The heritabilities, phenotypic correlations, and genetic correlations of lean color and palatability measures from longissimus muscle in beef cattle

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ABSTRACT: Data from a study conducted over 5 yr were analyzed to determine heritability estimates of LM lean color, as measured by subjective scoring and Hunter Colorimeter readings, and palatability, as measured by trained sensory panelists and Warner-Bratzler shear force (WBSF). Phenotypic and genetic correlations were determined between each of the measures of palatability and color. There were 1,066 cattle representing 12 different breeds in the study. Subjective lean color and a* (redness) and b* (yellowness) values were moderately heritable, 0.34 ± 0.122, 0.29 ± 0.115 and 0.28 ± 0.120, respectively, whereas the L* (lightness) was lowly heritable, 0.09 ± 0.087. The heritability of WBSF was moderately heritable ranging from 0.23 ± 0.114 (3 d) to 0.42 ± 0.148 (21 d). Sustained tenderness, as measured by sensory panelists, was found to be moderately heritable ranging from 0.16 ± 0.108 (21 d) to 0.33 ± 0.135 (14 d). Sustained juiciness and beef flavor, as measured by sensory panelists, were found to be lowly to moderately heritable ranging from 0.00 ± 0.089 (21 d) to 0.18 ± 0.105 (14 d) and 0.00 ± 0.080 (7 d) to 0.18 ± 0.110 (21 d), respectively. The significant phenotypic correlations were those between WBSF and subjective lean color, L* value, and a* value; both initial and sustained tenderness as well as beef flavor were correlated with subjective lean color and L* value. Flavor intensity and overall mouthfeel were associated with subjective lean color, L* value, a* value, and b* value. Both a* and b* values were highly correlated genetically with WBSF, −0.71 and −0.72, respectively, and subjective lean color was moderately correlated with WBSF, −0.46. The genetic correlation between subjective lean color and initial tenderness was also high, 0.56, whereas that between a* value and initial tenderness was 0.43, which was similar to that found between b* value and initial tenderness, 0.44. The genetic correlations between subjective lean color, a* value, and b* value with sustained tenderness were all high at 0.58, 0.70, and 0.58, respectively. The genetic correlations between a* value and b* value with beef flavor were low to moderate at 0.12 and 0.19, respectively, whereas that between subjective lean color and beef flavor was high, 0.64. The genetic correlations between a* value, b* value, and lean color with sustained juiciness were all moderate correlations at −0.35, −0.23, and −0.45, respectively. The genetic correlations between a* value and b* value with overall mouthfeel were high at 0.80 and 0.79, respectively, whereas that between subjective lean color and overall mouthfeel was moderate, 0.46. In conclusion, regardless of measurement technique of lean color, it was not only heritable but was also moderately to highly correlated with measurements of palatability in beef from LM.

Key words: beef, color, heritability, palatability, tenderness

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INTRODUCTION

According to the 2000 and 2005 National Beef Quality Audit (Roeber et al., 2002; Shook et al., 2008), inadequate tenderness was the number 1 concern of restaurateurs and the number 2 concern of beef producers, second only to inconsistencies in live cattle, carcasses, and cuts. The importance of beef tenderness
was substantiated by Miller et al. (2001), who reported that tenderness was important to consumers as they were willing to pay more for tender beef. In fact, if steaks were guaranteed to be tender, 78% percent of consumers would purchase steaks from that retailer. The retail steak value differences would result in the opportunity for a premium of US$76.26 (per 350-kg carcass) for a guaranteed tender [<3.0 kg Warner-Bratzler shear force (WBSF) value] carcass over the toughest (>5.7 kg) classification.

Review of published information regarding measures of palatability revealed heritabilities of WBSF values as high as 0.53 (Shackelford et al., 1994a) and when using trained sensory panel data, Dikeman et al. (2005) estimated the heritability of tenderness, juiciness, and flavor was 0.37, 0.46, and 0.07, respectively. The identification of indicators related to tenderness in beef cattle will provide valuable information to the industry and producers as it will allow them to pinpoint factors that are economically measured and highly correlated with tenderness in beef. Through this identification, the opportunity for premiums to be issued for carcasses obtaining superior tenderness quality will provide financial justification for producers to genetically select for those animals that produce superior meat tenderness. The objective of this study was to examine the heritability and correlation of palatability characteristics of one economically measured trait, color.

