Carcass and meat palatability breed differences and heterosis effects in an Angus-Brahman multibreed population

M. A. Elzo*, D. D. Johnson, J. G. Wasdin, J. D. Driver

Department of Animal Sciences, University of Florida, Gainesville, FL 32611-0910

ABSTRACT

Additive genetic Angus-Brahman differences, heterosis effects, and least squares means for six carcass and six meat palatability traits were estimated using data from 1367 steers from the Angus-Brahman multibreed herd of the University of Florida collected from 1989 to 2009. Brahman carcasses had higher dressing percent ($P < 0.0001$), lower marbling ($P < 0.0001$), smaller ribeye area ($P < 0.0001$), and less fat over the ribeye ($P < 0.0001$) than Angus carcasses. Brahman beef was less tender ($P < 0.0001$), had more connective tissue ($P < 0.0001$), and it was less juicy ($P < 0.001$) than Angus beef. Heterosis increased hot carcass weight ($P < 0.0001$), dressing percent ($P < 0.017$), ribeye area ($P < 0.0001$), fat over the ribeye ($P < 0.0001$), and kidney, pelvic, and heart fat ($P < 0.01$) in Angus-Brahman crossbred steers. Results indicated that crossbred animals with up to 50% Brahman showed limited negative impact on meat quality while maximizing meat yield due to heterosis.

Keywords: Beef; Breed; Carcass; Heterosis; Meat quality; Multibreed

* Corresponding Author. Department of Animal Sciences, University of Florida, P. O. Box 110910, Gainesville, FL 32611-0910, USA. Tel: +1-352-392-7564; Fax: +1-352-392-7652. Email address: maelzo@ufl.edu (M. A. Elzo).

1. Introduction

Carcass and meat palatability characteristics constitute key factors for the success of beef cattle operations (Glaze, Wilhelm, Rimbey, Jensen, Keetch, Cook et al., 2004; Wagner, 1998). Consumers prefer meat that has certain desirable degrees of tenderness, marbling, juiciness, and flavor. This has led to the establishment of over 60 branded beef products in the United States (USDA, 2010). Cattle producers must breed animals that take advantage of opportunities presented by branded beef programs while simultaneously breeding animals that survive well under a variety of environmental conditions. The Southern region of the US with its hot and humid subtropical environment presents serious challenges to beef producers. Most cattle in this region contain some percentage of Brahman to cope with climatic conditions, particularly during the summer season. However, meat from Brahman cattle has been found to have less desirable carcass and meat palatability characteristics than meat from *Bos taurus* breeds (Johnson, Huffman, Williams, & Hargrove, 1990; Pringle, Williams, Lamb, Johnson, & West, 1997; Shackelford, Koohmaraie, Miller, Crouse, & Reagan, 1991; Wheeler, Cundiff, Shackelford, & Koohmaraie, 2010). These studies were based on small numbers of animals or limited number of distinct Brahman-*Bos taurus* crossbred groups. Alternatively, the Angus-Brahman multibreed herd of the University of Florida was designed to generate groups of cattle spanning the range from 100% Angus to 100% Brahman. This herd, initiated in 1989, has yielded the most complete carcass and meat palatability dataset of an Angus-Brahman multibreed population of animals with known breed composition in the subtropics. Thus, the objectives of this research were to characterize additive genetic differences between Angus and Brahman, Angus ×

Brahman non-additive heterosis effects, and least squares means for various specific crossbred groups ranging from 100% Angus to 100% Brahman for six carcass and six meat palatability traits using the accumulated Angus-Brahman multibreed dataset of the University of Florida.

2. Materials and methods

2.1. Animals, data, and traits

Cattle were from a long-term genetic evaluation study utilizing Angus (A), Brahman (B), and Angus × Brahman crossbred cattle from the multibreed herd of the University of Florida. Established standards for animal care and use were followed. Research protocols were approved by the University of Florida Institutional Animal Care and Use Committee (IACUC number 201003744).

Cattle in the multibreed herd were assigned to six breed groups according to the following breed composition ranges: Angus = (1.0 to 0.80) A (0.0 to 0.20) B, ¾ A ¼ B = (0.79 to 0.60) A (0.21 to 0.40) B, Brangus = (0.625) A (0.375) B, ½ A ½ B = (0.59 to 0.40) A (0.41 to 0.60) B, ¼ A ¾ B = (0.39 to 0.20) A (0.61 to 0.80) B, and Brahman: (0.19 to 0.0) A (0.81 to 1.00) B. The mating design used in the multibreed herd was diallel (Elzo & Wakeman, 1998), where sires from the six mating groups (Angus, ¾ A ¼ B, Brangus, ½ A ½ B, ¼ A ¾ B, and Brahman) were mated across to dams from these same six mating groups. The dataset contained carcass and meat palatability information from 1367 steers born from 1989 to 2009 (216 Angus, 182 ¾ A ¼ B, 224 Brangus, 341 ½A ½B, 206 ¼ A ¾ B, and 198 Brahman). These steers were the progeny of 213 sires (44 Angus, 27 ¾ A ¼ B, 42 Brangus, 26 ½ A ½ B, 26 ¼ A ¾ B, and 48

Brahman) and 824 dams (145 Angus, 119 ¾ A ¼ B, 127 Brangus, 174 ½ A ½ B, 107 ¼ A ¾ B, and 152 Brahman).

