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Influence of diverse finishing systems on carcass characteristics, proximate composition, and meat quality attributes of striploins from bison heifers

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Bison producers commonly utilize grain- or grass-finishing across both extensive and intensive management systems that can vary in diet composition and nutrient concentration. Finishing systems may impact the growth rate and composition of gain, as well as tenderness and sensory characteristics of bison meat. Therefore, the objective of this study was to determine the effect of diverse finishing systems on carcass composition and meat quality of bison. Bison heifers ($n = 263$, approximately 25 months of age) from a single source were randomly assigned to one of six finishing systems: 1) pen-finished with free choice access to each feedstuff (grass hay, alfalfa, and corn grain in separate feeders) at low stocking density (55 m^2 per animal, $n = 45$); 2) pen-finished with grass hay, alfalfa, and corn provided as a total mixed ration (TMR) at low stocking density ($n = 43$); 3) pen-finished with the same TMR at high stocking density (27 m^2 per animal, $n = 44$); 4) range-finished on high diversity rangeland ($n = 44$); 5) range-finished on low diversity rangeland ($n = 44$); and 6) range-finished on low diversity rangeland with free choice access to corn supplement ($n = 43$). At approximately 31–32 months of age, all heifers were transported to a commercial harvest facility. Carcass data were recorded, and one striploin was collected from a subsample of carcasses for analysis of composition, meat tenderness, and trained sensory panel evaluation. Addition of corn grain increased live weight, carcass weight, dressing percentage, ribeye area, and backfat thickness compared with heifers finished only on rangeland. Finishing systems did not influence objective tenderness. Pen-finishing systems that included corn grain improved perception of several sensory attributes including juiciness, brown/roasted, sweetness, and umami, whereas the intensity of characteristic bison flavor was more prominent in range-finished bison. However, corn supplementation on rangeland, pen stocking density, rangeland diversity, and pen-based feed delivery rarely

influenced sensory attributes. Collectively, finishing systems influenced many bison carcass composition and meat characteristics, suggesting that bison meat products from differing finishing systems could influence economic outcomes of bison enterprises and provide alternative marketing opportunities to meet varied consumer preferences.

KEYWORDS

bison, carcass composition, finishing system, meat quality, sensory attributes, tenderness

Introduction

Bison production and consumption in the United States has increased ~20% in the last decade. The USDA Census of Agriculture reported that the bison inventory increased from 162,110 in 2012 to 192,477 bison in 2022 (USDA-NASS, 2022), whereas sales of bison increased from \$94 million in 2012 to \$122 million in 2022 (USDA-NASS, 2022). Bison production in the United States includes both grain- and grass-finishing systems, and these systems can be intensive or extensive in nature. Thus, systems used to finish bison can range from finishing completely on pasture, to supplementing concentrates while on pasture, providing harvested feedstuffs in loose confinement, or finishing animals in commercial style feedyards (Greenwood, 2021). Furthermore, ration ingredients and/or forage availability in these different systems can vary. For example, grass-finished animals can encounter variation in forage variety, quality, and quantity, and these characteristics can vary among pastures, terrain, and regions of the country. Bison producers using intensive systems have to consider the availability and quality of feedstuffs, as well as the most efficient manner to provide diets in a confinement setting. A consideration for finishing bison using an intensive system is stocking density within the confined space; however, research investigating the optimal stocking density for bison production to accommodate their social preferences and maximize efficiency of gain and potential impacts on carcass characteristics is limited. Efforts to better inform the unique management and production practices of bison to improve growth efficiency and carcass outcomes will also aid in meeting consumer demands for bison produced across multiple systems.

Details regarding finishing systems are often conveyed to consumers via marketing claims to differentiate products. While research in the bison industry has focused on understanding the influence of finishing systems on carcass characteristics (Rule et al., 2002; Janssen et al., 2021; Newton et al., 2024), studies investigating the impact of varied finishing systems on palatability of bison meat are limited. Additionally, these previous studies have focused on characterizing extreme differences (grain- vs. grass-finishing) and research investigating a more diverse range of bison finishing systems is lacking. Meat palatability includes measures of tenderness, juiciness, and flavor (Smith and Carpenter, 1974).

While tenderness has historically been cited as the key palatability trait in beef (Miller et al., 1995; Savell et al., 1987; Savell et al., 1999), recent research has identified flavor as the largest factor impacting overall beef eating satisfaction (Corbin et al., 2015; Lucherik et al., 2016; O'Quinn et al., 2012). While these palatability traits have been well researched in beef, the primary drivers of bison consumer satisfaction are less understood. We hypothesized that bison heifers finished in a pen system would have increased hot carcass weights, dressing percentage, ribeye areas, and marbling scores compared with bison heifers finished only on grass in a range system. We also hypothesized providing feedstuffs in a TMR would increase the proportion of protein and fat compared with heifers allowed a free choice diet. Furthermore, we hypothesized that pen-finished bison offered a grain diet would have improved tenderness and less off-flavor sensory attributes than range-finished bison and that bison finished on highly diverse range would have more off-flavor intensity than bison finished on range with limited forage diversity. To test these hypotheses, the objective of this study was to determine the influence of diverse finishing systems on carcass characteristics, color of lean and fat tissue, pH, proximate composition, tenderness, and sensory characteristics of steaks from bison heifers.

Materials and methods

Animals and sample collection

Bison heifers ($n = 263$) from a common source were allowed to graze native pasture in the Sandhills Ecoregion of Nebraska until assignment to treatment systems. Heifers were randomly assigned to one of six finishing systems when they were approximately 25 months of age (mean body weight = 253 ± 18.6 kg): 1) pen-finished with free choice access to each feedstuff (alfalfa hay, grass hay, and corn grain) at low stocking density (55 m^2 per animal, $n = 45$; low density-FC); 2) pen-finished with grass hay, alfalfa hay, and corn grain provided as a total mixed ration (TMR) at low stocking density ($n = 43$; low density-TMR); 3) pen-finished with grass hay, alfalfa hay, and corn grain provided as a total mixed ration at high stocking density (27 m^2 per animal, $n = 44$; high density-TMR), 4) range-finished on high diversity rangeland ($n = 44$; high-diversity),

