Alternative management strategies for growing and stocker cattle

by

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AN ABSTRACT OF A DISSERTATION

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DOCTOR OF PHILOSOPHY

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Abstract

A series of experiments were conducted to evaluate alternative management strategies for limit-fed growing beef cattle and yearling stocker cattle. Previous research reported improvements in feed efficiency when growing cattle were limit-fed a high-energy diet based on corn and corn co-products compared with a traditional high-roughage diet fed for ad libitum intake; however, cattle feeders have voiced concerns that limit-feeding may increase bunk space requirements. In Exp. 1, 385 crossbreed steers were assigned to 1 of 4 bunk allotment treatments: 25.4, 38.1, 50.8, or 63.5 cm of bunk per calf and limit-fed a high-energy diet once daily for 58 d. Average daily gains (ADG) tended to respond quadratically ($P = 0.10$) and were greatest for calves allotted 50.8 cm of bunk per calf; however, final body weights (BW), dry matter (DM) intake, and gain-to-feed (G:F) did not differ ($P \geq 0.34$) among treatments. In Exp. 2, almond hulls were evaluated as an alternative fiber source in limit-fed growing beef cattle diets. Three-hundred sixty-four steers and 8 ruminally cannulated heifers were fed 1 of 4 experimental diets. The control diet contained (DM basis) 39.5% dry-rolled corn, 7.5% supplement, 40% wet-corn gluten feed, and 13% prairie hay. Non-ground or ground almond hulls replaced prairie hay and were fed at 13% of diet DM or non-ground almond hulls were fed at 26% of diet DM and replaced 13% prairie hay and 13% dry-rolled corn. Replacing dry-rolled corn with almond hulls reduced growth performance, ruminal volatile fatty acid (VFA) concentrations, and ruminal ammonia concentrations; however, replacing prairie hay with almond hulls resulted in similar final BW, ADG, and apparent diet digestibility. Inclusion of wet distillers grains (WDGS) and wheat middlings (MIDDS) in growing and finishing diets have been evaluated; however, the effects of incorporating MIDDS into WDGS (i.e., WDGS+MIDDS) on apparent diet digestibility and ruminal fermentation characteristics are unknown. In Exp. 3, 4 ruminally cannulated crossbred heifers were fed a growing diet that contained WDGS or WDGS+MIDDS at 40% of diet DM. In addition, 4 ruminally cannulated Holstein steers were fed a finishing diet that contained WDGS or WDGS+MIDDS at 30% of diet DM. Inclusion of WDGS+MIDDS in a growing diet increased ($P = 0.03$) starch intake but did not influence ($P \geq 0.17$) apparent DM digestibility, total VFA concentrations, or ruminal pH. When fed in a finshing diet, WDGS+MIDDS increased ($P = 0.02$) ruminal pH and caused minor shifts in individual ruminal VFA concentrations. In addition, inclusion of WDGS+MIDDS in both growing and finishing diets reduced ruminal ammonia concentrations. The Kansas Flint Hills represent the largest segment of the United States stocker cattle industry. Prescribed fires are traditionally applied in March and April to improve grazing cattle growth performance and native warm season grass production. Shifting prescribed fire timing from March-April to August-October may reduce basal cover of invasive plant species and subsequently improve native forb diversity; however, effects of applying fire later in the year on stocker cattle growth performance during the subsequent grazing season have not been extensively evaluated. During a six-year experiment, 18 pastures were grouped by watershed and each watershed was randomly assigned to 1 of 3 prescribed-fire treatments: spring (11 April ± 5.7 d), summer (25 August ± 6.2 d), or autumn (2 October ± 9.0 d). Over 5 consecutive grazing seasons, 1,939 yearling stocker calves were grazed from May to August and rangeland plant composition was measured annually in June. Average daily gains were greater ($P = 0.02$) for calves assigned to spring-burned pastures compared with calves assigned to summer- or autumn-burned pastures but did not differ ($P \geq 0.55$) between calves grazing summer- or autumn-burned pastures. Basal cover of total graminoids and total forbs did not differ ($P \geq 0.30$); however, prescribed-fire timing tended to influence basal cover of C3 ($P = 0.06$) and C4 ($P = 0.08$) grasses. Overall, these data demonstrate how alternative management strategies can influence

growth performance of growing beef cattle or yearling stocker cattle. Cattle managers should evaluate the strengths and weaknesses of each alternative to determine how they best fit into their respective programs.

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Chapter 1 - Review of Literature

Newly Received Beef Cattle Diets

Beef cattle undergo numerous stressors such as marketing, feed and water deprivation, pathogen exposure, and transportation prior to arrival at the feedlot. Intakes during the initial two weeks of the feeding period are generally low and may create a negative energy balance in the animal (Hutcheson and Cole, 1986). As a consequence, the immune systems of newly received calves may become compromised and make them more susceptible to disease (Richeson et al., 2019). To mitigate the effects of low feed intake upon arrival, current recommendations are to increase the nutrient density of receiving cattle diets so that nutrient requirements of the animal can be met even when feed intake is low (NASEM, 2016). Over the last 50 years, several experiments seeking to improve growth performance of newly received beef cattle have been conducted.

Lofgreen et al. (1975) conducted a series of experiments evaluating different energy concentrations in receiving cattle diets. Diets were formulated to provide 0.84, 1.01, 1.10, or 1.19 Mcal of net energy for gain (NE_g)/kg DM and included 20, 55, 72, or 90% concentrates, respectively. Rolled barley replaced portions of alfalfa to increase the energy density of the diet. Growth performance improved as the energy density of the diet increased from 0.84 to 1.10 Mcal NE_g/kg DM; however, morbidity also increased. Researchers concluded that diets formulated to provide 1.10 Mcal NE_g/kg DM can be used to improve growth performance but may negatively affect animal health.

In a meta-analysis, Rivera et al. (2005) demonstrated that morbidity associated with bovine respiratory disease (BRD) decreased slightly in lightweight receiving calves as dietary roughage concentrations increased. For every 20% increase in roughage, morbidity was reduced by 1.35%; however, for every 20% increase in roughage in the diet, average daily gain (ADG) was also reduced by 0.178 kg/d. Despite a slight reduction in morbidity, an economic analysis indicated the costs associated with reduced incidence of BRD did not outweigh the costs associated with reduced growth performance when a 100% roughage diet was fed.

Fluharty and Loerch (1996) fed diets containing 70 to 85% concentrate and reported no difference in overall ADG, gain-to-feed (G:F), or health during a 28-d receiving period. Similarly, Berry et al. (2004) measured the impact of energy and starch concentrations on health and performance of newly received beef calves. Calves were arranged in a 2 × 2 factorial that included two energy concentrations (i.e., 0.85 or 1.07 Mcal NE_g/kg) and two starch concentrations (34 or 48% of ME from starch). Dietary energy or starch did not affect ADG or G:F; however, the percentage of calves treated once was numerically greater for calves consuming the high starch diet compared with the low starch diet and the percentage of calves treated thrice tended to be greater for calves consuming low-energy diets compared with calves consuming high-energy diets. In addition, calves fed high-energy diets that were initially treated for BRD tended to have lower concentrations of *Pasteurella multocida* and had lower concentrations of *Hameophilus somus* compared with those fed low-energy diets; therefore, feeding high-energy diets to newly received cattle could potentially be utilized as a strategy to reduce the prevalence of common respiratory pathogens.

Much of the early research that evaluated high-energy receiving cattle diets consistently demonstrated improvements in growth performance; however, many reported increased morbidity. In those experiments, cereal grains such as corn or barley replaced portions of roughage to increase the energy density of the diet. Ruminal acidosis occurs when large quantities of fermentable carbohydrates are converted to organic acids (Nagaraja and

Titgemeyer, 2007). Clinical signs of ruminal acidosis include reduced feed intake, anorexia, dehydration, increased respiratory rate, and diarrhea (Howard, 1981) whereas clinical signs of BRD include fever, reduced feed intake, depression, and coughing (Urban-Chmiel and Grooms, 2012). Because of the similarity in clinical signs between BRD and ruminal acidosis, it is possible that receiving calves fed high-energy diets containing large quantities of cereal grains in previous experiments could have been displaying signs of ruminal acidosis that were mistaken for BRD. Production of food and beverages for human consumption or ethanol from cereal grains generate co-products that can be incorporated into livestock diets (Stock et al., 2000). These co-products are relatively low in starch but high in digestible fiber and can be used to increase the energy density of the diet while minimizing the risk of ruminal acidosis.