MATERIALS AND METHODS

Animal care and use approval was not obtained for this study because the samples were obtained from federally inspected slaughter facilities.

Animals

Animals (n = 1,066) involved in the study were sired by 10 different breeds including Simbrah, Simmental, Santa Gertrudis, Saler, Parthenais, Hotlander, Red Angus, Angus, Waygu, and Brahman. There were a total of 122 sires including 47 Simbrah bulls siring 590 animals with a range of 1 to 85 progeny per sire, 10 Simmental bulls siring 73 animals with a range from 1 to 28 progeny per sire, 19 Santa Gertrudis bulls siring 147 animals with a range from 1 to 26 progeny per sire, 2 Saler bulls siring 18 animals with 6 and 12 animals sired, respectively, 4 Parthenais bulls siring 39 animals with 6, 25, 4, and 4 animals sired, respectively, 8 Hotlander bulls siring 50 animals with a range from 1 to 10 progeny per sire, 3 Red Angus bulls siring 18 animals with 6, 2, and 10 animals sired, respectively, 2 Waygu/Angus bull siring 3 animals, 3 Brahman bulls siring 50 animals with 17, 17, and 16 animals sired, respectively, and 24 bulls with unknown breeds siring 78 animals with a range from 1 to 10 progeny per sire.

The cattle were supplied from several producers across the state. Sire information on all cattle was provided by the producers who owned the cattle on feed. Cattle were fed at commercial feedyards (Caprock Industries, Gruver, TX; Lubbock Feedyard, Lubbock, TX; and Texas Tech University Burnett Center, New Deal, TX) from 1995 to 1999. Animals were randomly assigned to 1 of 5 treatment groups on arrival: control, no implants given; Synovex-S (Fort Dodge Animal Health, Overland Park, KS) followed by Revalor S (Intervet/Schering-Plough Animal Health, DeSoto, KS; given to steers); double Synovex-S; double Synovex-H (Fort Dodge Animal Health; given to heifers); and Synovex-H followed by Finaplix-H (Intervet/Schering-Plough Animal Health; given to heifers; Brooks, 1997; Barham, 1998). Implants were administered on d 0 and again after 80 to 90 d on feed.

Carcass

Lean color (1 = extremely dark; 8 = extremely bright cherry red) was evaluated on the LM between the 12th and 13th rib (Brooks, 1997). Commission Internationale de L'Eclairage L* (muscle lightness), a* (muscle redness), and b* (muscle yellowness) were measured on the LM between the 12th and 13th rib using a 3.5-cm aperture Minolta Chroma Meter (Model CR-200b; Osaka, Japan). The measurements were taken by trained personnel from Texas Tech University 48 h postmortem and approximately 1 h after ribbing allowing for oxygenation of the LM (Brooks, 1997).

Trained Sensory Panel

The USDA Select strip loins (Institutional Meat Purchase Specification number 180) were obtained from 1 side of each carcass. The strip loins were purchased and transported to Texas Tech University Meat Science Laboratory, a USDA Food Safety and Inspection Service inspected facility. Strip loins were fabricated by removing all external fat, and 2.5-cm-thick steaks were cut and vacuum packaged.

The steaks were then assigned randomly to 4 aging periods (3, 7, 14, and 21 d postmortem) for WBSF and trained sensory panel evaluations. One steak from each strip loin was randomly assigned to each aging/evaluation combination.

Steaks were stored under vacuum in high-barrier bags for the appropriate aging period at 4°C and frozen at −10°C until evaluation.

Steaks were thawed at 4°C for 24 h and cooked on a Farberware Open Hearth Broiler (Farberware, Inc.,
Beef palatability and lean color

Bovine palatability and lean color were assessed using a digital thermometer (Model SH66A; Cooper Instruments, Middlefield, CT). Steaks were trimmed to remove all visible external connective tissue, portioned into uniform samples (approximately 2.5 by 1.25 by 1.25 cm), and served to panelists from prewarmed serving pans filled with warm sand. Panelists were housed in individual booths under red lighting. Trained sensory panelists \( n = 6 \) to 8) were used for the study and were selected and trained according to American Meat Science Association (AMSA) guidelines (AMSA, 1995). Panelists were provided an expectorant cup and palate cleanser.