5) range-finished on low-diversity rangeland ($n = 44$; low-diversity), 6) range-finished on low diversity rangeland with free choice access to corn supplement ($n = 43$; low diversity with corn). For system 1, alfalfa hay (20% crude protein [CP], 0.28 Mcal/kg net energy of maintenance [NEm], 0.16 Mcal/kg net energy of gain [NEg]) and grass hay (8% CP, 0.20 Mcal/kg NEm, 0.09 Mcal/kg NEg) were delivered in large-round bales (658 or 590 kg for alfalfa or grass hay, respectively) to separate bale feeders. Whole corn grain (8.7% CP, 0.44 Mcal/kg NEm, 0.30 Mcal/kg NEg) was delivered to a separate feed bunk. All three feedstuffs were always available so heifers could freely choose how much of each feedstuff to consume. Over the feeding period, the heifers consumed an average of 40% alfalfa hay, 10% grass hay, and 50% corn grain (as-fed basis). For the TMR delivered to systems 2 and 3, ground alfalfa hay (44% as fed), ground grass hay (5% as fed), and whole corn grain (51% as fed) were mixed in a feed wagon and delivered in feed bunks. Ingredient proportions were based on historic consumption by bison receiving free choice access to all three ingredients. Corn grain was mixed at 15% of the TMR for the first 13 days of the feeding period and then gradually increased over the next 20 days to the final ration to adapt the rumen microbial population to a high-grain diet. The final TMR provided 12.6% CP, 0.37 Mcal/kg NEm, and 0.25 Mcal/kg NEg. High-diversity rangeland for system 4 was based on typical native Nebraska Sandhills upland pastures with interspersed wetlands and wet meadows, so the animals were exposed to broader plant community types and vegetation species diversity (greater than 100 different species of vegetation identified in a random ocular survey). Plots were clipped once each in late summer and fall, and the average nutrient composition of available forage was 4.2% CP, 0.22 Mcal/kg NEm, and 0.11 Mcal/kg NEg. Low-diversity rangeland for systems 5 and 6 was based on meadow pastures that were typically lower diversity (57 species identified by ocular survey) overall because they included only meadow and wetland habitat with rare inclusion of upland native range. Again, plots were clipped once each in late summer and fall, and the average nutrient composition of available forage was 4.0% CP, 0.24 Mcal/kg NEm, and 0.15 Mcal/kg NEg. Supplementation of whole corn grain to system 6 was delivered to feed bunks placed in the pasture. Corn grain was from the same source as used in system 1 and was always available so heifers could freely choose to consume as desired. On average, each bison heifer consumed 4.6 kg per d of corn grain throughout the grazing period. During late fall and winter, when dormant range forage was low in CP, alfalfa hay (22.4% CP, 0.28 Mcal/kg NEm, 0.16 Mcal/kg NEg) was delivered to all three range finishing systems as a protein supplement. On average, each heifer consumed 2.5 kg per day of alfalfa hay during this period.

Heifers were harvested when visually appraised to be at the appropriate market endpoint for their respective systems. At approximately 31 months of age, all heifers from systems offered corn grain (Low density-FC Pen, Low density-TMR Pen, High density-TMR Pen, and Low-diversity range w/corn) were transported (~608 km) to a commercial harvest facility and harvested over 2 d. On the first day of slaughter, all heifers in the High density-TMR Pen and Low-diversity range w/corn systems were slaughtered. On the second day, all heifers in the Low density-

FC Pen and Low density-TMR Pen systems were slaughtered. A month later, at approximately 32 months of age, all heifers from the grass-only systems (High-diversity or Low-diversity rangeland) were transported to the same commercial harvest facility and harvested on 1 day. Live weight of each heifer was recorded at the harvest facility shortly before slaughter, and hot carcass weight (HCW) was recorded immediately after slaughter upon entry into the chilling cooler. The dressing percentage was calculated as HCW divided by live weight $\times 100$. After an approximately 20-h chilling period, carcasses were ribbed between the 12th and 13th ribs and the ribeye area, backfat thickness, and marbling score were determined by trained evaluators. Additionally, objective color (CIE L^* [0 = Black, 100 = White], a^* [negative values = green, positive values = red], and b^* [negative values = blue, positive values = yellow]) of the exposed ribeye area and the subcutaneous fat of the carcass surface opposite the ribeye area were recorded using a handheld colorimeter (Chroma Meter CR 410, Konica Minolta, Inc., Tokyo, Japan) according to instrumental meat color measurement guidelines (King et al., 2023). The colorimeter was equipped with a 2° observer and 50-mm aperture and was calibrated using a standard white tile specific to the machine. A subsample ($n = 180$; 30 carcasses closest to the average HCW per system) was selected and transported to a commercial fabrication facility. The *longissimus lumborum* muscle (striploin) was removed from the left side of each subsample carcass unless unavailable. Due to bruising of some carcasses, striploins were removed from the right side of some carcasses to ensure an adequate amount of product for fabrication into steaks. Striploins were vacuum packaged and transported in a refrigerated van to the South Dakota State University Meat Laboratory for steak fabrication and further analysis.

Striploin fabrication and pH

Samples arrived at the South Dakota State University Meat Laboratory at 2 days (Low-diversity range w/corn, High density-TMR Pen, and High-diversity or Low-diversity rangeland) or 3 days (Low density-TMR Pen, Low density-FC) postmortem. Ultimate pH was measured on the posterior end of each striploin using a hand-held pH meter (Thermo Scientific Orion Star, Beverly, MA, Model #A221 and Star A321 Portable pH probe) just prior to fabrication into steaks. Samples were fabricated into 2.54-cm steaks beginning at the anterior end of the striploin. Steaks were individually vacuumed packaged, stored for 14 days at 4°C, and then frozen. One steak was designated for proximate analysis, one steak was designated for Warner-Bratzler shear force (WBSF) and cook loss analysis, and the final three steaks were designated for trained sensory panel evaluation.

Proximate analysis

To determine the proximate nutrient composition of the *longissimus lumborum*, steaks were thawed slightly and trimmed of excess external fat and accessory muscles. Steaks were sliced into small pieces, snap frozen in liquid N, and powdered for 30 s in

stainless-steel blender cups (Waring Products Division, New Hartford, CT, Model SS 110) until they achieved a uniform consistency. Powdered samples were stored in 11.43 × 22.86 cm sample bags (Fisher, Hanover Park, IL) at −20°C until chemical composition analyses.

Crude protein content was determined as described by Janssen et al. (2021) with modifications. Duplicate powdered samples were weighed (approximately 250 mg) into crucibles and were subjected to Dumas combustion by a N analyzer (Rapid N Exceed, Serial #17231090, Elementar, Hanau, Germany). Percent crude protein was calculated as the percent N detected for each sample multiplied by 6.25.

Crude fat and moisture content were determined using ether extraction as described by Mohrhauser et al. (2015) with modifications. Triplicate powdered samples (approximately 6 g) were weighed into dried aluminum tins (Fisher Aluminum Weighing Dishes, Model #08-732-101, Hanover Park, IL), covered with two pieces of dried filter papers (Cytiva Whatman Qualitative Filter Paper 55 mm, Model #09-805B), and dried in an oven at 100°C for 24 h. Empty aluminum tins were dried at 100°C for 24 h, and filter papers were dried at 100°C for 1 h to determine tare weight. Dried samples were then cooled in desiccators and reweighed after cooling. Percent moisture content was calculated as the difference between pre- and post-drying sample weights and expressed as a percentage of the pre-drying sample weight. Samples were then extracted with petroleum ether in a side-arm Soxhlet extractor (Thermo Fisher Scientific, Rockville, MD) for 72 h followed by evaporating under a laboratory hood at room temperature for 1 h and subsequent drying in an oven at 100°C for 4 h. Dried and extracted samples were cooled in desiccators, and samples were reweighed. To calculate the proximate intramuscular fat content, the difference between pre- and post-extraction weight was determined and expressed as a percentage of the wet sample weight.

Ash content was determined as described by Janssen et al. (2021) with modifications. Duplicate powdered samples were weighed (approximately 3 g) into dried aluminum tins (Fisher Aluminum Weighing Dishes, Model #08-732-101, Hanover Park, IL) and dried in an oven at 100°C for 24 h. Dried samples were then cooled in desiccators, and samples were reweighed. Samples were placed into a muffle furnace and ashed for 24 h at 525°C. Ashed samples were cooled in desiccators and reweighed. Proximate ash content was calculated as the difference between pre- and post-ashed sample weights expressed as a percentage of the pre-ashed sample weight.