Co-products

The most common co-product utilized by cattle feeders in North America is distillers grans plus solubles (DGS) that are generated as a by-product of ethanol production (NASEM, 2016). The production of ethanol via dry-milling has been described by Stock et al. (2000). Corn, or other cereal grains, are ground and mixed with yeast to ferment starch into alcohol and carbon dioxide. After fermentation, the alcohol is separated from the mash leaving behind whole stillage. Whole stillage is centrifuged and separated into distillers grains and distillers solubles. Distillers grains can either be sold as is as wet distillers grains (WDG) or dried and sold as dried distillers grains (DDG). The distillers solubles, or thin stillage, are evaporated to produce a syrup-like product and can be added back to WDG or DDG to produce WDGS or DDGS, respectively. Because corn contains approximately two-thirds starch, removal of starch during the dry-milling process increases protein, fat, fermentable fiber, and phosphorus three-fold.

Stock et al. (2000) indicated that average protein, fat, NDF, and phosphorus concentrations of DDGS were approximately 30, 12, 36, and 0.9% of DM, respectively.

In two separate experiments, Larson et al. (1993) fed growing (initial body weight = 277 kg) or yearling (initial body weight = 329 kg) cattle diets containing 0, 5.2, 12.6, or 40% WDGS (DM basis). Experiments were replicated over a two-year period and growing and yearling calves were fed for approximately 188 and 123 d, respectively. In both experiments, feed efficiency throughout the entire feeding period increased linearly as WDGS in the diet increased. Bremer et al. (2011) conducted a meta-analysis that evaluated the effects of replacing dry-rolled or high-moisture corn with WDGS in finishing diets. Average daily gains and G:F responded quadratically when WDGS replaced portions of dry-rolled corn or high-moisture corn up to 40% of diet DM. In that analysis, ADG and G:F were maximized when WDGS replaced portions of dry-rolled or high-moisture corn at 20 to 30% of diet DM. Vander Pol et al. (2008) fed diets containing 61.4% corn and 30% WDGS (DM basis) and determined that G:F did not differ among steers fed dry-rolled, high-moisture, or steam-flaked corn but was lesser for steers fed whole-shelled or finely ground corn.

Corrigan et al. (2009) evaluated the effects of corn processing and WDGS inclusion level in finishing diets. Steers were fed dry-rolled, high-moisture, or steam-flaked corn with 0, 15, 27.5 or 40% WDGS (DM basis) for a 168-d finishing period. Gain-to-feed increased linearly as WDGS increased in diets based on dry-rolled or high-moisture corn based diets but was unaffected in diets based on steam-flaked corn based diets. In a subsequent experiment, authors also reported that DM, OM, and NDF intakes were greater whereas starch intake was lesser for calves fed diets containing 40% WDGS (DM basis) compared with no WDGS. In addition, apparent OM digestibility was lesser in diets containing 40% WDGS compared with no WDGS.

Differences in nutrient intakes and digestibility were likely associated with diet composition. These data demonstrate that WDGS appear to be a suitable alternative to dry-rolled or high-moisture corn and can be incorporated into growing or finishing diets at relatively high inclusion rates.

Wheat middlings are a by-product of flour milling and can also be incorporated into beef cattle diets. Production of wheat middlings through the flour milling process has been previously described by Blasi et al. (1998a). Wheat grain is initially cleaned to remove debris, and water may be added to increase the moisture concentration to approximately 15%. The grain is subsequently processed through a series of breaker rollers to reduce particle size. Following each particle size reduction, the grain is sifted to separate the endosperm from the bran and germ. The endosperm is further processed into flour for human consumption and what remains can be marketed as feed ingredients for livestock. Wheat middlings are defined as fine particles of wheat bran, germ, flour, and the offal from the "tail of the mill" (AFFCO, 2022). Nutrient composition of wheat middlings varies by source and wheat variety; however, a survey that included samples from 14 different sources reported that wheat middlings contain on average 89.6% DM, 16.2% CP, 36.9% NDF, 0.12 % calcium, and 0.97% phosphorus (Cromwell et al., 2000).

Brandt et al. (1986) replaced portions of cracked corn with pelleted wheat middlings at 0, 10, 20, or 30% of diet DM in finshing cattle diets. Average daily gains throughout the 120-d feeding period decreased and feed-to-gain (F:G) increased linearly as wheat middling inclusion in the diet increased. Growth performance was similar between steers fed wheat middlings at 0 and 10% of diet DM; therefore, authors suggested that wheat middlings could replace up to 10% of cracked corn in finishing diets without reducing growth performance. Conversely, Blasi et al.

(1998b) reported a linear reduction in ADG when wheat middlings replaced dry-rolled corn in either a high-roughage diet fed for ad libitum intake or a limit-fed high-energy diet.

Dalke et al. (1997) evaluated the use of wheat middlings as either a concentrate or roughage source in finishing diets. In that experiment, 120 steers were fed a high-concentrate diet, and pelleted wheat middlings replaced either 0, 5, 10, or 15% dry-rolled corn or 5 or 10% alfalfa (DM basis). Replacing portions of dry-rolled corn with wheat middlings did not influence ADG; however, dry matter intake (DMI) increased linearly as wheat middlings inclusion increased and ultimately caused a linear increase in F:G. Conversely, replacing alfalfa with pelleted wheat middlings reduced DMI but did not influence ADG, F:G, or ruminal pH. Overall, authors concluded that pelleted wheat middlings could only replace up to 5% of dry-rolled corn in finishing diets before growth performance was negatively influenced; however, pelleted wheat middlings may be considered as an alternative to alfalfa.

Holtshausen et al. (2011) evaluated wheat middling inclusion in a corn-silage based growing diet. In that experiment, authors compared growth performance of heifers fed tempered barley grain at 40% of diet DM or wheat middlings at 40% of diet DM. Heifers fed wheat middlings had greater DMI and tended to have greater ADG; however, G:F did not differ between treatments. Similarly, ZoBell et al. (2003) conducted two experiments evaluating inclusion of wheat middlings in diets fed to replacement heifers and growing steers. When fed to replacement heifers, wheat middlings replaced barley and were fed at 32.1% of diet DM. When fed to growing steers, wheat middlings replaced barley and corn and were fed at 35.5% of diet DM. All diets were isoenergetic and isonitrogenous. Regardless of diet, ADG, DMI, and F:G did not differ at the completion of the 84-d feeding period; however, ADG for steers fed wheat middlings was numerically lower (0.13 kg/d) compared with steers fed the combination of barley and corn.

These experiments demonstrate that wheat middlings can be incorporated into beef cattle diets; however, cattle feeders should consider what feed ingredients they are replacing when formulating diets containing wheat middlings. Overall, it appears that wheat middlings can replace small portions of dry-rolled corn without reducing growth performance and may be able to replace larger portions of roughages.

Bunk Space Requirements in Limit Fed Diets

One strategy that can be used to improve feed efficiency of newly received beef cattle is to restrict or program feed. Restricted feeding involves feeding an animal below expected ad libitum intake whereas programmed feeding uses net energy equations to predict the amount of feed required to target a specific gain (Galyean, 1999). Wagner et al. (1990) conducted two experiments that compared growth performance of growing calves fed a traditional high-roughage diet for ad libitum intake or limit-fed a high-energy diet. In both experiments, gain-to-feed was greater in limit-fed calves compared with calves fed for ad libitum intake. In addition, limit feeding calves during the growing period did not negatively influence growth performance during the finishing period.

In a similar experiment, Spore et al. (2019) fed newly received heifers diets formulated to provide 0.99, 1.10, 1.21, or 1.32 Mcal NE_g/kg of DM at a targeted gain of 1 kg/d. In that experiment, all diets contained 40% wet-corn gluten feed (DM basis) and the energy density of the diet was increased by replacing portions of alfalfa and prairie hay with dry-rolled corn. Average daily gains did not differ among treatments; however, by design dry matter intake decreased as the energy density of the diet increased. As a result, G:F increased linearly as dietary energy increased. In addition, morbidity, mortality, serum haptoglobin, BVD-I, BVD-II, or IBR titers did not differ among treatments (Spore et al., 2018; Spore et al., 2019).