Carcass traits were hot carcass weight (HCW, kg), dressing percent (DP, %), ribeye area at the 12th rib (REA, cm^2), fat over the ribeye at the 12th rib (FOE, cm), kidney, pelvic, and heart fat (KPH, %), and marbling score (MAB; 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).

Meat palatability traits were Warner-Bratzler shear force (WBSF, N), tenderness score (TEND; 1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, and 8 = extremely tender), connective tissue score (CTI; 1 = abundant amount, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate amount, 5 = slight amount, 6 = traces amount, 7 = practically none, and 8 = none detected), juiciness score (JUIC; 1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, and 8 = extremely juicy), beef flavor score (FLAV; 1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, and 8 = extremely intense), and off-flavor score (OFLAV; 1 = extreme off-flavor, 2 = strong off-flavor, 3 = moderately off-flavor, 4 slight off-flavor, 5 = barely detected, and 6 = none detected).

2.2. Reproduction, feeding, and management

Cows were synchronized in March with an intra-vaginal progesterone device for 7 d

(CIDR, Pfizer Animal Health, Hamilton, New Zealand), and subsequently injected with 5 ml of $PGF_{2\alpha}$ (LUTALYSE, Pfizer Animal Health, Hamilton, New Zealand) after removal of CIDR. Subsequently, cows were artificially inseminated twice, and then exposed to a natural service sire for 60 d (six single-sire natural service groups, one for each breed group of sire). Calves were born from mid-December to mid-March, castrated at birth, and weaned in September.

Cows and calves were kept on bahiagrass (*Paspalum notatum*) pastures throughout the year with free access to a complete mineral supplement (Lakeland Animal Nutrition, Lakeland, FL). Winter supplementation consisted of bermudagrass (*Cynodon dactylon*) hay, cottonseed meal, and molasses. After weaning, steers were either taken directly to a contract feeder (1989 to 2005; King Ranch Feedyard, Kingsville, Texas), or to the University of Florida Feed Efficiency Facility (FEF) in Marianna, Florida for 100 d, and then transported to a contract feeder (2006 to 2009; Suwannee Farms, O Brien, Florida). Steers at the FEF were placed in pens and fed a concentrate diet composed of whole corn, cottonseed hulls, and a protein, vitamin, and mineral supplement (FRM, Bainbridge, Georgia, US). The concentrate diet at FEF 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. Steers were provided a standard commercial corn-protein diet with vitamins and minerals at the contract feeder until they reached a subcutaneous fat thickness of approximately 1.27 cm.

2.3. Carcass and meat palatability evaluation

At the end of the feeding period at the contract feeder, steers were transported to a commercial packing plant (Sam Kane Beef Processors, Corpus Christi, Texas), and harvested in a conventional manner under USDA, FSIS inspection. After 24 h postmortem, carcasses were ribbed and HCW, DP, REA, FOE, KPH, and MAB data were collected (USDA, 1997). After carcass evaluation, carcasses were fabricated and a wholesale rib was removed and transported to the University of Florida Meat Processing Center (Gainesville, Florida, USA). Two 2.54 cm steaks were removed from the 12^{th} rib end of the wholesale rib, one for Warner-Bratzler shear force determination, and one for sensory panel evaluation. Steaks were frozen (-40° C) at 14 d postmortem and remained frozen until subsequent shear force and sensory evaluation. Steaks for shear force analysis were thawed at 3° C for 24 h and cooked on an open-top grill (Farberware Open Hearth Broiler; Farberware Products, Nashville, TN, from 1989 to 1999; Hamilton Beach Indoor/Outdoor Grill; Hamilton Beach Brands, Southern Pines, SC, from 2000 to 2009) to an internal temperature of 71° C. Internal temperature was monitored using copper-constantan thermocouples (Omega Engineering Inc., Stamford, CT) placed in the geometric center of the steak, and recorded using a 1100 Labtech Notebook Pro Software version 12.1 (Computer Boards Inc., Middleboro, MA). Steaks were turned once at 35° C. Cooked steaks were then chilled at 3° C for 24 h. Once chilled, six 1.27 cm cores were obtained from each steak parallel to the orientation of the muscle fibers. Each core was sheared once through the center (crosshead speed = 200 mm/min) using an Instron Universal Testing Machine (Instron Corporation, Canton, Massachusetts, USA) with a Warner-Bratzler shear head attached to a 490 N load cell. Steaks designated for sensory panel evaluation were treated and cooked in the same manner as the Warner-Bratzler shear samples. When reaching an internal temperature of 71° C, steaks were cut into 1.27 cm cubes and served to trained panelists while still warm. A 7 to 11 member trained (AMSA, 1995) panel evaluated each sample for five sensory attributes (TEND, CTI, JUIC, FLAV, OFLAV).