Warner-Bratzler shear force and cook loss

Frozen steaks were thawed for 24 h at 4°C before cooking, and all steaks were weighed prior to cooking to an internal temperature of 71°C. Steaks were cooked on an electric clamshell grill (George Forman 9 Serving Classic Plate Grill, Model #GR2144P, Middleton, WI). Internal temperature was monitored using a digital thermometer (Cooper-Atkins Aqua Tuff NSF Series, Middlefield,

CT, Model #41-983430-5) placed near the geometric center of each steak. Peak temperature was recorded for each steak. After cooking, all steaks were cooled for 24 h at 4°C. Steaks were allowed to warm to room temperature and then reweighed. Cook loss was calculated as the difference between pre- and post-cooking steak weights expressed as a percentage of the pre-cooking weight. After weighing, five cores (1.27 cm in diameter) were removed parallel to the muscle fiber orientation and sheared once perpendicular to the muscle fiber orientation. A texture analyzer (Shimadzu Scientific Instruments Inc., Lenexa, KS, Model #30825535050) with a Warner-Bratzler attachment was used to determine peak force required to shear each core. Peak force was recorded, and an average shear force peak value was reported for each steak (American Meat Science Association, 2015).

Trained descriptive sensory analysis

Trained descriptive sensory analysis was conducted at Texas Tech University (Lubbock, TX; Institutional Review Board protocol deemed exempt). The American Meat Science Association Sensory Guidelines (2015) were utilized with modification appropriate for this study. Experienced panelists were trained for 2 weeks prior to testing and completed approximately 20 h of training. Panelists (n = 10) were trained to identify and quantify the intensity of 15 flavor and texture attributes described by Adhikari et al. (2011) and American Meat Science Association (2015). These attributes included tenderness, juiciness, bison identity, bitter, blood/serum, brown/roasted, fat-like, green hay-like, liver-like, metallic, musty/earthy/humus, overall sweet, oxidized, sour aromatics, and umami. Definitions and references for flavor and texture attributes are provided in Table 1.

Frozen steaks were thawed for 24 h at 4°C before cooking to an internal temperature of 71°C. Steaks were cooked on an electric clamshell grill (Cuisinart Griddler Deluxe, Model GR-150P1, Glendale, AZ). Internal temperature was monitored using a digital thermometer (Atkins AquaTuff, Model 351, Type K, Middlefield, CT) placed near the geometric center of each steak. Following cooking, steaks were wrapped in aluminum foil and held at 50 to 55°C in a food service warmer (Cambro MFG CO, Heater Model CAM6000, Huntington Beach, CA). Exterior fat and heavy connective tissue were removed before cutting steaks into 1.27 cm × 1.27 cm × 2.54 cm cubes. Steaks from each system designated for the sensory panel and training steaks (various bison steaks sourced from local grocery) were cooked and prepared using the same procedure. Panelists evaluated a minimum of two steak cubes under red gel lights and recorded attribute ratings using a digital survey on a tablet (Qualtrics; iPad, Apple, Inc.). Attributes were rated on a 100-point scale where 0 = extremely dry/tough/not detectable and 100 = extremely juicy/tender/intense. Prior to the first sample, and in between samples, panelists were instructed to cleanse their palate with apple juice, saltless crackers, and distilled water. Panelists were also provided an expectorant cup, a napkin, and toothpicks. Six samples (1 per system), in random order, were evaluated per session with approximately 4 min between each sample.

TABLE 1 Definitions and standard references for descriptive bison flavor and texture attributes, where 0 = extremely dry/tough/not detectable and 100 = extremely juicy/tender/intense, modified from [Adhikari et al. \(2011\)](#) and [American Meat Science Association \(2015\)](#).

Reference caption	Definition	Point Value
Bison identity	Amount of bison flavor in a sample.	Ground bison (90/10) = 25, bison ribeye = 33, bison sirloin = 40
Bitter	The fundamental taste factor associated with a caffeine solution.	0.01% caffeine solution = 15, 0.02% caffeine solution = 25
Bloody/serum	The aromatics associated with blood on cooked meat products. Closely related to metallic aromatics.	USDA Beef Choice strip steak cooked to 60°C = 40
Brown/roasted	A round, full aromatic generally associated with beef suet that has been broiled.	Bison suet = 57, beef suet = 53
Fat-like	The aromatics associated with cooked animal fat.	Lit'l smokies = 44, beef suet = 80
Green hay-like	Brown/green dusty aromatics associated with dry grasses, hay, dry parsley, and tea leaves	Dry parsley in snifter = 30 (aroma), dry parsley, tasted = 40 (flavor)
Juiciness	Amount of perceived juice released during mastication.	Carrot = 56, mushroom = 66, cucumber = 80, watermelon = 100
Liver-like	The aromatics associated with cooked organ meat/liver.	Beef flat-iron = 20, beef calf liver = 60
Metallic	The impression of slightly oxidized metals such as iron, copper, and silver spoons.	0.1% potassium chloride = 10 USDA choice strip steak cooked to 60°C = 25 Dole canned pineapple juice = 38
Musty/earthy/humus	Musty, sweet, decaying vegetation.	Button mushroom = 20
Overall sweet	The combination of sweet taste and sweet aromatics.	Post shredded wheat = 10, Lit'l smokies = 20
Oxidized	The aromatics associated with oxidized fats and oils. These aromatics may include cardboard, painty, varnish, and fishy.	Microwaved Wesson vegetable oil microwaved for 3 min = 40, Microwaved Wesson vegetable oil microwaved for 5 min = 56
Sour aromatics	The aromatics associated with sour substances	Buttermilk = 33
Tenderness	Amount of force required to masticate meat.	Beef eye of round steak = 33, beef striploin steak = 55, beef tenderloin = 90

(Continued)

TABLE 1 Continued

Reference caption	Definition	Point Value
Umami	Flat, salty, somewhat brothly. The taste of glutamate, salts of amino acids and other molecules called nucleotides.	0.035% accent flavor enhancer solution = 7.5 (flavor)

Statistical analysis

Carcass traits, lean and external fat color, ultimate pH, proximate composition, WBSF, and cook loss were analyzed as a completely randomized design using mixed model procedures of SAS (SAS Inst. Inc., Cary, NC, v 9.4). The finishing system was specified in the model as a fixed effect. Heifer/carcass served as the experimental unit. Peak temperature was tested as a covariate for WBSF and cook loss but was not significant and omitted from the model. Least-squares means were calculated, and five orthogonal contrast statements were used to test hypotheses: 1) all pen-based systems vs. all range-based systems, 2) Low stocking density-TMR vs. High stocking density-TMR, 3) Low density-FC vs. Low density-TMR, 4) Low-diversity range vs. High-diversity range, and 5) Low-diversity range vs. Low-diversity range with corn supplementation. Statistical significance was considered at an alpha level of < 0.05 for all contrasts, with tendencies considered at alpha levels ranging from 0.05 to 0.10.

Sensory attributes were analyzed as a randomized complete block design, also using mixed model procedures of SAS. Panelist was considered the blocking factor and specified as a random effect. Finishing system was specified in the model as a fixed effect. Sample order and session were also included as fixed effects but were omitted from the model if not significant ($P < 0.05$). Least-squares means were calculated, and the same five orthogonal contrast statements were used to test hypotheses. Statistical significance was considered at an alpha level of ≤ 0.05 , with tendencies considered at alpha levels ranging from 0.05 to 0.10.