Although previous research has demonstrated that limit-feeding high-energy diets to growing cattle can improve feed efficiency, cattle feeders have voiced concerns that bunk space allotments may need to be increased when feed is restricted so that all calves can eat simultaneously. Additionally, if bunk space allotments are not adequate when feed is restricted, aggressive calves could potentially consume a large portion of the daily feed delivery which may increase within pen variation in ADG and final body weight (BW). Current recommendations for growing cattle (180 to 380 kg) fed once per day are 45.7 to 55.9 cm of bunk per head (FASS, 2020) whereas current industry standards average 30.3 cm but range from 15.2 to 45.7 cm of bunk per head (Samuelson et al., 2016). Feed bunks cost between $82 to $98 per linear meter and can be a significant investment for cattle feeders (Kammel and Halfman, 2015); therefore, research evaluating the amount of bunk space required to maximize growth performance of limit-fed growing cattle is warranted.

Zinn (1989) conducted two experiments that evaluated the impact of bunk space allocation on performance of limit-fed feedlot steers. In Exp. 1, 64 steers (initial BW = 234 kg) were allotted 15, 30, 45, or 60 cm of bunk per calf for a 76-d feeding period. Feed intake was restricted to target 1.45 kg of body weight gain per day. Final BW and ADG did not differ among treatments. In Exp. 2, 72 steers (initial BW = 295) were allotted 15, 30, or 45 cm of bunk per calf over a 63-d feeding period. Feed intake was restricted further to target 1.22 kg of BW gain per day. Final BW and ADG did not differ among calves allotted 15, 30, or 45 cm of bunk. In addition, variation in final body weights and ADG within pen did not differ between bunk space treatments in either experiment.

Lake (1986) indicated bunk allotments of 22.9 or 30.5 cm of bunk per head did not impact growth performance of heifers limit-fed a high-energy diet during the growing period. In a similar experiment, Gunter et al. (1996) evaluated the effects of 12.7, 20.3, 27.9, or 35.6 cm of bunk per head on growth performance of limit-fed steers during an 84-d growing period. Bunk allotment of 12.7 to 35.6 cm per calf did not affect final body weights, ADG, DMI, or feed-to-gain during the growing period. Conversely, final BW variation within pen increased linearly with increased bunk allotment suggesting that reducing bunk allotment may reduce variation in final BW. More recently, Gubbels et al. (2023) compared growth performance of Charolais × Angus heifers programed to gain 1.36 kg/d and allotted either 20.3 or 40.6 cm of bunk space per calf for a 109-d feeding period. At the conclusion of that experiment, final BW, ADG, DMI, or G:F did not differ between heifers allotted 20.3 or 40.6 cm of bunk per head. In addition, the standard deviation of average daily gain did not differ between treatments.

When evaluating the effects of bunk allotment in calves fed for ad libitum intake, Gottardo et al. (2004) reported that bunk allotments of 60 or 80 cm of bunk per head did not impact final body weights, ADG, DMI, G:F, white blood cells, neutrophils, lymphocytes, or neutrophil-to-lymphocyte ratio following a 250-d feeding period. In addition, Harrison and Oltjen (2021) evaluated the effects of bunk-space allotment in growing and finishing steers. Fifty-six steers (initial BW = 268 kg) were assigned to one of two treatments (i.e., 87 cm of bunk or 20 cm of bunk per calf) for an 84 d growing period. Steers were fed twice daily using the slick bunk protocol. Bunk allotment did not impact final BW, DMI, ADG, or G:F following the growing period. In a second experiment, 48 steers (initial BW= 501 kg) were assigned to one of two bunk treatments (i.e., 87 cm of bunk or 30 cm of bunk per steer) for a 64-d finishing period. Final BW and DMI did not differ between treatments; however, ADG was greater for steers allotted 87-cm of bunk compared with steers allotted 30-cm of bunk. As a result, G:F tended to be greater for the 87-cm bunk allotment compared with the 30-cm bunk allotment.

Taken together, these data demonstrated that bunk allotments of 12.7 to 60 cm of bunk space per calf had minimal impacts on growth performance of limit-fed calves. One potential limitation to these reports is the relatively few number of calves used in each pen. Restricting bunk allotments to 12.7 or 15 cm of bunk per head did not influence growth performance in pens containing 4 head (Zinn, 1989; Gunter et al., 1996). Similarly, growth performance of calves allotted 20.3 or 40.6 cm of bunk per head did not differ in pens containing 10 head (Gubbels et al., 2023). Restricting bunk allotments in pens containing larger numbers of cattle could potentially create more competition at the feed bunk and increase the variability of weight gain within the pen.

Almond Hulls Inclusion in Growing Beef Cattle Diets

Roughages are an essential aspect of growing beef cattle diets and often include alfalfa, hay, corn stalks, cottonseed hulls, or silages, and prices vary depending on the nutrient quality and availability of the product. For example, the cost of roughage generally increases during periods of drought and often force cattle feeders to seek cheaper alternatives. One potential alternative that has not been extensively evaluated in beef cattle diets is almond hulls. Almond hulls are a by-product of almond production and contain soluble sugars that make them a suitable feed ingredient for livestock diets (DePeters, 2020). California is the global leader in almond production and is estimated to produce 1.18 billion kg of almonds in 2023 (Huang and Lapsley, 2019; NASS, 2023). Almonds are a tree nut that grows within a shell surrounded by a hull; hulls and nuts are separated following harvest (Huang and Lapsley, 2019). Almond hulls represent

49% of the almond tree fruit weight and approximately 1.85 billon kg of almond hulls were generated during the 2022 harvest year (ABC, 2023).

Today, almond hulls are primarily marketed to local California dairy cattle farms; however, increased environmental regulations have led to a decline in the California dairy cattle inventory (MacDonald et al., 2020). A continued reduction in the California dairy cattle inventory could result in reduced almond hull demand and create a potential opportunity for beef cattle feeders to purchase almond hulls; however, experiments evaluating almond hull inclusion in beef cattle diets is limited. When evaluating almond hulls as an alternative fiber source in finishing diets, Becket et al. (1992) replaced portions of alfalfa and oat hay and fed ground almond hulls at 7.5% of diet DM or completely replaced alfalfa and oat hay and fed ground almond hulls at 15% of diet DM. At the completion of the 140-d feeding period, final BW, ADG, DMI, G:F, did not differ between calves fed traditional roughage sources compared with calves fed almond hulls.

The use of almond hulls in dairy cattle diets has been more extensively evaluated. Aguilar et al. (1984) replaced portions of alfalfa and oat hay and fed almond hulls at 12.5 or 25% of diet DM. Because the crude protein concentration of almond hulls is low, urea was added to the diet as almond hull inclusion increased. Dry matter intake, milk yield, and milk fat were similar among treatments. Williams et al. (2018) also evaluated almond hull inclusion in lactating dairy cattle diets. Cows assigned to the control diet were offered 14.5 kg of alfalfa cubes (DM basis) whereas calves assigned to the almond hull diet were offered 10.5 kg of alfalfa cubes and 4 kg of almond hulls (DM basis). Dry matter intake did not differ among treatments, but overall milk yield and milk protein yield were greater for cows consuming the control diet compared with cows consuming the almond hull diet. In that experiment, urea was not added to the diet when almond hulls replaced alfalfa which likely contributed to reduced milk protein yield. Conversely, ruminal acetate concentrations were lesser whereas ruminal propionate concentrations were greater cows fed almond hulls compared with cows not fed almond hulls. Greater concentrations of ruminal propionate in diets containing almond hulls were likely associated with increased fermentation of non-structural carbohydrates.

In contrast to previous experiments, Swanson et al. (2021) evaluated almond hulls as a potential replacement of concentrates rather than roughages. In that experiment, almond hulls were fed at 0, 7, 13, or 20% of diet DM. As the concentration of almond hulls in the diet increased, portions of steam-flaked corn, soyhull pellets, and oat hay were removed and soybean meal was added. Authors observed a cubic response where dry matter intake, milk yield, and energy corrected milk was greatest when almond hulls were included at 7% of diet DM. Milk protein yield and milk protein concentrations decreased linearly as almond hull inclusion increased; however, milk fat concentrations and apparent dry matter digestibility increased linearly as almond hull inclusion increased. Overall, authors concluded that almond hulls could be used as a potential concentrate and fed up to 7% of diet DM to maximize feed intake, milk yield, and milk protein yield.