2.4. Statistical analysis

Carcass traits (HCW, DP, REA, FOE, KPH, and MAB) and meat palatability traits (WBSF, TEND, CTI, JUIC, FLAV, and OFLAV) were analyzed using single-trait mixed model procedures that accounted for additive genetic, non-additive genetic, and environmental effects, and assumed a homogeneous residual covariance structure. The model used for all traits contained the fixed subclass effect of year of birth, the fixed regression effects of slaughter age of steer, Brahman breed effect as a function of the expected Brahman fraction of the steer, and heterosis effect as a function of the heterozygosity of the steer (i.e., the probability of a steer having Angus and Brahman alleles in 1 locus), and random sire and residual effects. Random sire and residual effects were each assumed to have zero mean, a common variance, and be uncorrelated. Brahman breed effects estimated the additive genetic difference between Brahman and Angus. Heterosis effects estimated the difference between intralocus interbreed (i.e., Angus × Brahman and Brahman × Angus) and intrabreed interactions (i.e., Angus × Angus and Brahman × Brahman). The mixed model procedure of SAS (SAS Inst., Inc., Cary, North Carolina, USA) was used to carry out computations. The statistical significance of solutions for effects in the model was assessed with a t-test. Least squares means were computed for the six defined breed groups of steers (Angus, ¾ A ¼ B, Brangus, ½ A ½ B, ¼ A ¾ B, and Brahman) using a linear combination of additive genetic breed effects and non-additive genetic heterosis effects. Considering that Angus has become the reference beef cattle breed in the US, differences between the least squares means for ¾ A ¼ B, Brangus, ½ A ½ B, ¼ A ¾ B, and Brahman breed groups and the least square mean for Angus were computed using the ESTIMATE statement of the Mixed procedure of SAS, and tested for significance with a t-test. Figures displaying trends in least squares means for carcass and meat palatability traits from Angus to Brahman across the six chosen breed groups of steers were drawn using SAS procedure GPLOT.

3. Results and discussion

3.1. Carcass traits

Table 1 presents estimates of additive genetic differences between Brahman and Angus and non-additive Angus × Brahman heterosis effects and their corresponding standard errors for HCW, DP, REA, FOE, KPH, and MAB. Additive genetic breed differences indicated that Brahman and Angus carcasses had similar HCW and KPH. However, Brahman carcasses had significantly greater DP (1.60 ± 0.25 %; $P < 0.0001$), lower MAB (-105.97 ± 7.68 units; $P < 0.0001$), smaller REA (-3.82 ± 0.93 cm^2; $P < 0.0001$), and less FOE (-0.38 ± 0.05 cm; $P < 0.0001$) than Angus carcasses. On the other hand, Peacock, Palmer, Carpenter, and Koger (1979) reported that Angus had lower chilled carcass weights and higher FOE and REA per 100 kg of carcass weight than Brahman in Florida, and Lunt, Smith, Murphey, Savell, and Carpenter (1985) indicated that Angus had heavier HCW, similar FOE, and greater MAB, REA, and KPH than Brahman in Texas. Both studies were based on small numbers of experimental animals.

Samples of animals used in each study and changes in population characteristics over time may account for differences in results. One important characteristic of the UF Angus-Brahman multibreed herd (Elzo & Wakeman, 1998) is that Angus, Brahman, and Brangus sires from their respective US populations, as well as ¾ A ¼ B, ½ A ½ B, ¼ A ¾ B crossbred sires from various Southern states were used as artificial insemination or natural service sires. Although the sample of sires was not random, it ensured a wide representation of genetic material over the years of the 21 yr of the study. Thus, results here should provide a reasonably close representation of the purebred and crossbred populations in the UF multibreed herd.

Heterosis effects increased HCW (35.01 ± 3.95 kg; $P < 0.0001$), DP (0.69 ± 0.29 %; $P < 0.017$), REA (5.38 ± 1.08 cm^2; $P < 0.0001$), FOE (0.26 ± 0.05 cm; $P < 0.0001$), and KPH (0.16 ± 0.06 %; $P < 0.01$), but it did not affect MAB. The large positive effect of heterosis on HCW (35.01 ± 3.95 kg, $P < 0.0001$) would overshadow the negative additive difference between Brahman and Angus for MAB (-105.97 ± 7.68 units, $P < 0.0001$) on carcass price for crossbred animals under current market conditions. Positive Angus-Brahman heterosis effects for HCW and REA were found by DeRouen, Franke, Bidner, and Blouin (1992), whereas Peacock et al. (1979) reported positive Angus-Brahman heterosis effects for chilled carcass weight and FOE, but negative heterosis effects for REA per 100 kg of carcass weight.

Table 2 shows least squares means and their standard errors computed for the six breed groups of steers. Trends resulting from these steer group least squares means are shown in Figure 1. Crossbred steers had heavier HCW than Angus (from 17.41 ± 2.34 kg, $P < 0.0001$, for Brangus to 36.34 ± 4.42 kg, $P < 0.0001$, for ½ A ½ B) and Brahman (from 14.76 ± 2.73 kg, $P <$

0.0001, for Brangus to 33.68 ± 4.18 kg, $P < 0.0001$, for ½ A ½ B) steers due primarily to heterosis effects, thus the heaviest carcasses were those from F1 ½ A ½ B steers (359.62 ± 2.43 kg). Dressing percent tended to increase linearly from Angus (61.66 ± 0.19 %) to ½ A ½ B (63.16 ± 0.18 %), and to remain at this level in steers with higher Brahman percentages up to 100% Brahman. Marbling score decreased steadily from Angus (446.51 ± 5.87 units) to Brahman (340.55 ± 5.72 units). Trends similar to HCW existed for REA, FOE, and KPH. Least squares means for three traits increased from Angus to ½ A ½ B, and subsequently decreased towards Brahman. Breed group means for REA were 81.54 ± 0.71 cm^2 for Angus, 89.94 ± 0.66 cm^2 for ½ A ½ B, and 77.72 ± 0.70 cm^2 for Brahman. Corresponding estimates for FOE were 1.27 ± 0.04 cm for Angus, 1.34 ± 0.03 cm for ½ A ½ B, and 0.90 ± 0.03 cm for Brahman, and for KPH they were 2.14 ± 0.04 % for Angus, 2.26 ± 0.04 % for ½ A ½ B, and 2.06 ± 0.04 % for Brahman.