Results and discussion

Carcass characteristics

Carcass measurements were evaluated using the United States Department of Agriculture (USDA) beef grading standards because there is currently no system for assigning yield or quality grades to bison in the United States. Carcass characteristics are presented in [Table 2](#). Pen-finished heifers had heavier ($P < 0.05$) final live weights and HCWs compared with range-finished heifers. Heifers stocked at a lower density in pen finishing systems tended to have higher ($P = 0.066$) final live weight and had higher ($P < 0.05$) HCW than heifers stocked at high density. Providing feedstuffs free choice rather than as a TMR did not influence ($P > 0.05$) final live weight or HCW. Low or

high rangeland diversity did not influence ($P > 0.05$) final live weight or HCW. However, corn supplementation to grazing heifers increased final live weight and HCW ($P < 0.05$) despite being harvested 1 month earlier. Similar results were observed by Janssen et al. (2021) and Newton et al. (2024) with grain-finishing resulting in heavier ($P < 0.05$) HCW compared with grass-finishing. Hot carcass weights of all pen-finished heifers in this study were comparable with the average HCW of grain-finished young bison heifers (240 kg) reported in December 2023 by the USDA-AMS in the National Monthly Bison Report (USDA-AMS, 2024). Hot carcass weights of range-finished heifers supplemented with corn (221.7 kg) were similar to HCW of bison heifers (229 kg) reported by López-Campos et al. (2014) and grass-finished heifers (226 kg) reported by Janssen et al. (2021). However, the HCW of heifers finished only on grass was lighter than other reports, but the trend of grass-finishing producing lighter carcasses is in agreement with other studies.

Pen-finished heifers had higher ($P < 0.05$) dressing percentages compared with range-finished heifers, and corn-supplemented heifers on rangeland also had a higher ($P < 0.05$) dressing percentage than heifers finished on range without corn (Table 2). Overall, access to grain resulted in improved dressing percentage. This is likely due to grain-finishing resulting in more backfat and heavier muscling. Pen stocking density, free-choice vs. TMR, and rangeland diversity did not influence ($P > 0.05$) the dressing percentage. Dressing percentages of heifers offered grain were similar to those reported by Janssen et al. (2021), whereas dressing percentage of heifers finished on range with no supplemental corn was lower than grass-finished heifers reported by Janssen et al. (2021).

Pen-finished heifers had larger ($P < 0.05$) ribeye areas compared with range-finished heifers (Table 2). Within pen-finishing systems, high stocking density reduced ($P < 0.05$) ribeye area relative to low stocking density, while free choice or TMR did not influence ($P > 0.05$) ribeye area. Within range finishing systems, higher range diversity or supplementation with corn both increased ($P < 0.05$) ribeye area compared with low-diversity rangeland without supplementation. The ribeye areas of pen-finished and range-finished heifers from this study were similar to the ribeye area of grain-finished (64.58 cm²) and grass-finished bison heifers (57.48 cm²), respectively, reported by Janssen et al. (2021); Lee et al. (2012) conducted a stocking density evaluation with Hanwoo steers and reported that steers finished with 32 and 16 m² produced carcasses with larger *longissimus* muscle area ($P < 0.01$) compared with steers finished with 10.6 or 8.0 m² per steer, similar to the bison heifers in this study. In beef, research has evaluated the effects of grazing mixtures of varying diversity of forages on animal and carcass performance of steers during the finishing period (Maciel et al., 2022). Steers assigned to a five-species small grain-brassica mixture had increased HCW compared with steers finished on a two-species small grain-brassica mixture and mixed pasture (Maciel et al., 2022). Alternatively, Borders et al. (2025) reported no difference in carcass traits among beef steers grazed on three levels of species diversity on mixed-grass native rangeland in South Dakota. However, the steers in Borders et al. (2025) were grown on these treatments during a stocker

program and finished on a common grain-based ration in pens. Research in beef cattle has shown supplementation with corn increased average daily gain, HCW, and dressing percentage compared with steers not supplemented with corn (Wright et al., 2015; Klopatek et al., 2022). This study may indicate that improving forage diversity and/or supplementation with corn can enhance muscle growth of bison heifers.

Pen-finished heifers had increased ($P < 0.05$) backfat thickness and marbling scores compared with range-finished heifers (Table 2), and corn-supplemented heifers on rangeland also had thicker ($P < 0.05$) backfat but had similar ($P > 0.05$) marbling to heifers finished on range without corn. This would be expected given the increase in dietary energy available to the pen-finished and corn-supplemented heifers. Pen stocking density and rangeland diversity did not influence ($P > 0.05$) backfat thickness or marbling score, whereas free choice feed delivery increased ($P < 0.05$) the marbling score over TMR, although feed delivery did not influence ($P > 0.05$) backfat thickness. The marbling scores of pen-finished heifers fed a TMR would fall into the traces category of the USDA beef quality grading system, whereas pen-finished heifers with free choice access would fall into the slight category. The marbling scores of Low-diversity range-finished heifers (with and without corn) would fall into the traces category, whereas marbling scores of High-diversity range-finished heifers would fall into the practically devoid category.

Objective color and ultimate pH

Heifers in all pen-finishing systems (Low density-FC, Low density-TMR, and High density-TMR) had higher ($P < 0.05$) L^* values of the lean surface of the ribeye compared with all range-finished heifers (High-diversity, Low-diversity, Low-diversity w/ corn) (Table 3). Pen stocking density, free-choice or TMR feed delivery, and supplementation of range-finished heifers with corn did not influence L^* ($P > 0.05$), but high range diversity reduced L^* ($P < 0.05$) compared with low diversity. These results differ from Newton et al. (2024) and Janssen et al. (2021), who reported finishing system did not influence ($P > 0.05$) the L^* value of the lean surface in bison. Pen-finishing increased ($P < 0.05$) a^* values of the lean face of the ribeye relative to range-finishing. The TMR feed delivery and corn supplementation of range-finished heifers increased lean tissue a^* ($P < 0.05$), whereas low range diversity tended ($P = 0.052$) to increase a^* , but pen stocking density did not influence lean tissue a^* ($P > 0.05$). The overall pattern of increased redness with the inclusion of grain in pen-finished diets or as a supplement to grazing heifers aligns with data reported by Newton et al. (2024) and Janssen et al. (2021), indicating that grain-finished bison have increased a^* values compared with grass-finished bison carcasses. The b^* values of the lean surface of the ribeye were increased ($P < 0.05$) by pen-finishing systems over range-finished systems and by supplemental corn provided to range-finished heifers ($P < 0.05$). Pen stocking density did not influence ($P > 0.05$) b^* values; however, free-choice ration delivery and High-diversity rangeland both reduced ($P < 0.05$) b^* values of the lean

TABLE 2 Least square means for the effect of diverse finishing system on live weight and carcass characteristics of bison heifers.

	Pen-finished systems ¹			Range-finished systems ¹			SEM ³	Contrasts ²				
	Low density-FC	Low density-TMR	High density-TMR	High diversity	Low diversity	Low diversity w/corn		Pen v. range	Low v. high pen density	Free ch. v. mixed ration	Low v. high range diversity	Range w/ or w/o corn
Live wt, kg ⁴	410.3	410.7	395.6	342.3	334.9	371.0	5.84	<0.001	0.066	0.962	0.369	<0.001
HCW, kg ⁵	252.9	251.8	238.5	183.5	176.1	221.7	4.38	<0.001	0.031	0.852	0.231	<0.001
Dressing, %	61.60	61.33	60.18	53.26	52.46	59.71	0.0059	<0.001	0.164	0.746	0.333	<0.001
Ribeye, cm ²	62.3	64.2	61.0	57.9	53.1	58.5	1.05	<0.001	0.009	0.116	<0.001	<0.001
Backfat, cm	1.79	1.68	2.22	0.49	0.41	1.24	0.323	<0.001	0.134	0.756	0.842	0.025
Marbling score ⁶	308	274	267	197	204	209	14.0	<0.001	0.678	0.031	0.719	0.734

¹Finishing systems: 1) pen finished with free choice access to each feedstuff (grass hay, alfalfa, and corn in separate feeders) at low stocking density (55 m² per animal, n = 45; Low density-FC), 2) pen-finished with grass hay, alfalfa, and corn provided as a total mixed ration at low stocking density (n = 44; Low density-TMR), 3) pen-finished with hay, alfalfa, and corn provided as a total mixed ration at high stocking density (27 m² per animal, n = 44; High density-TMR), 4) Range-finished on high diversity rangeland (n = 44; High-diversity), 5) range-finished on low diversity rangeland (n = 44; Low-diversity), 6) range-finished on low diversity rangeland with free choice access to corn supplement (n = 43; Low-diversity w/corn).