Several experiments have evaluated almond hull inclusion in diets fed to sheep. Phillips et al. (2015) fed diets containing 65% concentrate and 35% roughage based diet to finishing lambs. In that experiment, almond hulls replaced portions of alfalfa and were fed at 0, 5, or 10% of diet DM. At the completion of the 63-d feeding period, final BW, ADG, DMI, G:F, and carcass characteristics did not differ among treatments. Similarly, Imani Rad et al. (2016) reported no differences in ADG, G:F, DMI, or apparent DM digestibility when urea-treated almond hulls replaced alfalfa and were fed up to 40% of diet DM. In addition, Scerra et al.

(2022) evaluated almond hull inclusions of 0, 15, or 30% of diet DM in finishing lambs. In that experiment, almond hulls replaced portions of barley and corn. At the completion of the 40-d feeding period, final BW, ADG, DMI, G:F, and carcass weight did not differ among treatments.

Yalchi (2011) conducted a series of experiments to determine the composition and digestibility of almond hulls in diets fed to sheep. When the nutrient composition of almond hulls and alfalfa were compared, crude protein, NDF, ADF, cellulose, and hemicellulose concentrations were greater in alfalfa compared with almond hulls; however, almond hulls contained greater concentrations of non-fibrous carbohydrates and acid detergent lignin (ADL) compared with alfalfa. In a subsequent experiment, Yalchi (2011) compared apparent digestibilities of a mixed diet (i.e., 70% alfalfa and 30% almond hulls) or alfalfa when fed to mature sheep. Apparent DM and organic matter digestibilities did not differ between diets; however, apparent NDF and ADF digestibilities were lesser in the mixed diet compared with alfalfa. The reduction observed in fiber digestibility when almond hulls were fed may have been associated with increased concentrations of ADL in almond hulls compared with alfalfa.

Overall, replacing traditional roughage sources such as alfalfa or oat hay with almond hulls leads to similar growth performance of finishing beef cattle and lambs and milk production in dairy cattle. Because crude protein concentrations of almond hulls are low, additional protein supplementation may be necessary when almond hulls replace higher protein feed ingredients such as alfalfa. Conversely, utilizing almond hulls as a replacement for concentrate may reduce milk yields when almond hull inclusion exceeds 7% of diet DM. Additional research evaluating the optimal inclusion rate of almond hulls which maximizes growth performance of growing and finishing beef cattle is warranted.

Prescribed Fire Timing

The Kansas Flint Hills are the largest contiguous remnant of the original tallgrass prairie in the world (Samson and Knopf, 1994). Fires played an important role in the formation and preservation of the prairie by suppressing encroachment of woody-stemmed plant species (Sauer, 1950; Buell and Facey, 1960). Prior to European settlement (i.e., 1770-1871) fires occurred on average every 3.36 years; however, from 1871 to 2005 the mean fire return interval decreased from 3.36 years to 1.33 years (Allen and Palmer, 2011). During Flint Hills settlement, ranchers realized that growth performance was greater for yearling stocker cattle grazing burned pastures compared with those grazing non-burned pastures (Anderson, 1953). As a result, annual prescribed fire became a common practice in the Kansas Flint Hills and remains so today.

Much of the early research evaluating the use of prescribed fire in the Flint Hills sought to determine the optimal time in which fire should be applied to maximize yearling stocker cattle weight gains and native warm season grass production. Towne and Owensby (1984) summarized data evaluating the effects of prescribed fires applied in early spring (March 20), mid-spring (April 10), late spring (May 1) or winter (December 1) in non-grazed plots over a 56-year period. Fires applied during late spring maximized forage yields, increased basal cover of *Andropogon gerardii* (big bluestem) and *Sorghastrum nutans* (Indiangrass), and reduced basal cover of perennial forbs and *Carex* spp. (sedges) compared with fire applied at other times throughout the year. Similarly, Anderson et al. (1970) evaluated the effects of early spring (March 20), mid spring (April 10), or late spring (May 1) prescribed fire on yearling stocker cattle performance. After 14 grazing seasons, calves grazing mid- and late-spring burned pastures outperformed calves grazing non-burned pastures. In addition, growth performance was greater for calves grazing pastures burned in late spring compared with pastures burned in early spring.

This research led to the almost exclusive recommendation that prescribed fires in the Flint Hills should be applied from mid- to late spring to maximize yearling stocker cattle growth performance and native warm season grass production. Today, an average of 850,000 ha of native Flint Hills rangeland are burned annually between mid-March and early May (KDHE, 2022). In addition, 74 to 93% of annual prescribed-fire detections in Kansas occurred in March and April (Baker et al., 2019). Despite improvements in stocker cattle growth performance and warm-season grass production, there are challenges associated with spring prescribed fire. Strong spring-season winds combined with low relative humidity and elevated fuel loads typically limit the number of days available to safely conduct a burn. Because of this, Baldwin et al. (2022) reported that up to 40,000 ha of native rangeland can be burned in a single day.

Burning large amounts of rangeland during a short period of time produces large volumes of smoke that can travel to urban municipalities downwind of the Flint Hills and reduce air quality. In 2003, air quality monitors in Kansas City detected ozone concentrations, which resulted from burning the Flint Hills, that exceeded the federally mandated standards (KDHE, 2010). Smoke contains particulate matter and precursors for ozone that can negatively impact human health (KDHE, 2010). Additional burn dates outside of the traditional spring-season window may need to be evaluated so that smoke produced from burning the Flint Hills can be distributed more uniformly throughout the year.

Alexander et al. (2021) reported that shifting prescribed-fire from April to August or September sharply reduced *Lespedeza cuneata* (sericea lespedeza) basal cover, seed production, and vigor and subsequently improved forb diversity. Sericea lespedeza in an invasive perennial legume that has degraded approximately 190,000 ha of native Kansas rangeland, most of which has occurred in the Flint Hills (KDA, 2022). Management of sericea lespedeza via grazing of beef cattle has been ineffective because high-concentrations of condensed-tannins discourage herbivory of sericea lespedeza by cattle (Preedy et al., 2013; Sowers et al., 2019). In addition to sericea lespedeza control, shifting prescribed-fire timing from April to August or September did not negatively influence standing forage biomass accumulation or basal cover of C4 grass species (Alexander et al., 2021).

Weir and Scasta (2017) reported that C4 tallgrass cover was greatest in plots burned in September-October and November-December compared with plots burned at other times of the year. In addition, September-October prescribed-fire increased basal cover of forbs and was the only treatment to reduce basal cover of woody plants. In a similar experiment, Reemts et al. (2019) evaluated the effects of September prescribed fire on *Bothrochloa ischaemum* (Yellow bluestem) populations at two field sites. Yellow bluestem is an invasive C4 grass that has spread across the Great Plains. At both sites, yellow bluestem frequency was reduced by 65 and 42% following September prescribed-fire. Three years following fire application, yellow bluestem frequencies remained lesser in burned plots compared with non-burned plots.

Despite recent research reports, the use of growing season fires by Flint Hills ranchers have not been widely adopted because of perceived effects of fire applied later in the year on yearling grazing cattle performance and potential protracted stress on warm-season forage grasses. Currently, comparisons of yearling cattle growth performance for cattle grazing pastures burned during the dormant or growing season is limited. McMillian et al. (2022) reported that calves grazing pastures burned in August-September gained 24 kg less than calves grazing pastures burned in March-April. In that experiment, cattle were grazed from April to September and burns were applied to one-third of the pasture each year. In addition, growing season prescribed fires were not applied prior to grazing in year 1 and were applied during the grazing season for the remainder of the experiment. As a result, calves assigned to the growing season treatment had less opportunity to graze plant regrowth following prescribed fire application compared with calves assigned to the dormant season treatment. More research evaluating the effects of growing season prescribed fire on yearling stocker cattle weight gains is needed.