Huffman, Williams, Hargrove, Johnson, and Marshall (1990) reported a largely similar trend for HCW, DP, and adjusted FOE in a study involving 125 Angus, ¾ A ¼ B, ½ A ½ B, and ¼ A ¾ B steers purchased from eight commercial herds in Florida. In their study, least squares means for HCW, DP, and adjusted FOE increased from Angus to ¼ A ¾ B, instead of increasing only up to ½ A ½ B as obtained here. Huffman et al. (1990) also found that REA was larger in Angus and ¼ A ¾ B than in ¾ A ¼ B and ½ A ½ B, and that KPHP was similar in these four breed groups. Sampling and numbers of animals per breed group as well as the use of different models likely contributed to differences in trends of least squares means between these two studies. In particular, the model used by Huffman et al. (1990) treated breed groups as subclass effects (which include additive and non-additive genetic effects) as opposed to the model here that separated additive and non-additive genetic effects and treated them as covariates. Under temperate environmental conditions, Koch, Dikeman, and Crouse (1982) found that Brahman crossbred steers (Brahman sires mated to Angus and Hereford females) adjusted to a common age had higher least squares means for HCW, DP, REA, and KPH, and lower means for FOE and MAB than Hereford-Angus crossbreds. On the other hand, Crouse, Cundiff, Koch, Koohmaraie, and Seideman (1989) indicated that HCW, MAB, adjusted FOE, and KPH decreased as Brahman percent increased up to 75%, whereas REA was similar to purebreds (Brahman, Angus, Hereford).

3.2. Meat palatability traits

Table 3 shows estimates of additive genetic differences between Brahman and Angus as well as Angus-Brahman heterosis effects and their standard errors for WBSF, TEND, CTI, JUIC, FLAV, and OFLAV. Additive genetic breed differences suggested that Brahman steaks were significantly less tender based on WBSF (6.86 ± 1.10 N; $P < 0.0001$) and sensory panel TEND (-1.18 ± 0.15 units; $P < 0.0001$), and sensory panel members perceived them to have higher levels of CTI (-0.97 ± 0.14 units; $P < 0.0001$) and to have lower levels of JUIC (-0.40 ± 0.12; $P < 0.001$). However, no significant differences between Brahman and Angus were detected for FLAV and OFLAV. Heterosis effects had no impact on any of the six meat palatability traits (Table 3).

Table 4 contains least squares means for the six defined breed groups of steers, and

Figure 2 shows trends for the six meat palatability traits from Angus to Brahman. Least squares means for WBSF showed a clear upward trend from Angus (33.83 ± 0.86 N; most tender meat) to Brahman (40.68 ± 0.81 N; least tender meat), whereas the opposite trend was observed for sensory panel tenderness (Angus: 5.80 ± 0.12 units; most tender meat; Brahman: 4.62 ± 0.11 units; least tender meat). The decreasing trend for CTI was similar to the one found for tenderness (Angus: 6.11 ± 0.11 units; least CTI; Brahman: 5.14 ± 0.10 units; most CTI). Juiciness showed a steady decline from Angus (5.31 ± 0.10 units) to Brahman (4.91 ± 0.09 units). As expected from the non-significant additive genetic breed and non-additive genetic heterosis effects, means for FLAV and OFLAV showed no trend from Angus to Brahman.

Pringle et al. (1997) found that WBSF, CTI, and FLAV increased, and TEND and JUIC decreased as Brahman percentage increased with a sample of 79 steers from the six breed groups in this study. These authors also found that calpastatin activity increased linearly and μ-calpain activity decreased as Brahman percentage increased. Thus, the linear increase in WBSF and linear decrease in TEND as percent Brahman increased obtained in the population of animals included in the accumulated UF multibreed dataset was likely due to higher calpastatin activity combined with a lower μ-calpain activity. Johnson et al. (1990) obtained WBSF and sensory evaluation data from the same 125 Angus, ¾ A ¼ B, ½ A ½ B, and ¼ A ¾ B steers from eight commercial herds in Florida as Huffman et al. (1990). As observed in this study, the least squares means for WBSF increased, those for TEND and JUIC decreased, and FLAV and OFLAV showed no trend from Angus to ¼ A ¾ B. Also in agreement with results here, Crouse et al. (1989) found an increasing trend for WBSF, decreasing trends for TEND and CTI, and non-significant differences among breed groups for JUIC, FLAV, and OFLAV as Brahman fraction increased up to 75% in Brahman crossbred steers under temperate environmental conditions. Further, numerous researchers have reported negative associations between MARB and WBSF, and positive associations between MARB and TEND, CTI, JUIC, and FLAV (Blumer, 1963; Platter, Tatum, Belk, Chapman, Scanga, & Smith, 2003; Tatum, Smith, & Carpenter, 1982; Wheeler, Cundiff, & Koch, 1994). Thus, another factor that may have contributed to the increasing trend for WBSF, and the decreasing trends for TEND, CTI, and JUIC is the corresponding decreasing trend in MARB as percent Brahman increased in the steers from the Angus-Brahman population.