²Contrasts: pen v. range compares pen-based systems v. all range-based systems; low v. high pen density compares low density-TMR system v. the high density-TMR system; free ch. v. mixed ration compares low density-FC system vs. the low density-TMR system; low v. high range diversity compares Low-diversity range system vs. the High-diversity range system; and range w/or w/o corn compares Low-diversity range system vs. the Low-diversity range with corn system. Values are the probability of difference among contrast combinations.

³Standard error of the mean.

⁴Live weight of animals at slaughter facility before slaughter.

⁵Hot carcass weight.

⁶Marbling score: 100 = practically devoid⁰, 200 = traces⁰, 300 = slight⁰.

tissue. Janssen et al. (2021) and Newton et al. (2024) also reported that grass-finishing on native range resulted in lower b^* values than bison finished with grain.

The L^* value of backfat opposite the ribeye from pen-finished heifers was reduced ($P < 0.05$) compared with L^* of range-finished heifers and reduced ($P < 0.05$) by corn supplementation of range-finished heifers (Table 3). Additionally, L^* of backfat was reduced ($P < 0.05$) when feed was provided free-choice to pen-finished heifers rather than as a TMR. The stocking density of pen-finished heifers and diversity of rangeland grazed by range-finished heifers did not influence ($P > 0.05$) L^* of backfat. The a^* value of backfat opposite the ribeye was higher ($P < 0.05$) for pen-finished heifers than range-finished heifers and for range-heifers supplemented with corn. The a^* value was also increased ($P < 0.05$) by low stocking density of pen-finished heifers. However, a^* was not influenced ($P > 0.05$) by feed delivery method or range diversity. The b^* values of backfat opposite the ribeye were reduced ($P < 0.05$) for heifers finished in pens or supplemented with corn when range-finished. High pen stocking density tended ($P = 0.064$) to reduce b^* of backfat, whereas delivery as a TMR reduced ($P < 0.05$) b^* values. Rangeland diversity did not influence b^* values of backfat. Similar findings were reported by Janssen et al. (2021) and Newton et al. (2024) with grass-finished bison carcasses having increased b^* values of backfat. Increased b^* value is indicative of a more yellow color and is due to carotenoids found in green forage, resulting in increased yellowness of carcass fat from beef cattle in grass-based production systems (Dunne et al., 2009; Kim et al., 2023). Carotenoids are fat soluble with β -carotene being most abundant and primarily responsible for the yellow tint to subcutaneous fat (van Vliet et al., 2023).

Ultimate pH of striploins was not different ($P > 0.05$) between pen- or range-finishing systems and only tended ($P = 0.077$) to be reduced by corn supplementation of range-finished heifers (Table 4). Ultimate pH was reduced ($P < 0.05$) by free-choice ration delivery, tended ($P = 0.053$) to be reduced by high diversity rangeland, but was not influenced ($P > 0.05$) by pen stocking density. Ultimate pH values from this study were similar to values reported by Newton et al. (2024) and Janssen et al. (2021), who also did not observe a pen- vs. range-finishing system effect on pH. It was unlikely that differences detected among systems are biologically significant, given that all pH values differed by less than 1/10th of a pH unit and were well within the normal ultimate pH of meat, which ranges from 5.3 to 5.8 (Aberle et al., 2012).

Proximate chemical composition

Steaks from heifers in all pen-finishing systems had greater ($P < 0.05$) crude protein percentage than those from all range-finishing systems, and supplementing corn on rangeland also increased ($P < 0.05$) crude protein content relative to range-only systems (Table 4). Steaks from heifers provided their diet as a TMR had increased ($P < 0.05$) crude protein content compared with free-choice feed delivery. Stocking density in pens and diversity of rangeland vegetation did not influence ($P > 0.05$) the crude protein content

of steaks. These results closely follow compositional values for bison reported by Janssen et al. (2021) and Newton et al. (2024), indicating that grass-finishing results in lower crude protein percentage compared with grain-finishing. Other studies have reported the crude protein percentage of ribeye samples from grass-finished bison [21.5%; (Marchello and Driskell, 2001)] and concentrate-fed bison [22.1% (Marchello et al., 1998)], which were similar to the crude protein percentages from the *longissimus lumborum* samples reported here.

Steaks from heifers finished on range had increased percent moisture ($P < 0.05$) compared with all pen-finished systems and range-finished heifers provided corn (Table 4). Steaks from heifers on Low-diversity rangeland vegetation had increased ($P < 0.05$) moisture content compared with High-diversity rangeland. Stocking density in pens and method of feed delivery (free-choice or TMR) did not influence ($P > 0.05$) the moisture content of steaks. Similar findings were reported by Janssen et al. (2021) and Newton et al. (2024), with grass-finished steaks having increased moisture percentage compared with grain-finished steaks. These results follow trends established in beef, where moisture content generally correlates negatively with fat content (Savell et al., 1986; Soren and Biswas, 2020).

Steaks from heifers provided grain (all pen-finishing systems and corn supplementation of range-finished heifers) had increased ($P < 0.05$) the percentage of crude fat compared with steaks from heifers finished on range (Table 4). Pen stocking density, method of feed delivery, and range diversity did not influence ($P > 0.05$) the crude fat content of steaks. These results were similar to compositional values for the proportion of fat reported by Janssen et al. (2021) and Newton et al. (2024), with grass-finished bison having less crude fat percentage compared with grain-finished bison. The increased proportion of fat in steaks from heifers provided grain is supported by these systems also having higher ($P < 0.05$) marbling scores than heifers finished only on grass. Research in beef has also concluded that grain-fed animals generally consume higher levels of energy in a high-concentrate diet, resulting in excess energy being deposited as intramuscular fat (Leheska et al., 2008; Klopatek et al., 2022).

Steaks from pen-finished heifers that had free-choice access to feeds had an increased ($P < 0.05$) proportion of ash compared with steaks from heifers that received a TMR (Table 4). Otherwise, none of the other finishing systems influenced ($P > 0.05$) ash content. Newton et al. (2024) reported increased percentage of ash in samples from grain-finished bulls compared with grass-finished; however, no differences were observed by Janssen et al. (2021) for the proportion of ash from heifers finished in different systems. When evaluating ash percentages from ribeye samples, Marchello et al. (1998) and Marchello and Driskell (2001) reported percent ranges of 1.2% and 1.14% respectively, which are slightly higher numerically compared with the current study.

Warner-Bratzler shear force and cook loss

While Janssen et al. (2021) reported that grain-finished bison heifers produced more tender steaks compared with grass-finished heifers, in our study finishing systems did not influence ($P > 0.05$)

TABLE 3 Least square means for the effect of diverse finishing system on instrumental color measurements of lean and fat tissue from bison heifers.