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Chapter 2 - Bunk space requirements for beef cattle limit-fed a high-energy corn and corn co-product diet

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Abstract

Bunk requirements for optimal growth performance of growing calves limit-fed high energy corn and corn co-product diets have not been widely evaluated. Three-hundred eighty-five crossbred steers (initial body weight = 215 ± 25 kg) were purchased in Texas, transported to the Kansas State Beef Stocker Unit, and weighed at arrival. Steers were stratified by body weight and randomly assigned to 1 of 28 pens containing 12 to 14 head. Within block, pens were randomly assigned to 1 of 4 bunk allotment treatments: 25.4, 38.1, 50.8 or 63.5 cm of bunk per head for a 58-d receiving period. Calves were fed at 0700 h once daily at 1.8% of bodyweight (dry matter basis) from February 2 to March 13, 2021; thereafter the daily feed allotment was increased to 2.0% of bodyweight. The diet contained (dry matter basis) 39.5% dry-rolled corn, 7.5% supplement, 40% wet corn gluten feed, and 13% prairie hay. Steers were individually weighed on d 29 and d 58 and pen weights were measured weekly to determine feed offered for the following week. Body weights on d 29 and 58, dry matter intake, or gain-to-feed ratio during the receiving period did not differ ($P \geq 0.34$) between treatments. During the first 29-days, average daily gain (ADG) increased linearly as bunk space increased ($P = 0.03$); however, no treatment effects were observed thereafter. In addition, ADG standard deviation from d 0 to 29 responded quadratically ($P = 0.05$) where ADG standard deviation tended to be greater in the 38.1-cm allotment and was greater in the 50.8-cm allotment compared with the 25.4-cm allotment ($P = 0.07$ and $P = 0.04$, respectively). Bunk score tended to decrease linearly as bunk allotment decreased ($P = 0.06$). Following the receiving period, steers were blocked by bunk treatment and randomly assigned to 1 of 18 pastures. Steers were grazed for 90-d from May to August at a targeted stocking density of 280 kg live-weight $\cdot$ ha^{-1}. During the grazing season, ADG increased linearly with reduced ($P < 0.01$) bunk allotment; however; body weights did not differ ($P = 0.91$)

between bunk treatments at the completion of the grazing period. In addition, overall total body weight gains and ADG from the receiving and grazing periods did not differ (*P* > 0.57) between bunk treatments. We interpreted our data to suggest that bunk space allotments of 25.4 to 63.5 cm per head had minimal impact on growth performance during a 58-d receiving period and did not affect final body weights following a 90-d grazing season.

Key words: bunk, grazing, growing calves, limit-feeding

Introduction

Limit-fed high energy diets can improve feed efficiency in growing calves compared with traditional high-roughage diets fed ad libitum (Wagner et al., 1990; Spore et al., 2019). One concern associated with limit feeding is bunk requirements may need to be increased when feed is restricted to ensure all calves can eat simultaneously. Lake (1986) reported bunk allotments of 23 cm per head allowed approximately 55% of calves to eat at once while 30 cm of bunk allowed approximately 75% of calves to eat at once. Current recommendations for 180 to 380 kg beef calves fed once daily are 45.7 to 55.9 cm of bunk per calf (FASS, 2020).

Feed bunks represent a significant investment for cattle feeders and currently cost up to $82 to $98 per linear meter (Kammel and Halfman, 2015). Although limit-fed diets can improve feed efficiency in growing calves, the cost of purchasing additional bunk may outweigh the benefits in improved performance. Determining bunk allotment required for limit-fed growing calves is necessary to optimize growth performance and maximize pen capacity; therefore, the objective of this experiment was to evaluate the effects of bunk-space allotment on growth performance of growing calves limit-fed a high-energy corn and corn co-product diet during a 58-d receiving period. An additional objective was to determine if bunk-space allotment during the receiving period impacted subsequent growth performance during a 90-d grazing season in the Kansas Flint Hills.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee reviewed and approved all animal handling and animal care practices used in our experiment. All animal procedures were conducted in accordance with the Guide for the Care and Use of Animals in Agricultural Research and Teaching (FASS, 2020).

A total of 385 crossbred steers (initial body weight: 215 ± 25 kg) were purchased in Texas and transported to the Kansas State Beef Stocker Unit. The first two truckloads of cattle were received on 2 February and the second two truckloads were received on 2 March. Steers were arranged in a randomized block design to determine the effects of bunk-space allotment on growth performance of growing beef cattle limit-fed a high-energy corn and corn co-product diet. Calves were blocked by arrival date (2), stratified by individual arrival weight within block, and assigned to pens containing 12 to 14 head. Within block, pens were randomly assigned to 1 of 4 treatments which resulted in 7 pens per treatment for a total of 28 pens. Soil surfaced pens equal in size (9.1 × 15.2 m) contained a fenceline feed bunk, a 3.6-m concrete apron, and an individual automatic waterer. Bunk length was adjusted to allow 25.4, 38.1, 50.8, or 63.5 cm of bunk per calf. Panels were fastened along each fenceline bunk to restrict bunk allotment without altering pen size.

Upon arrival, steers were individually restrained using a hydraulic squeeze chute (Silencer, Moly Manufacturing Inc., Lorraine, KS), bodyweight (BW) was recorded, and a visual identification tag was applied. Subsequently, animals were randomly assigned to pens containing 12 to 14 steers and provided prairie hay and ad libitum access to water overnight. The following morning (d 0), steers were individually weighed, vaccinated for viral respiratory (Vista Once SQ; Merck Animal Health, Kenilworth, NJ) and clostridial (Vison 7 with Spur; Merck Animal Heath, Kenilworth, NJ) pathogens and treated for internal (Valbazen, Zoetis; Parisippany, NJ) and external (Stand Guard, Elanco; Greenfield, Indiana) parasites.

Individual BW were measured on d 0, d 29, and d 58. In addition, pen weights were measured weekly (d 0, 14, 21, 28, 35, 42, 49, and 56) using a pen scale (Rice Lake Weighing Systems; Rice Lake, WI) and were used to calculate the feed delivered for the following week. Steers were fed once daily at 0700 h using a Roto-Mix feed wagon (Model #414-14B; Roto-Mix, Dodge City, KS). The experimental diet (Table 2.1) was offered at 1.8% of BW (dry matter basis) from February 2 to March 13, 2021; thereafter, the daily feed allotment was increased to 2.0% of BW (dry matter basis). Individual feed ingredient samples were collected weekly and immediately frozen at -20°C. At the completion of the experiment, feed ingredient samples were composited and sent to a commercial laboratory for nutrient analysis (SDK Laboratories; Hutchinson, KS).

Feed bunks were assessed twice daily to determine the effects of bunk space allotment on rate of feed consumption. Feed bunks were evaluated three (i.e., 1000 h) and six (i.e., 1300 h) hours post-feeding using the feed bunk scoring system adapted from Boyles et al., (2003; Table 2.2). Briefly, feed bunks were assigned a score of one to six based on feed remaining in the bunk. A score of one indicated no feed residue remained while a score of six indicated greater than 30% of feed delivered at 0700 h remained.

At the completion of the receiving period, steers were individually weighed, blocked by bunk treatment, and randomly assigned to 1 of 18 pastures (22 ± 4.0 ha). The following day, calves were treated for internal (Valbazen, Zoetis; Parisippany, NJ) and external (Stand Guard, Elanco; Greenfield, Indiana) parasites and administered a growth-promoting implant (Ralgro, Merck Animal Health; Kenilworth, NJ). Steers were sorted by pasture, held in pens where bunk allotment was not limited, and fed the experimental diet at 2.0% of BW (dry matter basis). Calves were allotted to their respective pasture over the following three days (i.e., six pastures per day). Individual BW were measured immediately prior to turnout. Steers were grazed for 90 days from May to August at a targeted density of 280 kg live weight $\cdot$ ha^{-1}. At the completion of the grazing period, steers were gathered and individual BW were immediately measured.

Calculations. Individual BW measured on day 0, 29, and 58 were used to determine average daily gain (ADG) and gain-to-feed ratio (G:F), using pen-level intakes. Within pen variation in ADG was determined by calculating the standard deviation of ADG for each pen during the receiving period. Individual BW measured on d 0 and 90 of the grazing season were used to calculate grazing ADG. In addition, overall BW gains were calculated as grazing d 90 weight – receiving d 0 weight.