4. Conclusions

Estimates of additive breed genetic effects indicated that Brahman carcasses had higher dressing percent, lower marbling, smaller ribeye area, and less fat over the ribeye than Angus. Brahman beef was less tender, had more connective tissue, and was less juicy than Angus beef. Heterosis increased hot carcass weight, dressing percent, ribeye area, fat over the ribeye, and kidney, pelvic, and heart fat in Angus × Brahman crossbred steers. Results indicated that crossbred animals with percentage Brahman up to 50% showed limited negative impact on meat quality while maximizing meat yield due to heterosis.

References

AMSA. (1995). Research guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat. American Meat Science Association and National Livestock and Meat Board, Chicago, Illinois.

Blumer, T. N. (1963). Relationships of marbling to the palatability of beef. *Journal of Animal Science, 22,* 771-778.

Crouse, J. D., Cundiff, L. V., Koch, R. M., Koohmaraie, M., & Seideman, S. C. (1989). Comparisons of *Bos indicus* and *Bos taurus* inheritance for carcass beef characteristics and meat palatability. *Journal of Animal Science, 67*, 2661-2668.

DeRouen, S. M., Franke, D. E., Bidner, T. D., & Blouin, D. C. 1992. Direct and maternal genetic effects for carcass traits in beef cattle. *Journal of Animal Science, 70*, 3677-3685.

Elzo, M. A., & Wakeman, D. L. (1998). Covariance components and prediction for additive and nonadditive preweaning growth genetic effects in an Angus-Brahman multibreed herd. *Journal of Animal Science, 76*, 1290-1302.

Glaze, J. B. Jr., Wilhelm, B., Rimbey, N. R., Jensen, K. S., Keetch, G. C., Cook, W. F., Gray, C. W., Hawkins, J. N., Morrison, E. J., Williams, S. K., Church, J. A., & Momont, P. A. (2004). A to Z Retained Ownership, Inc.: Factors affecting profitability in the inland northwest. *Proceedings of the Western Section of the American Society of Animal Sciences, vol. 55.* (pp. 198-201).

Huffman, R. F., Williams, S. E., Hargrove, D. D., Johnson, D. D., & Marshall, T. T. (1990). Effects of percentage Brahman and Angus breeding, age-season of feeding and slaughter end point on feedlot performance and carcass characteristics. *Journal of Animal Science, 68*, 2243-2252.

Johnson, D. D., Huffman, R. D., Williams, S. E., & Hargrove, D. D. (1990). Breeding, age-season of feeding and slaughter end point on meat palatability and muscle characteristics. *Journal of Animal Science, 68*, 1980-1986.

Koch, R. M., Dikeman, M. E., & Crouse, J. D. (1982). Characterization of biological types of cattle (Cycle III). III. Carcass composition, quality and palatability. *Journal of Animal Science, 54*, 35-45.

Lunt, D. K., Smith, G. C., Murphey, C. E., Savell, J. W., & Carpenter, Z. L. (1985). Carcass characteristics and composition of Brahman, Angus, Brahman × Angus steers fed for different times-on-feed. *Meat Science, 14*, 137-152.

Peacock, F. M., Palmer, A. Z., Carpenter, J. W., & Koger, M. (1979). Breed heterosis effects on carcass characteristics of Angus, Brahman, Charolais, and crossbred steers. *Journal of Animal Science, 49*, 391-395.

Platter, W. J., Tatum, J. D., Belk, K. E., Chapman, P. L., Scanga, J. A., & Smith, G. C. (2003). Relationships of consumer sensory ratings, marbling score, and shear force value to consumer acceptance of beef strip loin steaks. *Journal of Animal Science, 81*, 2741-2750.

Pringle, T. D., Williams, S. E., Lamb, B. S., Johnson, D. D., & West, R. L. (1997). Carcass characteristics, the calpain proteinase system, and aged tenderness of Angus and Brahman crossbred steers. *Journal of Animal Science, 75*, 2955-2961.

Shackelford, S. D., Koohmaraie, M., Miller, M. F., Crouse, J. D., & Reagan, J. O. (1991). An evaluation of tenderness of the longissimus muscle of Angus by Hereford versus Brahman crossbred heifers. *Journal of Animal Science, 69*, 171-177.

Tatum, J. D., Smith, G. C., & Carpenter, Z. L. (1982). Interrelationships Between Marbling, Subcutaneous Fat Thickness and Cooked Beef Palatability. *Journal of Animal Science, 54*, 777-784.

Wagner, W. R. (1998). Genetics for profit. West Virginia University Extension Service. (http://www.wvu.edu/~Agexten/forglvst/genetics.htm).

Wheeler, T. L., Cundiff, L. V., & Koch, R. M. (1994). Effect of marbling degree on beef palatability in *Bos taurus* and *Bos indicus* cattle. *Journal of Animal Science, 72*, 3145-3151.

Wheeler, T. L., Cundiff, L. V., Shackelford, S. D., & Koohmaraie, M., 2010. Characterization of biological types of cattle (Cycle VIII): Carcass, yield, and longissimus palatability traits. *Journal of Animal Science, 88*, 3070-3083.

