, kg	254.25[a]	246.88[a]	251.14[a]	243.65[a]	238.64[a]	206.68[b]	5.73	268.69	4.862	−3.998[S]
HCW, kg	339.61[a]	349.00[a]	350.48[a]	338.92[a]	341.30[a]	304.90[b]	5.48	368.09	13.654[S]	−5.591[S]
Dressing percentage, %	58.88[b]	60.59[a]	60.90[a]	60.27[a]	61.23[a]	60.20[a]	0.38	61.242	1.443[S]	−0.291[S]
Fat over the eye, cm	1.64	1.42	1.45	1.4	1.44	1.4	0.11	1.676	−0.042	–
Ribeye area, cm²	79.41[a]	80.77[a]	81.14[a]	77.07[ab]	77.98[a]	73.23[b]	1.66	89.766	−1.769[S]	–
Yield grade	3.57	3.39	3.44	3.54	3.46	3.25	0.13	3.536	−0.066	–
Quality grade	613.80[a]	604.24[ab]	612.20[a]	590.82[b]	582.58[b]	547.37[c]	7.21	619.59	0.597	−4.255[S]
Marbling Score[3]	464.12[a]	443.02[ab]	456.48[ab]	422.95[bc]	399.01[c]	352.85[d]	13.31	486.02	−28.79[S]	–
WBSF, kg	4.38	4.78	4.58	4.63	4.94	4.7	0.17	3.927	0.069	–
Juiciness[4]	5.15[a]	5.12[a]	5.13[a]	5.04[ab]	4.87[ab]	4.80[b]	0.11	5.049	−0.095[S]	–
Flavor[4]	5.62	5.59	5.6	5.53	5.45	5.41	0.07	5.427	−0.057[S]	–
Tenderness[4]	5.75[a]	5.53[ab]	5.51[ab]	5.21[bc]	5.07[cd]	4.84[d]	0.13	5.554	−0.231[S]	–
Connective tissue[4]	6.29[a]	6.00[ab]	6.02[ab]	5.84[bc]	5.49[cd]	5.49[d]	0.14	76.19	−0.205[S]	–
Off-flavor[4]	5.74	5.72	5.73	5.66	5.71	5.7	0.05	5.631	−0.009	–

Within each row, means without common letters differ (P < 0.05).

[1]Average SE across the breed groups.

[2]Intercept (i), linear (b_1), and quadratic (b_2) effect of percent Brahman genetics.

[3]Marbling score: 100 to 199 = Devoid, 200 to 299 = traces, 300 to 399 = Slight, 400 to 499 = Small, 500 to 599 = Modest, 600 to 699 = Moderate, 700 to 799 = Slightly abundant.

[4]Sensory traits: tenderness, connective tissue, beef flavor intensity, and juiciness on scales form 1 to 8 (1 = extremely tough, abundant amount, extremely bland, extremely dry; 8 = extremely tender, none detected, extremely intense, extremely juicy). Off-flavor was evaluated on a scale from 1 to 6 (1 = extreme off-flavor to 6 = none detected).

[S]Linear or quadratic effect significant at P < 0.05.

this study are not sufficiently large to be detectable by consumers. These results suggest that selection programs aimed at improving tenderness in these *B. indicus* populations are producing the intended results and the historical perception of tougher beef associated with *indicine*-influenced cattle needs to be reevaluated.

Breed Effect on Fatty Acid Composition

Percentages of the three main fatty acids categories in the overall population were as expected, with approximately 47.52% to 49.92% of the total lipid content being represented by SFA, 45.10% to 46.10% by MUFA, and 3.98% to 7.38% PUFA (Pitchford et al., 2002; Daley et al., 2010; Garmyn et al., 2011). The fatty acid composition in steers from 6 breed groups, expressed both as percentage of total fatty acids and as mg/100 g muscle, is presented in Tables 3 and 4, respectively.

Breed group significantly affected the percentage of several individual fatty acids, SFA, and PUFA, but not MUFA. The Angus group had the highest percentage of SFA at 49.92%, which was significantly higher than the SFA percentage in the 50%, 75%, and 100% Brahman breed groups (P = 0.006, 0.008, and 0.002, respectively). Brangus animals also had a significantly (P = 0.04) higher SFA percentage compared with the 100% Brahman animals. These differences were mainly a consequence of higher percentages of C16:0 and C18:0 in Angus or Brangus compared with animals with higher Brahman composition.