Sensory characteristics were quantified for the following palatability traits: initial tenderness, sustained tenderness, initial juiciness, sustained juiciness, flavor intensity, beef flavor, and overall mouthfeel using an 8-point scale (1 = extremely tough, dry, bland, uncharacteristic beef flavor, non-beef-like mouthfeel; 8 = extremely tender, juicy, intense, characteristic beef flavor, beef-like mouthfeel, respectively; AMSA, 1995; Brooks, 1997).

**Warner Bratzler Shear Force Measurements**

Steaks were thawed for 18 to 24 h at 2 to 5°C. The initial internal temperature of the steaks was measured using a digital thermometer (Model SH66A; Cooper Instruments) in the geometric center of the steak and recorded. Each steak was placed on a belt grill (model TBG-60 Magigrill; Magi-Kitch’n Inc., Quakertown, PA) with a grill-plate temperature of 163°C and cooked using the same procedure as those cooked for the trained sensory panelists. Steak weights were recorded before and after cooking. Additionally, final internal temperature for each steak was measured in the geometric center of the steak and recorded (end-point temperatures were approximately 68 to 71°C).

All steaks were placed on a tray, covered with plastic overwrap, and stored in a cooler at 2 to 5°C for 24 h. The WBSF instrument was set up and 6 cores were obtained from each steak parallel to the muscle fibers. All cores were devoid of connective tissue and fat. The degree of doneness was recorded using the color chart in the AMSA guidelines (AMSA, 1995). Each of the 6 cores was sheared perpendicular to the muscle fiber with a crosshead speed of 200 mm/min and the values were recorded (Brooks, 1997).

**Statistical Analyses**

Phenotypic correlations were estimated using the PROC CORR procedure (SAS Inst., Inc., Cary, NC). Sire information was provided and pedigree information of the sire was obtained through a registration number search. The relationship among the animals was included by incorporation of 2 generations of pedigree information of the sires used. Estimates of heritability were obtained from single-trait animal models, and correlations were estimated using 2-trait animal models. Variance and covariance components were obtained through the use of a multiple-trait derivative-free restricted maximum likelihood methodology (Boldman et al., 1995). Two-trait analyses were conducted to estimate the genetic and phenotypic correlations between pairs of traits. Cold restarts from apparent converged estimates (with no variances held constant) were again run at least twice to ensure convergence was not falsely obtained at a local maximum site. Convergence criterion were met when the logarithmic value of the likelihood function was less than or equal to \( 10^{-9} \). The effects fitted in the model were sex, implant regimen, and contemporary group, which was defined by the date that cattle entered the feedlot and the date they were harvested. There were 25 contemporary groups for all traits in the study, with an average of 42.64 calves per group.

**RESULTS AND DISCUSSION**

The agreement among the cooperating researchers on this project was the study was not to be used as a comparison among breeds. Only 4 breeds were represented by more than 5 different sires and the amount of pedigree information was variable among the sires. Additionally, there were sires included in the study that had unique identification, limited pedigree information, and no breed specified. In addition, the dam breed matched the sire breed in some but not all instances.

Table 1 contains mean, minimum, maximum, and SD values for lean color, Hunter colorimeter readings, taste sensory panel ratings, and WBSF values. It has been shown that individuals can detect a difference of 1 kg in meat tenderness (Miller et al., 1995; Huffman et al., 1996) and the threshold of acceptability for tenderness, in kilograms, as measured by WBSF, has been evaluated by numerous trained panels with average values ranging from 4.31 to 5.99 kg (Shackelford et al., 1991; Miller et al., 1995, 2001; Boleman et al., 1997; Shackelford et al., 1997). In the present study, 14% of the carcasses had greater than 4.31 kg recorded for 21-d WBSF. In addition, 20.7% of the steaks had taste sensory panel ratings for initial tenderness less than a rating of 5 (5 = slightly tender and 4 = slightly tough) and 10.8% of the steaks had sensory panel ratings for sustained tenderness less than 5.