USDA. (1997). Official United States standards for grades of carcass beef. United States Department of Agriculture, Agricultural Marketing Service, Washington, District of Columbia.

USDA. (2010). USDA Certified Beef Programs. (http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELDEV3025674).

Table 1

Additive genetic breed differences and heterosis effects for six carcass traits

Trait[a]	n	Effect	Estimate	Standard Error	Pr > $\lvert t \rvert$
HCW, kg	1359	Brahman - Angus	2.65	3.44	0.44
		Heterosis	35.01	3.95	<0.0001
DP, %	1359	Brahman - Angus	1.60	0.25	<0.0001
		Heterosis	0.69	0.29	0.017
MAB, units[b]	1357	Brahman - Angus	-105.97	7.68	<0.0001
		Heterosis	0.26	8.83	0.98
REA, cm^2	1328	Brahman - Angus	-3.82	0.93	<0.0001
		Heterosis	5.31	1.08	<0.0001
FOE, cm	1353	Brahman - Angus	-0.38	0.05	<0.0001
		Heterosis	0.26	0.05	<0.0001
KPH, %	1275	Brahman - Angus	-0.08	0.05	0.15
		Heterosis	0.16	0.06	0.01

[a]HCW = hot carcass weight, DP = dressing percent, MAB = marbling score, REA = ribeye area at the 12th rib, FOE = fat over the ribeye at the 12th rib, and KPH = kidney, pelvic, and heart fat.

[b]100 to 199 = practically devoid, 900 to 999 = abundant.

Table 2

Steer breed group least squares means for six carcass traits

	Breed Group					
Trait[a]	Angus	¾ A ¼ B	Brangus	½ A ½ B	¼ A ¾ B	Brahman
HCW, kg	323.28[c]	341.45[x,z]	340.70[x,z]	359.62[x,z]	342.78[x,z]	325.93
	2.63[d]	1.23	1.00	2.43	1.36	2.56
DP, %	61.66[z]	62.41[x,z]	62.59[x,z]	63.16[x]	63.21[x]	63.26[x]
	0.19	0.09	0.07	0.18	0.10	0.19
MAB, units[b]	446.51[z]	420.15[x,z]	406.90[x,z]	393.79[x,z]	367.17[x,z]	340.55[x]
	5.87	2.74	2.22	5.43	3.03	5.72
REA, cm^2	81.54[z]	83.24[x,z]	82.60[z]	84.94[x,z]	81.33[z]	77.72[x]
	0.71	0.34	0.27	0.66	0.37	0.70
FOE, cm	1.27[z]	1.31[z]	1.25[z]	1.34[z]	1.12[x,z]	0.90[x]
	0.04	0.02	0.01	0.03	0.02	0.03
KPH, %	2.14	2.20[z]	2.19[z]	2.26[z]	2.16[z]	2.06
	0.04	0.02	0.02	0.04	0.02	0.04

[a]HCW = hot carcass weight, DP = dressing percent, MAB = marbling score, REA = ribeye area at the 12th rib, FOE = fat over the ribeye at the 12th rib, and KPH = kidney, pelvic, and heart fat.

[b]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.

[c]Least squares mean.

[d]Standard error.

[x]Significantly different from Angus ($P < 0.0047$ to $P < 0.0001$).

[z]Significantly different from Brahman ($P < 0.0057$ to $P < 0.0001$).

Table 3

Additive genetic breed differences and heterosis effects for six meat palatability traits

Trait[a]	n	Effect	Estimate	Standard Error	$Pr > \lvert t \rvert$
WBSF, N	662	Brahman - Angus	6.86	1.10	<0.0001
		Heterosis	-0.54	1.33	0.68
TEND, units[b]	352	Brahman - Angus	-1.18	0.15	<0.0001
		Heterosis	0.26	0.17	0.13
CTI, units[c]	352	Brahman - Angus	-0.97	0.14	<0.0001
		Heterosis	0.29	0.16	0.062
JUIC, units[d]	352	Brahman - Angus	-0.40	0.12	0.001
		Heterosis	-0.09	0.14	0.54
FLAV, units[e]	352	Brahman - Angus	0.05	0.09	0.56
		Heterosis	0.18	0.10	0.08
OFLAV, units[f]	352	Brahman - Angus	-0.04	0.07	0.57
		Heterosis	-0.10	0.08	0.22

[a]WBSF = Warner-Bratzler shear force, TEND = tenderness score, CTI = connective tissue score, JUIC = juiciness score, FLAV = beef flavor score, and OFLAV = off-flavor score.

[b]1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, and 8 = extremely tender.

[c]1 = abundant amount, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate amount, 5 = slight amount, 6 = traces amount, 7 = practically none, and 8 = none detected.

[d]1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, and 8 = extremely juicy.

[e]1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, and 8 = extremely intense.

[f]1 = extreme off-flavor, 2 = strong off-flavor, 3 = moderately off-flavor, 4 slight off-flavor, 5 = barely detected, and 6 = none detected.