The opposite relationship was observed for PUFA, with the percentage of these classes of fatty acids increasing as the percentage of Brahman genetics increased. Meat from Brahman steers had the highest percentage of PUFA (7.38 ± 0.39) compared with all other breed groups, whereas steers from the Angus group had a significantly lower percentage of PUFA compared with the 50%, 75%, and 100% Brahman breed groups.

The fatty acid concentration (mg/g meat) showed a significant breed group effect for most of the individual fatty acids and for total fat, SFA, and MUFA. No significant effect was identified for the concentration of PUFA across the 6 breed groups (P = 0.14). Least squares means showed a downward trend from Angus to Brahman for concentration of total fat, SFA, and MUFA. For all 3 fatty acid

Table 3. Least squares means and SE for fatty acid proportion (g/100 g of total fatty acids) in Angus (n = 39), 75% Angus (n = 33), Brangus (n = 30), 50% Angus (n = 42), 25% Angus (n = 27), and Brahman (n = 59) cattle

	Breed group									
Trait	Angus	75% A	Brangus	50% A	25% A	Brahman	SE[1]	I[2]	b_1[2]	b_2[2]
C10:0	0.05^{c}	0.06^{bc}	0.06^{bc}	0.05^{bc}	0.06^{b}	0.07^{a}	0.003	0.053	−0.001	0.001^{S}
C11:0	0.01^{b}	0.02^{b}	0.02^{b}	0.02^{b}	0.02^{b}	0.04^{a}	0.003	0.024	−0.002	0.002^{S}
C12:0	0.07^{c}	0.08^{b}	0.08^{b}	0.07^{bc}	0.08^{b}	0.09^{a}	0.003	0.069	0.006^{S}	–
C13:0	0.01	0.02	0.02	0.01	0.01	0.02	0.002	0.014	0.001^{S}	–
C14:0	3.15	3.33	3.52	3.21	3.39	3.26	0.104	3.931	0.011	–
C14:1	0.70	0.82	0.87	0.81	0.83	0.86	0.046	0.833	0.029^{S}	–
C15:0	0.39	0.40	0.41	0.38	0.39	0.40	0.013	0.558	0.0008	–
C16:0	30.39^{a}	29.82^{a}	30.03^{a}	28.6^{b}	28.48^{b}	28.51^{b}	0.365	28.751	−0.496^{S}	–
C16:1	3.35^{c}	3.67^{ab}	3.73^{ab}	3.56^{abc}	3.41^{bc}	3.76^{a}	0.114	3.736	0.063	–
C17:0	1.16^{a}	1.12^{a}	1.10^{a}	1.10^{a}	1.15^{a}	1.14^{a}	0.038	1.541	−0.0008	–
C17:1	0.70^{abc}	0.79^{ab}	0.62^{bc}	0.61^{c}	0.72^{abc}	0.82^{a}	0.062	0.919	−0.112	0.033^{S}
C18:0	14.47	13.91	13.80	14.00	14.45	13.71	0.326	13.451	−0.115	–
C18:1	41.02	40.30	40.24	41.68	40.73	39.28	0.865	41.768	−0.359	–
C18:2n-6 *cis*	2.51^{c}	3.37^{b}	3.17^{bc}	3.43^{b}	3.73^{b}	4.8^{a}	0.270	3.298	0.530^{S}	–
C18:2n-6 *trans*	0.29^{c}	0.30^{bc}	0.32^{ab}	0.32^{a}	0.31^{abc}	0.31^{ab}	0.008	0.265	0.023^{S}	−0.005^{S}
C18:3n-6	0.04	0.05	0.07	0.05	0.05	0.07	0.009	0.044	0.006^{S}	–
C18:3n-3	0.23^{c}	0.25^{bc}	0.26^{bc}	0.27^{b}	0.27^{b}	0.31^{a}	0.008	0.202	0.019^{S}	–
C20:0	0.11^{a}	0.11^{a}	0.10^{ab}	0.11^{a}	0.10^{ab}	0.10^{b}	0.003	0.084	−0.003^{S}	–
C20:1n-9	0.28	0.30	0.29	0.03	0.27	0.28	0.010	0.319	−0.004	–
C20:2	0.08^{d}	0.08^{cd}	0.08^{cd}	0.09^{bc}	0.10^{b}	0.14^{a}	0.006	0.052	−0.0003	0.004^{S}
C20:3n-6	0.17^{c}	0.21^{bc}	0.23^{bc}	0.23^{bc}	0.26^{b}	0.34^{a}	0.026	0.161	0.039^{S}	–
C20:3n-3	0.55^{c}	0.67^{bc}	0.61^{bc}	0.75^{bc}	0.85^{b}	1.18^{a}	0.079	0.443	−0.002	0.039^{S}
C20:5n-3	0.05^{c}	0.05^{bc}	0.06^{bc}	0.06^{bc}	0.07^{b}	0.10^{a}	0.007	0.016	−0.001	0.004^{S}
C22:0	0.01	0.01	0.01	0.01	0.02	0.02	0.002	0.017	0.002^{S}	–
C22:2	0.01^{c}	0.01^{bc}	0.02^{ab}	0.02^{abc}	0.02^{abc}	0.02^{a}	0.003	0.034	0.002^{S}	–
C23:0	0.10^{bc}	0.13^{bc}	0.09^{c}	0.11^{bc}	0.14^{ab}	0.17^{a}	0.015	0.083	0.017^{S}	–
C22:6n-3	0.05^{c}	0.06^{bc}	0.11^{ab}	0.08^{abc}	0.05^{c}	0.12^{a}	0.020	0.009	0.012^{S}	–
C24:1n-9	0.05^{c}	0.05^{c}	0.10^{ab}	0.06^{bc}	0.04^{c}	0.10^{a}	0.014	0.025	0.009^{S}	–
SFA	49.92^{a}	49^{abc}	49.23^{ab}	47.69^{bc}	48.29^{abc}	47.52^{c}	0.602	48.031	−0.566^{S}	–
MUFA	46.10	45.93	45.84	47.02	45.99	45.10	0.830	47.531	−0.235	–
PUFA	3.98^{c}	5.06^{bc}	4.93^{bc}	5.29^{b}	5.72^{b}	7.38^{a}	0.391	4.438	0.802^{S}	–