Statistical Analysis. All data were analyzed as a randomized block design using the MIXED procedure in SAS (PROC MIXED; SAS 9.4, SAS Inst. Inc, Cary, NC). For performance during the receiving period, class variables included treatment, pen, and block. Two truckloads of calves were in each block, with 14 pens per block. The model included a fixed effect of treatment and random effect of block. For grazing and overall performance, pasture was added as a random effect. Treatment effects were evaluated using orthogonal, polynomial contrasts. For bunk score data, class variables included treatment, pen, block, and day. The model included fixed effects for treatment, day, and treatment × day and a random effect of block. Day served as the repeated term and the subject was pen. The covariance structure was spatial power as determined by AIC and BIC fit statistics. When protected by a significant *F*-test ($P \leq 0.05$), treatment means were separated using the method of Least Significant Difference.

Results and Discussion

Receiving performance. Body weights on d 29 and d 58 of the receiving period did not differ ($P > 0.49$; Table 2.3) between bunk treatments. During the first 29 days, ADG increased linearly ($P = 0.03$) with increased bunk space; however, no differences in ADG were observed thereafter. In addition, dry matter intake (DMI; $P = 0.34$) or G:F ($P = 0.39$) did not differ between bunk treatments following the 58-d receiving period.

Our results agree with previous research that demonstrated limit-fed diets with bunk allotments of 12.7 to 60 cm per calf did not impact growth performance during the growing or finishing periods (Zinn, 1989; Gunter et al.,1996). Lake (1986) reported bunk allotments of 23 or 30 cm of bunk per head did not impact performance of limit-fed heifers fed twice daily (i.e., first half of their daily feed allotment at initial feeding and then the second half two hours later). In addition, Harrison and Oltjen (2021) indicated bunk allotments of 20 cm or 87 cm per calf did not impact final body weights, DMI, ADG, or G:F following an 84-d growing period when steers were fed twice daily using the slick bunk protocol. Steers in our experiment were limit-fed once daily and growth performance did not differ between steers allotted 25.4 to 63.5 cm of bunk per calf. Despite differences in feeding protocols between our experiment and previous work, it appears that bunk allotments greater than 25.4 cm per head do not improve performance of growing calves when limit-fed a high-energy diet once daily.

A potential concern associated with reduced bunk space in limit-fed diets is an increase in weight variation within pen. Average daily gain standard deviation from d 0 to 29 responded quadratically ($P = 0.05$; Table 2.4) where ADG standard deviation tended to be greater for the

38.1-cm allotment and was greater for the 50.8-cm allotment compared with the 25.4-cm allotment (*P* = 0.07 and *P* = 0.04, respectively). Gunter et al., (1996) observed similar trends, where reduced bunk allotment was associated with a linear decrease in final body weight variation within pen. In addition, Zinn (1989) indicated that bunk allotments of 15 to 60 cm per calf in finishing calves did not impact variation in final body weights and ADG within pen. Taken together these data suggest that reduced bunk allotment does not increase variation in weight gain.

Bunk score. Bunks were evaluated daily at 1000 h and 1300 h to determine the impact of bunk allotment on rate of feed consumption. Bunk score at 1000 h tended to decrease linearly (*P* = 0.06; Table 2.3) with reduced bunk allotment. Reduced bunk score was interpreted to suggest that decreasing bunk allotment may result in more rapid feed consumption. Conversely, bunk score at 1300 h did not differ (*P* = 0.63; Table 2.3) between treatments. Bunk scores of 1.01 to 1.02 at 1300 h indicated that feed was consumed within six hours of feed delivery. Schmidt et al., (2005) observed similar trends in feed consumption when evaluating the effects of feed restriction on growth performance of finishing beef steers. Steers restricted to 80% of ad libitum intake had a bunk score of 1.29 seven hours after feed delivery. These data were interpreted to suggest that limit-fed diets used in these experiments were consumed within six to seven hours of feed delivery and a reduction in bunk allotment may increase rate of feed consumption.

Grazing and overall performance. Body weights did not differ (*P* = 0.55; Table 2.5) at the beginning of the grazing period. Average daily gains during the grazing season increased linearly with reduced (*P* < 0.01; orthogonal polynomial contrast) bunk allotment; however, final body weights at the completion of the grazing period did not differ (*P* = 0.91; treatment main effect) between treatments. Average daily gains in our experiment were 1.10, 1.09, 1.04, and 1.05 kg · calf^{-1} for 25.4-cm, 38.1-cm, 50.8-cm, or 63.5-cm bunk allotments, respectively.

The cause of the linear increase in ADG that resulted from reduced bunk allotment is unclear. Horton and Holmes (1978) evaluated the effects of feed restriction during a 20-week period on subsequent growth performance during the grazing period. During the first 8-weeks of the grazing season in that experiment, BW gains and DMI were greater in calves fed to gain 0.22 kg per day compared with calves fed to gain 0.58 kg per day. Wanyoike and Holmes (1981) fed thirty-six Friesian and Friesian crossbred steers at two growth rates (i.e., 0.5 or 1.08 kg per day) for a twelve-week period. Following the feeding period, steers were grazed on perennial ryegrass pasture. Body weight gains during the grazing period were greater in steers fed to gain 0.5 kg per day compared with steers fed to gain 1.08 kg per day. In addition, calves fed at a modest rate of gain consumed 12% more forage compared with calves fed at a more aggressive high rate of gain.

Lawrence and Pearce (1964) observed similar effects in weight compensation when feeding calves at high, medium, or low rates of gain (i.e., 0.73, 0.22, or 0.01 kg per day) for a 168-d period. During a subsequent 5-month grazing period, total BW gains were 1.20, 0.98, and 0.54 kg per day for calves fed at low, medium, or high rates of gain, respectively. Although BW prior to grazing did not differ statistically in our experiment, BW decreased numerically with reduced bunk allotment. Calves assigned smaller bunk allotments during the receiving period may have experienced a small degree of body weight compensation during the grazing season. Reducing bunk allotment during the receiving period could have resulted in greater forage intake and improved ADG during the grazing season; however, overall total BW and ADG following the 58-d receiving period and the 90-d grazing season did not differ ($P > 0.57$) between bunk space treatments.

Conclusions

These data suggest that bunk allotments of 25.4 to 63.5 cm of bunk per head had minimal impact on growth performance of limit-fed growing calves during a 58-d receiving period. Reduced bunk allotment tended to increase rate of feed consumption and reduce weight gain variation early in the feeding period. In addition, reduced bunk space during the receiving period was associated with increased ADG during the subsequent 90-d grazing season; however, final BW and overall BW gains following the receiving period and grazing season did not differ between bunk treatments. Overall, it appeared bunk allotments of 25.4 to 63.5 cm per calf were adequate for maintaining growth performance of growing steers limit-fed a high-energy corn and corn co-product diet. Under limit-feeding conditions, bunk allotments of 25.4 cm per calf may be used maximize pen capacity without reducing performance during the growing period.

Disclosures

Authors of this manuscript declare no conflict of interest.

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Tables

Table 2.1 Composition of experimental diet

Item,	
Ingredient, % of dry matter	
Dry-rolled corn	39.5
Supplement[1]	7.5
Wet corn gluten feed[2]	40.0
Prairie hay	13.0
Nutrient Composition, % of dry matter[3]	
Dry matter	75.3
Organic matter	94.1
Crude protein	14.9
Neutral detergent fiber	24.7
Acid detergent fiber	9.4
Calculated Composition[4], Mcal/kg	
NEm	1.95
NEg	1.31

[1] Supplement pellet formulated to contain (dry matter basis) 8.4% Ca, 5% NaCl, and 360 mg/kg monensin. Supplement ingredients: 72.15% wheat middlings, 22.0% calcium carbonate, 5% NaCl, 0.35% soybean oil, 0.18% Rumensin 90 (Elanco, Greedfield, IN), 0.11% zinc sulfate, 0.08% manganese (Mn) sulfate (32% Mn), 0.06% vitamin E premix (500,000 IU/kg), 0.05% copper sulfate, 0.01% selenium premix (0.99% Se), 0.007% ethylenediamine dihydriodide (EDDI) premix (11.4% EDDI), and 0.004% vitamin A (650,000 IU/g).

[2] Sweet Bran (Cargill Corn Milling; Blair, NE)

[3] Nutrient analysis conducted by SDK Laboratories (Hutchinson, KS).

[4] Net energy of maintenance (NEm) and net energy of gain (NEg) were calculated using NASEM (2016) values of diet ingredients.