Heritabilities for lean color, Hunter colorimeter readings, WBSF, and sensory taste panel ratings are reported in Table 2. The heritability for lean color in this study was greater than that found by Shackelford et al. (1994b) who reported lean color was a lowly heritable...
trait (0.12 ± 0.05). This study differs from the previous study as the previous study used a 7-point scale and color was evaluated directly after chilling when the carcasses were ribbed.

King et al. (2010) found low heritability estimates for instrumental color at d 0 (L* = 0.24 ± 0.13, a* = 0.06 ± 0.09, and b* = 0.00 ± 0.05); these estimates slightly improved on d 6 (L* = 0.40 ± 0.16, a* = 0.14 ± 0.12, and b* = 0.13 ± 0.12). These values also differ from the current study as the L* value was extremely low in heritability and the heritabilities of both a* and b* values were greater.
The heritabilities of shear force and trained sensory panel results that have been reported were somewhat variable. Heritabilities of shear force values have varied from 0.06 to 0.53 ± 0.15 in previous studies (Shackelford et al., 1994a; Wheeler et al., 1996; Wulf et al., 1996; O’Connor et al., 1997; Splan et al., 1998; Crews and Kemp, 2001; Splan et al., 2002; Riley et al., 2003; Nephawe et al., 2004; Dikeman et al., 2005; Smith et al., 2007). Like the current results, Shackelford et al. (1994a) also found WBSF was highly heritable (0.53). In that study purebreds, composite populations, and F1 crosses were included. However, Gregory et al. (1994) reported a shear force heritability of 0.12 for ribs steaks aged 9 d postmortem from 3 composite breeds. In addition, Riley et al. (2003) reported much lower estimates of heritability for 7-, 14-, and 21-d shear force (0.14, 0.14, and 0.06, respectively); however, the population used in that study was a single breed: Brahman. The population differences potentially explain the variation in heritability estimates found among the studies with the present results more closely resembling those from similar populations of cattle.

Gregory et al. (1994) found the heritability of sensory panel tenderness score was 0.21, juiciness score was 0.24, and flavor score was 0.06. Splan et al. (1998) reported heritability estimates for taste panel tenderness, juiciness, and flavor were 0.31, 0.00, and 0.04, respectively. Although heritability for tenderness was comparable with the current results, heritability values for juiciness and flavor in the present study were considerably greater. Using trained sensory panel data, Dikeman et al. (2005) estimated the heritability of tenderness, juiciness, and flavor was 0.37, 0.46, and 0.07, respectively. Riley et al. (2003) found sensory panel heritability estimates for tenderness (0.11), juiciness (0.05), and flavor intensity (0.04). Finally, Nephawe et al. (2004) found heritability estimates for taste panel flavor and taste panel juiciness were 0.05 and 0.01, respectively. The values of both Riley et al. (2003) and Nephawe et al. (2004) do not support the current findings as their heritability values were distinctly lower for all 3 palatability traits when compared with the present findings.

The phenotypic and genetic correlations between measures of palatability and color are shown in Table 3. These agree with findings of many studies including that of Wulf and Page (2000) who reported that tenderness traits were most closely related to lean color. Wulf et al. (1996) found a significant positive correlation between shear force and lean color, indicating that shear force values increased as lean color became darker. Lawrence et al. (2001) also agreed with these findings citing a significantly positive relationship between LM color score and WBSF (0.16). Whereas the genetic and phenotypic correlations found in this study between WBSF and lean color were moderately negative, they suggest that darker colored meat (those with lower lean color scores) had greater WBSF values, indicating the meat was less tender.