Within each row, means without common letters differ (P < 0.05).

[1]Average SE across the breed groups.

[2]Intercept (i), linear (b_1), and quadratic (b_2) effects of percent Brahman genetics.

[S]Linear or quadratic effect significant at P < 0.05.

categories, Angus concentrations were significantly higher than the concentrations in the 50%, 75%, and 100% Brahman breed groups, and the concentration in the 100% Brahman steers was significantly lower than steers from any other breed group.

In this study, the LM from Angus cattle was found to have 50% greater amount of intramuscular fat than Brahman cattle. The lower fat content of animals from the Brahman breed group is in agreement with many previous reports (Wood et al., 2008; Mateescu, 2015), describing a lower intramuscular fat content of *B. indicus* animals. This greater accumulation of fat in Angus animals was achieved by approximately 50% increase in total SFA and MUFA concentration compared with Brahman. This is to be expected, as triacylglycerols deposited into adipocytes are mostly SFA and MUFA from dietary sources and de novo synthesis (Jenkins, 1994; Scollan et al., 2014), whereas the concentration of phospholipids which are rich in PUFA remains constant and relatively independent of the total fat amount. However, several important trends with respect to the healthfulness of the beef products from different breed groups are emerging. On a percentage basis, steaks from animals with a high Brahman percentage had significantly lower SFA and significantly higher PUFA, which suggests a higher healthfulness value

Table 4. Least squares means and SE for fatty acid concentration (mg/100 g meat) in Angus (n = 39), 75% Angus (n = 33), Brangus (n = 30), 50% Angus (n = 42), 25% Angus (n = 27), and Brahman (n = 59) cattle