	Pen-finished systems ¹			Range-finished systems ¹			SEM ³	Contrasts ²				
	Low density-FC	Low density-TMR	High density-TMR	High diversity	Low diversity	Low diversity w/corn		Pen v. range	Low v. high pen density	Free ch. v. mixed ration	Low v. high range diversity	Range w/ or w/o corn
Objective color: lean tissue at ribeye area ⁴												
<i>L</i> *	35.27	35.43	35.66	33.50	35.12	34.58	0.313	<0.001	0.516	0.658	<0.001	0.151
<i>a</i> *	21.27	22.35	22.09	18.71	19.53	20.88	0.315	<0.001	0.473	0.002	0.052	<0.001
<i>b</i> *	6.68	7.45	7.34	5.39	6.14	6.81	0.188	<0.001	0.608	<0.001	0.003	0.003
Objective color: subcutaneous backfat ⁵												
<i>L</i> *	72.60	74.33	74.58	76.78	76.55	72.13	0.554	<0.001	0.686	0.006	0.756	<0.001
<i>a</i> *	4.05	3.75	3.36	1.64	1.66	3.53	0.169	<0.001	0.041	0.108	0.957	<0.001
<i>b</i> *	15.94	14.45	13.42	23.65	23.26	21.29	0.495	<0.001	0.064	0.008	0.554	<0.001

¹Finishing systems: 1) pen finished with free choice access to each feedstuff (grass hay, alfalfa, and corn in separate feeders) at low stocking density (55 m² per animal, n = 45; Low density-FC), 2) pen-finished with grass hay, alfalfa, and corn provided as a total mixed ration at low stocking density (n = 44; Low density-TMR), 3) pen-finished with hay, alfalfa, and corn provided as a total mixed ration at high stocking density (27 m² per animal, n = 44; High density-TMR), 4) range-finished on high diversity rangeland (n = 44; High-diversity), 5) range-finished on low diversity rangeland (n = 44; Low-diversity), 6) range-finished on low diversity rangeland with free choice access to corn supplement (n = 43; Low-diversity w/corn).

²Contrasts: pen v. range compares pen-based systems v. all range-based systems; low v. high pen density compares low density-TMR system v. the high density-TMR system; free ch. v. mixed ration compares low density-FC system vs. the low density-TMR system; low v. high range diversity compares Low-diversity range system vs. the High-diversity range system; and range w/or w/o corn compares Low-diversity range system vs. the Low-diversity range with corn system. Values are the probability of difference among contrast combinations.

³Standard error of the mean.

⁴Objective color measurement recorded on the face of the ribeye following approximately 30 min bloom time; *L**: 0 = Black, 100 = White; *a**: negative values = green; positive values = red; *b**: negative = blue; positive values = yellow.

⁵Objective color measurement recorded on the backfat of the external surface of the carcass, opposite the exposed ribeye.

WBSF; however, supplementation of corn to range-finished heifers did tend ($P = 0.071$) to reduce (improve) WBSF compared with range only (Table 4). O'Sullivan et al. (2025) described a finishing treatment by aging day interaction for WBSF of steaks from grain- or grass-finished bison bulls. Steaks from grain-finished bulls were more tender as aging time increased from 4 to 14 days, whereas WBSF of steaks from grass-finished bulls did not differ during this period (O'Sullivan et al., 2025). Differences between studies are likely related to the specific aging periods evaluated. In the present study, all steaks were aged for 14 days, whereas these previous studies evaluated tenderness across several aging periods.

Tenderness has been identified as a critical palatability trait that impacts the overall eating experience for beef consumers (Miller et al., 1995; Savell et al., 1987; Savell et al., 1999; Gonzalez et al., 2024). Tenderness claims have been developed for beef products that meet threshold values based on WBSF. To be marketed as "USDA Tender" and "USDA Very Tender", WBSF must be <4.4 and ≤ 3.9 kg, respectively (ASTM-International, 2011). While these standards were developed for beef, bison steaks from all finishing systems in this study were below 3.9 kg at 14 days postmortem, indicating a very tender product can be produced from bison heifers across diverse finishing systems. Other studies have also reported WBSF values of bison striploin steaks that would meet the "USDA Very Tender" threshold (Janssen et al., 2021).

Steaks from heifers finished only on grass had greater ($P < 0.05$) cook loss compared with steaks from heifers provided grain (all pen-finished systems and corn supplementation of heifers on range; Table 4). These results are supported by the moisture percentage, wherein systems that increased moisture content also had greater cook loss (Table 4). Pen stocking density, pen feed delivery, and rangeland diversity did not influence ($P > 0.05$) cook loss. Other studies have also reported that steaks from grass-finished bison had increased percent cook loss compared with steaks from grain-finished bison (Janssen et al., 2021; Newton et al., 2024).

Trained descriptive sensory analysis

Tenderness intensity was greater ($P < 0.05$) for steaks from pen-finished bison at high stocking density compared with low stocking density (Table 5). Other finishing system contrasts did not indicate ($P > 0.05$) an influence on sensory tenderness. These results indicated overall agreement between WBSF and sensory perception of tenderness. However, differences in intramuscular fat (marbling) content can influence the sensory perception of tenderness (Corbin et al., 2015). Despite improved perceived tenderness, carcasses from the high stocking density pen system did not have increased marbling score (Table 2) or crude fat percentage (Table 4) compared with low stocking density. In bison, some research has focused on understanding the influence of finishing systems on WBSF, but the influence on consumer perception of tenderness has not been well characterized. Determining the influence of this palatability attribute on the sensory perception of bison will provide insight for possible development of tenderness marketing claims for bison products.

Juiciness was increased ($P < 0.05$) in steaks from pen-finishing systems, and corn supplementation of range-finished heifers tended ($P = 0.087$) to increase juiciness (Table 5). Pen stocking density, pen ration delivery, and range diversity did not influence ($P > 0.05$) perceived juiciness. Differences in intramuscular fat content (i.e., marbling score [Table 2] and crude fat [Table 4]) may have contributed to sensory responses for juiciness (Smith and Carpenter, 1974). Other studies investigating the impact of finishing system on sensory attributes of bison are lacking; however, Duckett et al. (2013) and Evers et al. (2020) evaluated the influence of forage or concentrate finishing on sensory attributes of beef and reported no influence of finishing method on tenderness or juiciness. Differences between studies could be related to specific diets provided or differences between the animal species investigated.

Bison identity was measured to determine the intensity of characteristic bison flavor and was increased ($P < 0.05$) in steaks from range-finishing systems (Table 5). Low pen stocking density and high range diversity also increased ($P < 0.05$) bison identity. Pen-finishing feed delivery and corn supplementation of range-finished heifers did not influence ($P > 0.05$) the bison identity attribute. Data in beef indicate that beef flavor intensity is greater for steaks from concentrate-fed beef compared with forage-fed beef. Evers et al. (2020) compared steaks from grass- and grain-finished beef raised in Australia and reported that grain-fed samples were rated more intense for beef flavor identity than grass-fed samples. Similarly, Duckett et al. (2013) compared steers finished on a forage or concentrate diet in the United States and also reported that steaks from concentrate-finished steers have increased beef flavor intensity ratings. Differences between beef and bison studies could be related to differences in overall fat content (marbling) in beef compared with bison, which could contribute to differences in flavor intensity.