Table 4

Steer breed group least squares means for six meat palatability traits

	Breed Group					
Trait[a]	Angus	¾ A ¼ B	Brangus	½ A ½ B	¼ A ¾ B	Brahman
WBSF, N	33.83[g,z]	35.27[y,z]	36.14[x,z]	36.71[y,z]	38.70[x,z]	40.68[x]
	0.86[h]	0.40	0.33	0.84	0.45	0.81
TEND, units[b]	5.80[z]	5.64[z]	5.48[x,z]	5.48[z]	5.05[x,z]	4.62[x]
	0.12	0.06	0.05	0.11	0.06	0.11
CTI, units[c]	6.11[z]	6.01[z]	5.88[x,z]	5.92[z]	5.53[x,z]	5.14[x]
	0.11	0.05	0.04	0.10	0.06	0.10
JUIC, units[d]	5.31[z]	5.17[z]	5.12[x,z]	5.02	4.97[x]	4.91[x]
	0.10	0.05	0.04	0.09	0.05	0.09
FLAV, units[e]	5.45	5.55	5.56	5.66	5.58	5.50
	0.07	0.03	0.03	0.06	0.04	0.07
OFLAV, units[f]	5.81	5.75	5.75	5.69	5.73	5.77
	0.06	0.03	0.02	0.05	0.03	0.05

[a]WBSF = Warner-Bratzler shear force, TEND = tenderness score, CTI = connective tissue score, JUIC = juiciness score, FLAV = beef flavor score, and OFLAV = off-flavor score.

[b]1 = extremely tough, 2 = very tough, 3 = moderately tough, 4 = slightly tough, 5 = slightly tender, 6 = moderately tender, 7 = very tender, and 8 = extremely tender.

[c]1 = abundant amount, 2 = moderately abundant, 3 = slightly abundant, 4 = moderate amount, 5 = slight amount, 6 = traces amount, 7 = practically none, and 8 = none detected.

[d]1 = extremely dry, 2 = very dry, 3 = moderately dry, 4 = slightly dry, 5 = slightly juicy, 6 = moderately juicy, 7 = very juicy, and 8 = extremely juicy.

[e]1 = extremely bland, 2 = very bland, 3 = moderately bland, 4 = slightly bland, 5 = slightly intense, 6 = moderately intense, 7 = very intense, and 8 = extremely intense.

[f]1 = extreme off-flavor, 2 = strong off-flavor, 3 = moderately off-flavor, 4 slight off-flavor, 5 =

barely detected, and 6 = none detected.

[g]Least squares mean.

[h]Standard error.

[x]Significantly different from Angus ($P < 0.0244$ to $P < 0.0001$).

[y]Difference from Angus close to significance ($P < 0.0546$).

[z]Significantly different from Brahman ($P < 0.0266$ to $P < 0.0001$).