	Breed group									
Trait	Angus	75% A	Brangus	50% A	25% A	Brahman	SE[1]	I[2]	b_1[2]	b_2[2]
C10:0	0.007^{a}	0.006^{ab}	0.006^{ab}	0.006^{ab}	0.006^{ab}	0.005^{b}	0.0012	0.005	−0.0006^{S}	–
C11:0	0.002	0.002	0.001	0.002	0.001	0.002	0.0002	0.001	5.68x10^{-6}	–
C12:0	0.009	0.008	0.009	0.008	0.008	0.006	0.0011	0.007	−0.0007^{S}	–
C13:0	0.001	0.002	0.002	0.002	0.001	0.001	0.0002	0.001	−0.0001^{S}	–
C14:0	0.446^{a}	0.380^{a}	0.401^{a}	0.352^{a}	0.336^{a}	0.230^{b}	0.0672	0.354	−0.052^{S}	–
C14:1	0.103^{a}	0.095^{a}	0.096^{a}	0.090^{a}	0.079^{ab}	0.056^{b}	0.0168	0.086	−0.012^{S}	–
C15:0	0.054^{a}	0.044^{ab}	0.047^{ab}	0.040^{b}	0.034^{bc}	0.025^{c}	0.0054	0.055	−0.007^{S}	–
C16:0	4.301^{a}	3.468^{ab}	3.481^{ab}	3.129^{b}	2.814^{bc}	1.967^{c}	0.6962	3.111	−0.556^{S}	–
C16:1	0.475^{a}	0.421^{ab}	0.417^{ab}	0.391^{ab}	0.321^{bc}	0.250^{c}	0.0682	0.387	−0.058^{S}	–
C17:0	0.156^{a}	0.123^{b}	0.126^{ab}	0.115^{b}	0.101^{bc}	0.073^{c}	0.0147	0.154	−0.019^{S}	–
C17:1	0.095^{a}	0.089^{ab}	0.073^{ab}	0.068^{bc}	0.063^{bc}	0.048^{c}	0.0121	0.086	−0.012^{S}	–
C18:0	2.015^{a}	1.612^{ab}	1.592^{b}	1.519^{b}	1.443^{b}	0.955^{c}	0.3157	1.450	−0.243^{S}	–
C18:1	5.695^{a}	4.789^{ab}	4.629^{ab}	4.461^{b}	3.949^{bc}	2.843^{c}	0.8208	4.516	−0.686^{S}	–
C18:2n-6 *cis*	0.346	0.337	0.337	0.335	0.312	0.272	0.0404	0.296	−0.019^{S}	–
C18:2n-6 *trans*	0.043^{a}	0.037^{ab}	0.037^{ab}	0.036^{ab}	0.031^{bc}	0.021^{c}	0.0085	0.030	−0.005^{S}	–
C18:3n-6	0.007	0.005	0.006	0.005	0.005	0.004	0.0014	0.004	−0.0006^{S}	–
C18:3n-3	0.034^{a}	0.029^{ab}	0.029^{ab}	0.029^{ab}	0.026^{bc}	0.021^{c}	0.0063	0.023	−0.003^{S}	–
C20:0	0.015^{a}	0.013^{ab}	0.012^{ab}	0.012^{b}	0.011^{b}	0.007^{c}	0.0031	0.009	−0.002^{S}	–
C20:1n-9	0.040^{a}	0.037^{a}	0.034^{ab}	0.032^{ab}	0.027^{bc}	0.019^{c}	0.0061	0.034	−0.005^{S}	–
C20:2	0.010	0.009	0.009	0.010	0.009	0.009	0.0008	0.025	−0.0004	–
C20:3n-6	0.022	0.021	0.023	0.022	0.022	0.018	0.0044	0.014	−0.0007	–
C20:3n-3	0.071	0.068	0.060	0.075	0.071	0.066	0.0195	0.032	−0.0005	–
C20:5n-3	0.006	0.006	0.005	0.007	0.006	0.006	0.0024	0.001	0.00006	–
C22:0	0.001	0.001	0.001	0.001	0.001	0.001	0.0002	0.001	−0.0001^{S}	–
C22:2	0.001^{b}	0.001^{bc}	0.002^{a}	0.001^{b}	0.001^{bc}	0.001^{c}	0.0001	0.002	0.0003^{S}	−0.0001^{S}
C23:0	0.013	0.012	0.010	0.010	0.012	0.010	0.0027	0.007	−0.0006	–
C22:6n-3	0.006	0.006	0.008	0.007	0.006	0.007	0.0019	0.001	0.0002	–
C24:1n-9	0.006	0.005	0.007	0.005	0.004	0.006	0.0029	0.002	−0.0001	–
SFA	7.023^{a}	5.670^{ab}	5.688^{ab}	5.195^{b}	4.771^{b}	3.282^{c}	1.0781	5.157	−0.885^{S}	–
MUFA	6.414^{a}	5.437^{ab}	5.256^{ab}	5.048^{b}	4.443^{bc}	3.221^{c}	0.9245	5.111	−0.774^{S}	–
PUFA	0.547	0.520	0.516	0.527	0.490	0.426	0.0876	0.411	−0.030^{S}	–
Total Fat	13.985^{a}	11.627^{ab}	11.461^{ab}	10.770^{b}	9.705^{bc}	6.929^{c}	2.088	10.679	−1.686^{S}	–