Differences ($P < 0.05$) were detected between pen- and range-finishing systems for most of the remaining sensory attributes, with fat-like flavor being the only attribute not influenced ($P > 0.05$) by pen- rather than range-finishing (Table 5). Intensity of bloody/serum, brown/roasted, overall sweet, and umami flavor attributes were increased by pen-finishing, whereas intensity of bitter, green hay-like, liver-like, metallic, musty/earthy/humus, oxidized, and sour aromatics flavor attributes were all reduced by pen-finishing systems compared with range-finishing systems. Evers et al. (2020) also reported stronger intensity ratings in grain-fed beef samples for sweet compared with grass-fed samples. Stocking density and feed delivery (free-choice or TMR) did not influence ($P > 0.05$) any of the remaining sensory attributes. Range-finishing on high-diversity rangeland increased ($P < 0.05$) intensity of liver-like, musty/earthy/humus, and sour aromatics sensory attributes tended to increase the green hay-like ($P = 0.050$) and umami ($P = 0.089$) attributes but did not influence ($P > 0.05$) any other sensory attributes compared with Low-diversity range. Supplementation of range heifers with corn grain decreased ($P < 0.05$) the intensity of liver-like and musty/earthy/humus attributes compared with grazing without supplementation but did not influence ($P > 0.05$) any other sensory attributes. In general, pen finishing appeared to reduce incidence of off-flavors, while increasing the intensity of flavors

TABLE 4 Least square means for the effect of diverse finishing system on ultimate pH, proximate composition, Warner-Bratzler shear force (WBSF), and cook loss of 14-day-aged striploin steaks from bison heifers.

	Pen-finished systems ¹			Range-finished systems ¹			SEM ³	Contrasts ²				
	Low density-FC	Low density-TMR	High density-TMR	High diversity	Low diversity	Low diversity w/corn		Pen v. range	Low v. high pen density	Free ch. v. mixed ration	Low v. high range diversity	Range w/ or w/o corn
Ultimate pH ⁴	5.60	5.63	5.63	5.62	5.64	5.62	0.006	0.248	0.887	0.010	0.053	0.077
Crude protein, %	22.35	23.12	23.20	21.98	21.72	22.35	0.158	<0.001	0.720	<0.001	0.248	0.005
Moisture, %	72.15	71.69	71.79	73.53	74.19	71.71	0.217	<0.001	0.745	0.130	0.031	<0.001
Crude fat, %	2.74	2.97	2.62	1.88	1.83	3.25	0.190	0.003	0.189	0.374	0.837	<0.001
Ash, %	1.18	0.95	0.97	1.05	1.00	1.06	0.039	0.869	0.810	<0.001	0.292	0.225
WBSF, kg	2.81	2.71	2.55	2.53	2.72	2.42	0.118	0.166	0.345	0.560	0.247	0.071
Cook loss, %	18.93	19.81	18.79	21.36	21.77	19.17	0.505	<0.001	0.154	0.218	0.566	<0.001

¹Finishing systems: 1) pen finished with free choice access to each feedstuff (grass hay, alfalfa, and corn in separate feeders) at low stocking density (55 m² per animal, n = 45; Low density-FC), 2) pen-finished with grass hay, alfalfa, and corn provided as a total mixed ration at low stocking density (n = 44; Low density-TMR), 3) pen-finished with hay, alfalfa, and corn provided as a total mixed ration at high stocking density (27 m² per animal, n = 44; High density-TMR), 4) range-finished on high diversity rangeland (n = 44; High-diversity), 5) range-finished on low diversity rangeland (n = 44; Low-diversity), 6) range-finished on low diversity rangeland with free choice access to corn supplement (n = 43; Low-diversity w/corn).

²Contrasts: pen v. range compares pen-based systems v. all range-based systems; low v. high pen density compares low density-TMR system v. the high density-TMR system; free ch. v. mixed ration compares low density-FC system vs. the low density-TMR system; low v. high range diversity compares Low-diversity range system vs. the High-diversity range system; and range w/or w/o corn compares Low-diversity range system vs. the Low-diversity range with corn system. Values are the probability of difference among contrast combinations.

³Standard error of the mean.

⁴Ultimate pH was measured at either 2 or 3 days postmortem on the posterior end of each striploin.

often viewed positively by consumers. In the comparison of grass- and grain-finished bison bulls described by O'Sullivan et al. (2025), steaks from bulls in the grass-finishing system also had increased off-flavor intensity and aroma intensity compared with steaks from grain-finished bulls. Duckett et al. (2013) also reported that off-flavor intensity was greater for steaks from forage-fed steers, regardless of forage species, compared with steaks from concentrate fed steers. The “green hay-like” attribute is described as “brown/green dusty aromatics associated with dry grasses, hay, dry parsley, and tea leaves” (Table 1); therefore, it is not unexpected for panelists to indicate elevated green/hay-like flavor in samples from heifers grazing high diversity range. Evers et al. (2020) also reported that steaks from grass-fed beef had greater green-hay flavor intensities compared with grain-fed samples.

The differences in sensory attributes observed between systems are likely attributed to differences in diet, as diet modification has been shown to be an effective approach to alter composition and flavor of meat (Zervas and Tsiplakou, 2011). Research in beef has demonstrated that volatile compounds (Elmore et al., 2004; Tansawat et al., 2013), fatty acids (Fruet et al., 2018), and antioxidants (Kearns et al., 2023) differ between grain- and forage-based diets. Mottram (1998) reported that differences in flavor characteristics between grain- and grass-finished beef are dependent on different volatile compounds derived from the lipid source, primarily intramuscular fat. Steaks from grass-fed beef cattle have been described as having more intense barny, bitter, gamey, and grass flavor notes while being less juicy and having less umami flavor, which have been classified as “negative” attributes compared with grain-fed beef (Maughan et al., 2012). Similarly, Musa et al. (2020) reported that samples from grass-fed beef had stronger rancid, grassy, and sour flavors. However, in contrast to Maughan et al. (2012); Musa et al. (2020) reported that grass-fed samples were juicier, which was attributed to the influence of increased moisture content and pH values on water holding capacity. Fruet et al. (2018) concluded that forage-fed beef had improved fatty acid profiles, decreased concentrations of volatile compounds associated with lipid oxidation, and less off-flavor compared with beef finished with concentrates. O'Sullivan et al. (2025) reported that steaks from grass-finished bison bulls had more intense ammonia, metallic, and gamey flavors than steaks from grain-finished bulls, whereas Janssen et al. (2021) reported no differences for off-flavor intensities between grain- and grass-finished steaks from bison heifers. Differences among studies may be due to the specific diets provided, differences between sexes, or differences between species, but overall, they support the findings of the present study highlighting the potential for animal diets to differentially impact palatability outcomes. Further research is needed in bison to understand the influence of diverse bison finishing systems on fatty acid composition, volatile compounds, and antioxidant capacity.

Conclusions

We hypothesized that bison heifers finished in a pen system with grain in their diet would have increased carcass weights, dressing percentage, ribeye areas, and marbling scores compared

with bison heifers finished only on grass in a range system. Furthermore, we hypothesized that pen-finished bison offered a grain diet would have improved tenderness and less off-flavor sensory attributes than range finished bison. We accept these hypotheses, except that tenderness was not influenced by pen-finishing. We further conclude that pen-finishing systems that included corn grain improved sensory perception of several positive attributes including juiciness, brown/roasted, sweetness, and umami, whereas the intensity of characteristic bison flavor was more prominent in range-finished bison.

Supplementing free-choice corn to heifers in a range-finishing system resulted in carcasses with heavier final live weight, hot carcass weight, improved dressing percentage, larger ribeye area, increased backfat, increased a^* and b^* values of the lean surface of the ribeye, increased crude protein and fat content, decreased cook loss, and a reduction of some off-flavors (liver-like and musty/earthy/humus) compared with heifers only consuming grass, indicating this may be an effective “hybrid” management system for bison.