Table 2.2 Feedbunk scoring system[1]

Score	Bunk Description
1	Empty Bunk; no feed residue remaining
2	Empty Bunk; evidence of fine feed particles
3	A few feed clumps and fine feed particles in the bunk
4	<15% of feed in bunk
5	15-30% of feed in bunk
6	>30% feed in the bunk

[1] Adapted from Boyles et al. (2003)

Table 2.3 Effects of bunk space allotment on performance of limit-fed growing calves during a 58-d receiving period

	Treatment, cm					*P*-value[2]		
Item,	25	38	51	64	SEM[1]	Lin	Quad	Cubic
No. of pens	7	7	7	7				
No of animals	96	97	95	97				
Body weight, kg								
d 0	214	216	215	216	3.5	0.76	0.93	0.67
d 29	238	241	243	243	3.8	0.16	0.50	0.92
d 58	257	260	263	260	3.6	0.38	0.29	0.58
ADG, kg/d								
0 to 29	0.81	0.88	0.98	0.94	0.067	0.03	0.23	0.38
29 to 58	0.65	0.64	0.70	0.59	0.047	0.40	0.15	0.10
0 to 58	0.73	0.76	0.84	0.76	0.045	0.22	0.10	0.12
DMI, kg/d								
0 to 29	4.10	4.10	4.11	4.10	0.013	0.48	0.12	0.27
29 to 58	4.76	4.76	4.80	4.75	0.037	0.89	0.44	0.30
0 to 58	4.42	4.41	4.46	4.42	0.025	0.56	0.50	0.12
G:F, kg/kg								
0 to 29	0.20	0.22	0.24	0.23	0.020	0.10	0.37	0.53
29 to 58	0.14	0.13	0.14	0.12	0.014	0.40	0.43	0.35
0 to 58	0.17	0.17	0.19	0.17	0.012	0.34	0.31	0.30
Bunk Score								
1000-h	1.64	1.72	2.03	1.83	0.451	0.06	0.20	0.13
1300-h	1.02	1.01	1.02	1.01	0.056	0.80	0.75	0.21

[1] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[2] *P*-value associated with linear, quadratic, or cubic effects of bunk allotment

Table 2.4 Effects of bunk allotment on average daily gain standard deviation of growing steers limit-fed a high-energy corn, corn co-product diet during a 58-d receiving period

	Treatment, cm					*P*-value[2]		
Standard Deviation, kg/d	25	38	51	64	SEM[1]	Lin	Quad	Cubic
0 to 58	0.28	0.30	0.31	0.31	0.040	0.32	0.75	0.96
0 to 29	0.37	0.47	0.48	0.43	0.049	0.22	0.05	0.92
29 to 58	0.30	0.28	0.29	0.34	0.049	0.40	0.36	0.95

[1] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[2] *P*-value associated with linear, quadratic, or cubic effects of bunk allotment

Table 2.5 Effects of bunk allotment during the receiving period on subsequent growth performance during a 90-d grazing season and overall performance

	Treatment, cm					*P*-value[2]		
Item,	25	38	51	64	SEM[1]	Lin	Quad	Cubic
Body weight, kg								
d 0	273	277	279	278	4.75	0.25	0.38	1.0
d 90	373	376	374	373	4.68	0.80	0.54	0.75
ADG, kg/d[3]								
d 0 to 90	1.10	1.09	1.04	1.02	0.028	< 0.01	0.99	0.39
Overall BW gain[4]								
Total gain, kg	159	160	159	156	3.2	0.34	0.38	0.96

[1] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[2] *P*-value associated with linear, quadratic, or cubic effects of bunk allotment

[3] Calculated as [(grazing d 90 weight – grazing d 0 weight) ÷ 90]

[4] Calculated as (grazing d 90 weight – receiving d 0 weight)

Chapter 3 - Almond hulls as an alternative fiber source in limit-fed growing beef cattle diets

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Lay Summary

The California Almond Industry produces large volumes of almond hulls that can be fed to beef and dairy cattle; however, literature evaluating incorporation of almond hulls into beef cattle diets is lacking. We evaluated the effects of feeding ground or non-ground almond hulls on growth performance, apparent diet digestibility, and ruminal fermentation characteristics of limit-fed growing calves. Growth performance, ruminal volatile fatty acid concentrations, and ruminal ammonia concentrations were reduced when non-ground almond hulls replaced 13% prairie hay and 13% dry-rolled corn (dry matter basis). Conversely, replacing prairie hay with non-ground almond hulls at 13% of diet dry matter resulted in similar final body weights, average daily gain, gain-to-feed, and volatile fatty acid concentrations. Almond hull inclusion did not influence apparent total tract digestibility. Replacing prairie hay with ground almond hulls at 13% of diet dry matter numerically improved growth performance and apparent diet digestibility. Overall, these data demonstrate that almond hulls can be used as an alternative to prairie hay in limit-fed growing diets.

Teaser Text

We evaluated the effects of almond hulls as an alternative to dry-rolled corn or prairie hay in growing beef cattle diets. We determined that almond hulls can be used as an alternative to prairie hay in limit-fed growing diets without negativity influencing growth performance or diet digestibility.

Abstract

Almond hulls are a by-product of almond production that can be incorporated as a feed ingredient in beef cattle diets. Three experiments were conducted to determine the effects of hammermill screen size on almond hull bulk density and inclusion of ground or non-ground almond hulls in limit-fed growing diets on growth performance, diet digestibility, and ruminal fermentation characteristics of beef cattle. In Exp. 1, almond hulls (9 kg per treatment) were ground with a laboratory-scale hammermill using no screen, a 11.1-mm screen, a 19.1-mm screen, or a 25.4-mm screen. Each screen-size treatment was ground at three separate time points (n = 3 replications/treatment). Grinding almond hulls with no screen increased bulk density by 111% and minimized proportions of fine particles; therefore, almond hulls ground using no screen were included as a treatment in the following experiments. In Exp. 2, 364 steers (initial BW: 257 ± 20.7 kg) were blocked by truckload (4), stratified by body weight (BW), and assigned to pen within block. Pens were randomly assigned to 1 of 4 experimental diets (n = 10 pens/treatment). The control diet (CON) contained (DM basis) 39.5% dry-rolled corn, 7.5% supplement, 40% wet-corn gluten feed, and 13% prairie hay. Non-ground (13AH) or ground (13GAH) almond hulls replaced prairie hay and were fed at 13% of diet DM or non-ground almond hulls were fed at 26% of diet DM and replaced 13% prairie hay and 13% dry-rolled corn (26AH). Diets were limit-fed at 2.2% of BW daily (DM basis) for 56 d. Overall average daily gains (ADG) were greater ($P \leq 0.05$) for CON, 13AH, and 13GAH compared with 26AH. In addition, ADG from d 14 to 56 were greater ($P = 0.03$) for 13GAH and tended to be greater ($P = 0.09$) for 13AH compared with CON. In Exp. 3, 8 ruminally-cannulated heifers (initial BW = 378 ± 44.0 kg) were arranged in a 4×4 replicated Latin square and fed diets from Exp. 2. Apparent dry matter digestibility did not differ ($P = 0.21$) among treatments. Total ruminal volatile fatty acid concentrations were greater ($P \leq 0.03$) for 13GAH and 13AH compared with 26AH and tended ($P = 0.06$) to be greater for 13GAH compared with CON. Overall, the energy value of almond hulls was slightly greater than that of prairie hay, but substantially less than that of dry-rolled corn; therefore, almond hulls can be utilized as an alternative to prairie hay in limit-fed growing diets without negatively influencing growth performance or diet digestibility.

Key words: almond hulls, growing cattle, limit-feeding

Introduction

California is the world leader in almond production and is projected to produce 1.18 billion kg of almonds in 2023 (Huang and Lapsley, 2019; NASS, 2023). Almonds are a tree nut that grows within a shell surrounded by a hull; hulls and nuts are separated following harvest (Huang and Lapsley, 2019). Almond hulls represent 49% of the almond tree fruit weight and approximately 1.85 billon kg of almond hulls were generated during the 2022 harvest year (ABC, 2023). Currently, almond hulls are marketed to local dairy farms because they contain large concentrations of soluble sugars making them a suitable feed ingredient. Increased environmental regulations and urbanization have reduced the California dairy cattle inventory (MacDonald et al., 2020). A continued reduction in the California dairy cattle herd could decrease almond hull demand; therefore, research evaluating alternatives for almond hull use is warranted.