Within each row, means without common letters differ (P < 0.05).

[1]Average SE across the breed groups.

[2]Intercept (i), linear (b_1), and quadratic (b_2) effects of percent Brahman genetics.

[S]Linear or quadratic effect significant at P < 0.05.

of steaks from Brahman cattle. More importantly, the lower SFA is due mostly to a decrease in the percent of short chain SFA (C10:0, C11:0, C12:0, and C16:0), whereas C18:0 showed no significant difference among breed groups. Palmitic acid (C16:0) is a saturated fatty acid accounting for about 27% of the fatty acids in beef and has been shown to raise serum cholesterol levels (Grundy, 1994) predominantly by increasing the LDL cholesterol levels. This fatty acid accounts for most of the cholesterol-raising activity from beef, thereby increasing the risk of atherosclerosis, cardiovascular disease, and stroke (Brouwer et al., 2010). On the other hand, stearic acid (C18:0) accounts for about 18% of the fatty acid in beef. Its effect on total cholesterol is minimal and not detrimental to human health (Bonanome and Grundy, 1988; Zock and Katan, 1992; Derr et al., 1993; Judd et al., 2002). For practical purposes, stearic acid is essentially neutral in its effects on serum total cholesterol, similar to C18:1 or oleic acid (Grundy, 1994).

The second and more important finding is related to the fatty acid concentration on a mg/g meat basis. Most studies on fatty acid composition in beef cattle have reported the normalized percentage of total fatty acids, which describes the lipid quality and is driven by strong relationships among fatty acids. Steers with a high Brahman breed composition have leaner meat compared with purebred or high Angus percentage steers and this is accompanied by a high ratio of phospholipid to triacylglycerol in the fat fraction (Scollan et al., 2007; Buchanan et al., 2015). This is expected and it is reflected in the significantly lower total fat content, which is a consequence of significantly lower SFA and MUFA content. However, the amount of PUFA shows no significant difference across the 6 breed groups, suggesting that meat from Brahman animals would be closely aligned with the international recommendation of lean red meat to be included in a healthy balanced diet (Wyness et al., 2011; McNeill and Van Elswyk, 2012; Cashman and Hayes, 2017). There is an increasing segment of consumers interested in the taste and health benefits of products they consume (Lusk and Parker, 2009; Cashman and Hayes, 2017). Recent focus of consumer interest is on weight loss and childhood obesity and the emphasis is on including protein in their diet while looking for lighter options. Leaner beef from Brahman animals could be a better-fitted product for this type of consumer. In this study, steaks from Brahman steers had about half the total fat content (6.92 ± 1.01 mg/100 g meat) compared with steaks from Angus cattle (14.06 ± 1.01 mg/100 g meat) as a result of decreased SFA and MUFA concentrations, whereas the PUFA concentration was not significantly changed.

Breed Effect on Mineral Composition

Least squares means of minerals concentration (µg/g muscle) are presented in Table 5. The mineral concentration in our study agrees with those of several other studies (Biesalski, 2005; 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 bioavailability from other food sources is considered, the amount of iron and zinc provided through consumption of lean beef plays a critical role toward meeting the nutritional requirements of these 2 nutrients and may provide major health benefits (Nicklas et al., 2012). The concentration of these 2 nutritionally critical minerals is essentially unchanged across breed groups, all having substantial nutritive value.