We hypothesized that providing feedstuffs in a TMR would increase the proportion of protein and fat compared with heifers allowed a free choice diet. The TMR did increase crude protein percentage but did not increase crude fat percentage. Furthermore, free-choice ration delivery increased the marbling score. Thus, we only partially accept this hypothesis.

Higher stocking density in pen-finishing systems reduced HCW and ribeye area but increased the intensity of sensory perception of tenderness and bison identity. Stocking bison heifers at an intermediate density for pen-finishing may be possible to improve return on investment of pen facilities. Further evaluation of intermediate increases in pen stocking density to avoid reduced carcass yield is warranted. Additionally, further research to evaluate social preferences, aggression, and behavior is warranted to determine optimal square footage per animal.

Finally, we hypothesized that bison finished on highly diverse range would have more off-flavor intensity than bison finished on range with limited forage diversity. We accept this hypothesis. However, utilization of high diversity range increased ribeye areas and lowered the moisture content of steaks. Unfortunately, the reduction in moisture content did not reduce cook loss.

This study provides some of the first data evaluating the influence of diverse finishing systems on bison palatability attributes. Furthermore, these results provide insight into the establishment of ratings for overall bison identity as panelists observed differences between finishing systems. Very little is known about consumer preferences for bison, and further research could aid in identifying unique marketing opportunities for bison products raised in different finishing systems.

These findings demonstrate that bison's adaptability across highly varied production systems supports agricultural enterprises that provide environmental, economic, and social sustainability. Environmentally, bison enterprises can flexibly integrate local resources, from grain-based feeding strategies that make use of existing crop infrastructure and by-products to grazing-based systems on native rangelands unsuited for cultivation. Economically, this flexibility allows producers to adjust practices

TABLE 5 Least square means for the effect of diverse finishing systems on sensory attributes¹ of 14-day-aged striploin steaks from bison heifers.

	Pen-finished systems ²			Range-finished systems ²			SEM ⁴	Contrasts ³				
	Low density-FC	Low density-TMR	High density-TMR	High diversity	Low diversity	Low diversity w/corn		Pen v. range	Low v. high pen density	Free ch. v. mixed ration	Low v. high range diversity	Range w/ or w/o corn
Tenderness	57.10	57.30	60.11	57.09	58.16	58.30	1.330	0.409	<0.001	0.764	0.108	0.837
Juiciness	53.40	53.54	54.46	52.57	52.88	51.89	0.944	<0.001	0.149	0.663	0.586	0.087
Bison identity	33.40	33.84	32.99	36.18	34.98	34.45	1.353	<0.001	0.031	0.260	0.002	0.181
Bitter	2.21	2.07	2.15	3.05	2.63	2.73	0.769	0.003	0.830	0.710	0.277	0.808
Bloody/serum	10.45	10.20	9.87	8.73	8.90	8.81	1.055	<0.001	0.499	0.620	0.727	0.857
Brown/roasted	44.17	43.98	43.91	43.63	43.41	42.69	1.719	0.014	0.895	0.722	0.684	0.193
Fat-like	10.75	10.65	10.70	10.51	10.36	10.61	0.545	0.183	0.867	0.722	0.577	0.335
Green hay-like	5.51	5.23	5.03	7.39	6.30	5.49	1.070	<0.001	0.711	0.616	0.050	0.144
Liver-like	4.14	4.97	4.27	9.66	7.04	5.57	1.142	<0.001	0.188	0.115	<0.001	0.006
Metallic	6.12	5.86	5.67	6.71	6.62	6.21	0.017	0.035	0.723	0.613	0.872	0.420
Musty/earthy/humus	12.05	12.62	11.99	16.78	14.71	13.15	1.282	<0.001	0.158	0.206	<0.001	<0.001
Overall sweet	9.70	9.65	9.75	8.57	9.09	9.42	0.996	0.001	0.777	0.875	0.148	0.346
Oxidized	0.47	0.75	0.54	0.86	1.17	0.87	0.321	0.007	0.394	0.249	0.205	0.213
Sour aromatics	6.38	6.34	5.53	7.87	6.28	6.36	1.208	0.011	0.114	0.931	0.002	0.871
Umami	15.41	15.58	15.13	15.09	14.53	14.93	1.444	0.006	0.172	0.601	0.089	0.225

¹ 0 = extremely dry/tough/not detectable and 100 = extremely juicy/tender/intense. Modified from Adhikari et al. (2021) and American Meat Science Association (2015).
²Finishing systems: 1) pen finished with free choice access to each feedstuff (grass hay, alfalfa, and corn in separate feeders) at low stocking density (55 m² per animal, n = 45; low density-FC), 2) pen-finished with grass hay, alfalfa, and corn provided as a total mixed ration at low stocking density (n = 44; Low density-TMR), 3) pen-finished with hay, alfalfa, and corn provided as a total mixed ration at high stocking density (27 m² per animal, n = 44; High density-TMR), 4) range-finished on high diversity rangeland (n = 44; High-diversity), 5) range-finished on low diversity rangeland (n = 44; Low-diversity), 6) range-finished on low diversity rangeland with free choice access to corn supplement (n = 43; Low-diversity w/corn).
³Contrasts: pen v. range compares pen-based systems v. all range-based systems; low v. high pen density compares low density-TMR system v. the high density-TMR system; free ch. v. mixed ration compares low density-FC system vs. the low density-TMR system; low v. high range diversity compares Low-diversity range system vs. the High-diversity range system; and range w/or w/o corn compares Low-diversity range system vs. the Low-diversity range with corn system. Values are the probability of difference among contrast combinations.
⁴ Standard error of the mean.

to balance cost of production with product value, enabling long-term enterprise viability and supporting rural communities. Socially, bison production offers consumers a lean red-meat option that accommodates varied taste preferences through grass- and grain-finished products. Taken collectively, these dimensions of sustainability illustrate how bison production aligns with One Health principles by simultaneously benefiting ecosystems, producers, and consumers. The adaptability of bison to diverse production systems also supports ecological resilience enabling bison managers to respond to changing environmental, market, and societal conditions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by Texas Tech University Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because sensory panel participation was deemed minimally invasive and the protocol was deemed exempt. Ethical approval was not required for the studies involving animals in accordance with the local legislation and institutional requirements because rearing and harvesting of bison were performed in accordance with relevant guidelines and regulations set forth by the United State Department of Agriculture. This study evaluated carcasses and meat samples from bison raised on a commercial ranch and did not involve intervention by the research team during the rearing phase; therefore, Institutional Animal Care and Use Committee approval was not necessary. Written informed consent was obtained from the owners for the participation of their animals in this study.

Author contributions

LO'S: Investigation, Writing – review & editing, Data curation, Formal analysis, Visualization, Writing – original draft. RA: Investigation, Writing – review & editing. GW: Investigation, Writing – review & editing. BC: Investigation, Writing – review & editing. MH: Investigation, Writing – review & editing. KU: Investigation, Writing – review & editing. JG: Investigation, Writing – review & editing, Funding acquisition. CB: Investigation, Writing – review & editing. JFL: Investigation, Writing – review & editing, Data curation, Supervision. JL: Writing – review & editing, Conceptualization, Methodology, Resources.

CK: Conceptualization, Methodology, Resources, Writing – review & editing. AB: Conceptualization, Methodology, Resources, Writing – review & editing, Funding acquisition, Investigation, Project administration, Supervision, Validation.

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Conflict of interest

Authors JL and CK are employed by Turner Enterprises, Inc.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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