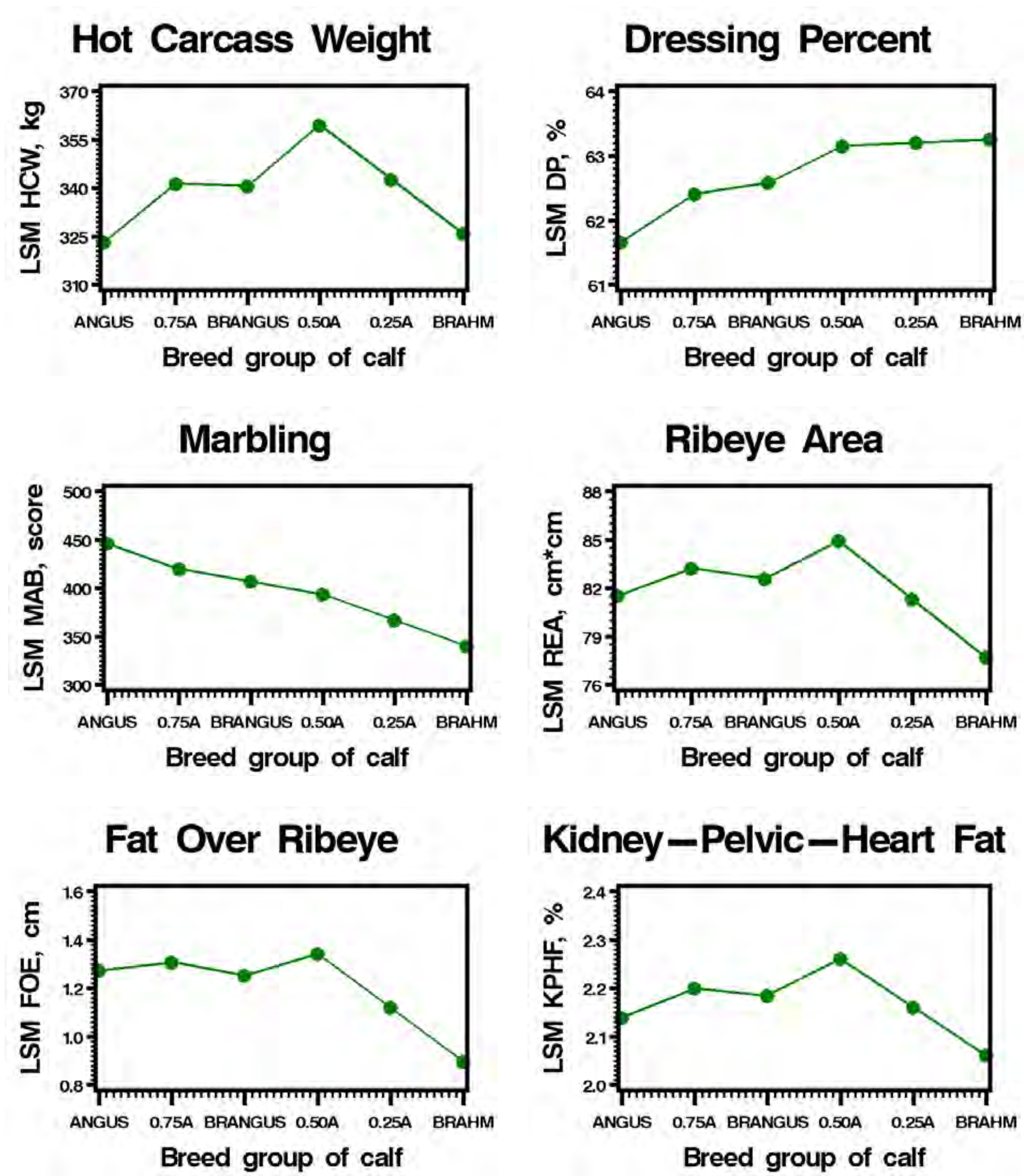

Fig. 1. Trends of least squares means for carcass traits for steers ranging in breed composition from 100% Angus to 100% Brahman

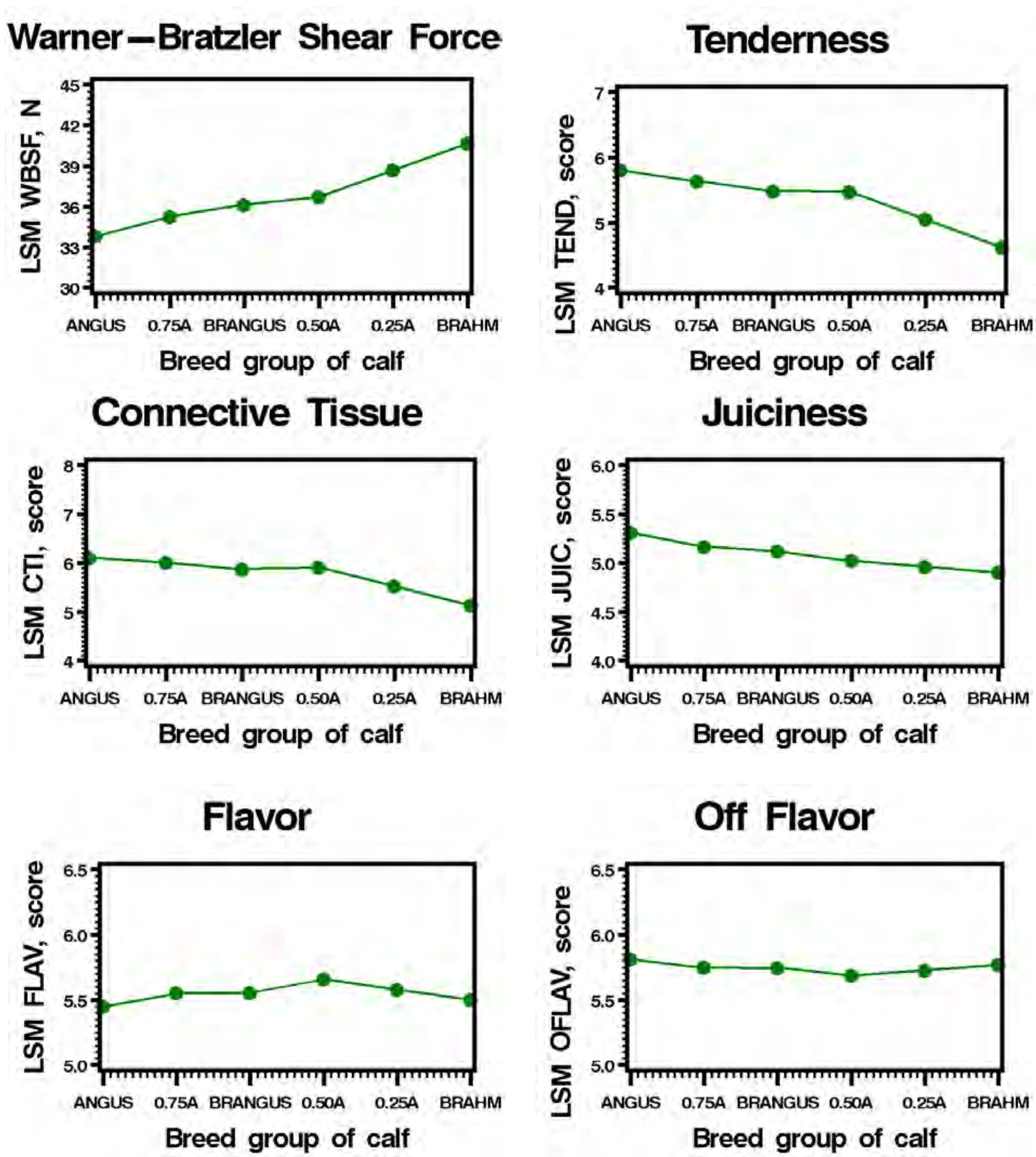

Fig. 2. Trends of least squares means for meat palatability traits for steers ranging in breed composition from 100% Angus to 100% Brahman