Breed effect was significant for magnesium ($P < 0.0001$), phosphorus ($P = 0.06$), and potassium ($P = 0.06$). The concentration of these 3 minerals increased with the Brahman percentage in our population as indicated by a significant linear effect. The magnesium concentration in steers from the 100% Angus breed group was significantly lower compared with steers from the 50%, 75%, and 100% Brahman groups, whereas 75% Angus and Brangus steers had significantly different magnesium concentrations compared with 75% and 100% Brahman steers. Steers from the Brahman breed group had significantly higher phosphorus and potassium concentrations compared with 100% Angus, 75% Angus, and Brangus steers. The identical direction of variation for these minerals is supported by the strong and positive genetic correlations reported between magnesium and phosphorus (0.88), magnesium and potassium (0.68), and phosphorus and potassium (0.69) (Mateescu et al., 2013). Magnesium is an essential mineral with important and extensive roles in human health including muscle and nerve function, immune system function, and bone health (Clarkson and Haymes, 1995; Saris et al., 2000; Tam et al., 2003; Spiegel, 2011; Genuis and Bouchard, 2012; Orchard et al., 2014). There is an increased interest in the role of magnesium in preventing and managing disorders such as

Table 5. Least squares means and SE for minerals concentration (µg/g muscle) in Angus (n = 39), 75% Angus (n = 33), Brangus (n = 30), 50% Angus (n = 42), 25% Angus (n = 27), and Brahman (n = 59) cattle

	Breed group								
Trait	Angus	75% A	Brangus	50% A	25% A	Brahman	SE[1]	I[2]	b_1[2]
Iron	14.58	14.44	13.55	15.28	14.70	14.62	0.65	14.56	0.05
Magnesium	196.83^{c}	198.88^{bc}	198.94^{bc}	212.79^{ab}	216.42^{ab}	222.86^{a}	8.18	202.97	7.40^{S}
Zinc	33.79	32.81	31.871	33.23	34.531	31.859	1.48	34.22	−0.30
Sodium	338.27	348.38	339.68	362.11	356.30	360.40	10.56	339.02	4.99
Phosphorus	1651.80^{b}	1677.07^{b}	1655.55^{b}	1709.01^{ab}	1748.20^{ab}	1803.98^{a}	58.06	1743.39	41.45^{S}
Potassium	3016.29^{b}	3041.87^{b}	3015.07^{b}	3138.67^{ab}	3221.53^{ab}	3273.92^{a}	103.75	3157.68	74.50^{S}

Within each row, means without common letters differ ($P < 0.05$).

[1]Average SE across the breed groups.

[2]Intercept (i) and linear (b_1) effects of percent Brahman genetics. No quadratic (b_2) effect was significant.

[S]Linear effect significant at $P < 0.05$.

hypertension, cardiovascular disease, and diabetes (Bo and Pisu, 2008; Champagne, 2008; Houston, 2011). However, although statistically significant, the differences reported in the present study 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. Irrespective of the differences found, the current study confirms previous reports on the nutritionally beneficial amounts of minerals, particularly iron and zinc, in beef cattle (Mateescu et al., 2013; Ahlberg et al., 2014). Large variation in the content of these minerals was found within each breed group in the present study.

CONCLUSION

One of the greatest marketing advantages of beef is that it provides a superior eating experience/taste over other protein sources. Over and above this eating experience, beef is a nutrient rich foodstuff. However, it is also perceived to have an unhealthful fatty acid composition. This study confirms that nutrient and fatty acid profiles are not uniform across cattle and variations in fatty acid composition and mineral content is partially attributable to breed composition and other genetic and management factors. As the percentage of Brahman increases, the percent of SFA out of the total fatty acids decreases and the percent of PUFA increases. These observed differences result in a more nutritionally desirable beef product, especially when we consider that the decrease in percent of SFA is mainly due to a decrease in short-chain SFA, which might have a detrimental effect on human health. Probably even more important, the relatively leaner meat of high percent Brahman steers have reduced content of SFA and MUFA but the same content of PUFA as purebred Angus, suggesting that this beef product would be of interest for those consumers seeking a low fat, healthy diet.

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