Goni et al. (2007) found that as tenderness decreased (increase in WBSF), meat became less red and less yellow, according to Hunter colorimeter readings. They found a significant negative relationship between 7-d WBSF and a* value (–0.29) as well as a significant negative relationship between 7-d WBSF and b* value (–0.31). Goni et al. (2007) reported significant negative relationships between 14-d WBSF with a* value (–0.26) and b* value (–0.29). Similarly, Wulf et al. (1997) reported a significant negative relationship between shear force and a* value (–0.24) as well as shear force and b* value (–0.38). Although the current

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<th>Trait</th>
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<td></td>
<td>Lean color3</td>
<td>a*</td>
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<tr>
<td>21 d WBSF, kg</td>
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<td>7 d IT</td>
<td>0.56</td>
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<td>3 d IJ</td>
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<td>14 d SJ</td>
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<td>21 d BF</td>
<td>0.64</td>
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<td>3 d FI</td>
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<td>3 y OVM</td>
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1WBSF = Warner-Bratzler shear force; IT = initial tenderness; STT = sustained tenderness; IJ = initial juiciness; SJ = sustained juiciness; BF = beef flavor; FI = flavor intensity; OVM = overall mouthfeel (1 = extremely tough, extremely dry, extremely uncharacteristic young beef, extremely bland beef, non-beef-like mouthfeel; 8 = extremely tender, extremely juicy, extremely characteristic young beef, extremely characteristic young beef, beef-like mouthfeel).

2For phenotypic correlations, P > 0.10, *P < 0.05, and **P < 0.01.

3Lean color: 1 = extremely dark, 8 = extremely bright cherry red.

4a* = redness, b* = yellowness, and L* = lightness.

Table 3. Genetic and phenotypic correlation estimates among the palatability traits and measures of subjective and objective color of LM
study analyzed the phenotypic and genetic correlation of 21-d WBSF to lean color at 48 h postmortem, the results were similar with the exception that the phenotypic correlation between b* value and 21-d WBSF was not significant and the genetic correlations were both highly negatively correlated compared with the moderate correlation found in previous studies.

Previous studies have also reported that dark meat is correlated with lower ratings for tenderness according to sensory taste panels. Wulf et al. (1996) found a significant relationship between the 2 traits citing that mean tenderness scores were 4.67, 5.26, and 5.76, respectively, for dark, normal, and pale beef. They also found that normal colored lean received greater ratings for flavor intensity than dark or pale colored lean; however, color was not a significant source of variation for taste panel juiciness. This study found no phenotypic and a negative genetic correlation between both initial and sustained juiciness and lean color but agreed with the previous studies showing significant positive phenotypic correlations \((P < 0.01)\) between lean color and initial tenderness, sustained tenderness, beef flavor, flavor intensity, and overall mouthfeel. Additionally, the results indicated a moderately positive genetic correlation between lean color and flavor intensity and high positive genetic correlations between lean color and tenderness, beef flavor, and overall mouthfeel.

Previous studies have reported significant relationships between Hunter colorimeter readings and sensory panel ratings. Wulf et al. (1997) found that there was a significant \((P < 0.05)\) positive correlation between a* value and panel tenderness as well as b* value and panel tenderness; however, a* and b* values were not related to juiciness or flavor. Panea et al. (2008), on the other hand, found a positive correlation between a* value and sensory taste panel juiciness \((0.36)\). Although the current results had no significant phenotypic correlations between a*, b*, and juiciness, significant positive phenotypic correlations were detected \((P < 0.05)\) between a* and b* values and flavor intensity and overall mouthfeel. In addition, high genetic correlations were found between the a* value and b* value with sustained tenderness and the a* value and b* value with overall mouthfeel. Both the a* value and b* value were moderately correlated with initial tenderness. Also, b* value and beef flavor were moderately correlated genetically. Low genetic correlations were found between a* value and beef flavor whereas a* value and sustained juiciness were moderately negatively correlated.

**Implications**

Results from this study clearly indicate that lean color is not only heritable but genetically correlated with the palatability of beef. Lean color is also a trait that is economically feasible to measure in commercial harvest facilities, therefore suggesting that this is a trait that could not only be selected for and improved on in the industry but could also be evaluated in the plants with the opportunity for standards to be established and premiums given for carcasses that qualify for tenderness programs. Finally, these findings lead us to believe that there are potential opportunities for genomic tools to be developed for these phenotypic traits allowing for selection of cattle that will improve the tenderness of the end product.

**LITERATURE CITED**