One possible use for almond hulls is incorporation into beef cattle diets. Growth performance was not negatively impacted when almond hulls replaced portions of alfalfa and oat hay in finishing diets (Beckett et al., 1992); however, research evaluating almond hull inclusion in growing diets is limited. One challenge associated with almond hull inclusion in beef cattle diets is that the bulk density of non-processed almond hulls makes transporting them long distances to cattle-feeding areas difficult and expensive. Grinding almond hulls is a potential solution to increase bulk density so that greater masses of hulls can be transported in a single load. In addition, grinding almond hulls may also improve digestibility, reduce sorting, and improve feed aggregation. Our objective was to evaluate the effects of hammermill screen size on almond hull particle size and bulk density. Additional objectives were to determine the effects of feeding ground or non-ground almond hulls on growth performance, apparent diet digestibility, and ruminal fermentation characteristics in growing calves limit-fed a high-energy diet based on corn and corn co-products.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee reviewed and approved all animal handling and animal care practices used in our experiment. All animal procedures were conducted in accordance with the Guide for the Care and Use of Animals in Agricultural Research and Teaching (FASS, 2020).

Experiment 1: Almond hull processing

Commercial almond hulls obtained from California's Central Valley were used to determine the effects of hammermill-screen size on particle size and bulk density. Treatments included grinding almond hulls with no screen, a 11.1-mm screen, a 19.1-mm screen, or a 25.4-mm screen. A laboratory scale 1.5 HP Bliss Hammermill (Model 6k630B; Bliss Industries, LLC, Ponca City, OK) was used to grind approximately 9 kg of almond hulls for each treatment. Each treatment was ground at separate time points to provide three replications per treatment.

Following processing, a subsample of each treatment was analyzed in duplicate for particle size according to ASABE 319.4 methods (ASABE, 2008). A 100 ± 5 g sample and 0.5 g of a flow agent were placed in the top sieve of a 13-sieve stainless steel sieve stack and sifted for ten minutes using a Ro-Tap machine (Model RX-29; W. S. Tyler Industrial Group, Mentor, OH). The sieve stack contained 16-mm rubber balls and bristle sieve cleaners. The proportion of sample remaining in each sieve after sifting was weighed and geometric mean diameter and geometric standard deviation were calculated. In addition, particle size was also evaluated using the Penn State Particle Separator (Heinrichs and Kononoff, 2013). Two hundred grams of sample were placed in the top sieve. The box was then shaken five times in one direction, rotated a quarter turn and shaken five more times; this process was repeated seven more times for a total of 40 shakes. Each sieve was weighed to determine the proportion of sample remaining. Lastly, the bulk density of the initial non-ground almond hulls and ground almond hulls was measured as described by Clementson et al. (2010).

Experiment 2: Growth performance

Three-hundred sixty-four steers (initial BW: 257 ± 20.7 kg) were purchased in Texas and Nebraska and transported to the Kansas State University Beef Stocker Unit. Four truckloads were received from February 17 to February 21, 2022. Steers were blocked by truckload (4), stratified by body weight (BW), and assigned to pens within each block. Two blocks were stratified across 12 pens (7 to 9 steers per pen) and two blocks were stratified across 8 pens (9 to 11 steers per pen). Within block, pens were randomly assigned to 1 of 4 treatments, resulting in 10 pens per treatment for 40 pens.

Experimental diets are presented in Table 3.1. The control diet (CON) included (dry matter basis) 39.5% dry-rolled corn, 40% wet corn gluten feed, 7.5% supplement, and 13% prairie hay. Non-ground almond hulls replaced prairie hay and were fed at 13% of diet DM (13AH) or replaced prairie hay (13%) and dry-rolled corn (13%) and were fed at 26% of diet DM (26AH). In addition, a subset of almond hulls was ground, replaced 13% prairie hay, and included at 13% (13GAH) of diet DM. For the almond hull processing and digestibility experiments, almond hulls used for 13GAH were ground with a laboratory-scale 1.5 HP Bliss Hammermill (Model 6K630B) using no screen. Due to the large quantity of ground almond hulls required for the receiving trial, almond hulls in Exp. 3 were ground using a grinder mixer (Gehl 100; West Bend, Wisconsin) with no screen.

Upon arrival, steers were weighed using a pen scale (Rice Lake Weighing Systems; Rice Lake, WI), placed in soil-surfaced pens within truckload, and fed the control diet at 2.2% of body weight (DM basis) until March 6. On March 6, steers were individually weighed (Silencer, Moly Manufacturing Inc., Lorraine, KS), and a visual identification ear tag was applied. The following day (d 0), steers were individually weighed, treated for clostridial (Vision 7; Merck Animal Health, Kenilworth, NJ) and viral respiratory (Titanium 5; Elanco Animal Health, Indianapolis, IN) pathogens and treated for external parasites (Clean Up II; Elanco Animal Health). Steers were revaccinated for viral respiratory pathogens (Titanium 5; Elanco Animal Health) on d 14.

Individual BW were measured on d 0, 14, and 56. In addition, pen weights were measured weekly using a pen scale, and weights were used to determine feed offered for the following week. Calves were fed once daily beginning at 0700 h using a Roto-Mix feed wagon (Model #414-14B; Roto-Mix, Dodge City, KS). Experimental diets were offered at 2.2% body weight (DM basis) for a 56-d period. Individual feed ingredient samples were collected weekly. A portion of each ingredient sample was dried in a forced-air oven at 105°C for 48 h to determine diet DM. The remaining sample was frozen at -20°C. Following the completion of the experiment, feed ingredient samples were composited and sent to a commercial laboratory for nutrient analysis.

Experiment 3: Apparent digestibility and ruminal fermentation characteristics

Eight ruminally cannulated heifers (initial BW = 378 ± 44.0 kg) were arranged in a 4×4 replicated Latin square to evaluate the effects of almond hull inclusion on ruminal fermentation characteristics and apparent diet digestibility. Experimental diets were identical to those used in Exp. 2. Diets were mixed daily using a Marion Mixer (model 2030; Marion, IA) and offered at 2.2% of BW (DM basis). Animals were fed once daily at 1000 h. The experiment consisted of four consecutive 15-d periods. Data from one heifer in period four was removed due to injury. Each period included 10 d of diet adaption, 4 d of fecal collection, and 1 d of ruminal fluid sample collection.

Ten grams of chromic oxide (Cr_2O_3) were administered intra-ruminally from d 4 to 14 of each period using a 1.5 oz. TORPAC® gel capsule (Leedstone; Melrose, MN). Individual fecal samples were collected on d 11 through d 14 from the rectum of each animal at 8-h intervals. Collection time advanced 2 h each d so each 2-h interval over 24 h was represented. Following collection, fecal samples were composited for each animal within period. Individual feed ingredient samples were collected on d 10 through 14 of each period and were composited within period.

On d 15, digesta samples were collected from 4 separate locations in the rumen prior to feeding. Following 0-h sampling, 3 g of cobalt-EDTA dissolved in 200 mL of water was dosed via the ruminal cannula. Animals were fed, and ruminal digesta samples were collected again at 2, 4, 6, 8, 12, 18, and 24 h post-feeding. Following each collection, samples were strained through 8 layers of cheesecloth. Strained rumen fluid (1 mL) was pipetted into four 2-mL micro-centrifuge tubes containing 250 μL of m-phosphoric acid. In addition, 15 mL of strained rumen fluid was retained for cobalt analysis to estimate liquid passage rate. Following collection, ruminal fluid samples were immediately frozen (-20 °C) pending analysis. Ruminal pH was measured prior to feeding and again 2, 4, 6, 8, 12, 18, and 24 h post-feeding using a portable pH meter (Pinpoint; American Marine Inc., Ridgefield, CT).

Laboratory analysis

Individual feed ingredient and fecal samples were sent to a commercial laboratory (SDK Laboratories; Hutchinson, KS) for nutrient analysis. Samples were analyzed for dry matter (DM), crude protein (N × 6.25; AOAC International, 1999), neutral detergent fiber (NDF; Van Soest et al., 1991), acid detergent fiber (ADF; Van Soest et al., 1991), calcium (Bowers and Rains, 1988), phosphorus (AOAC International, 1999; procedure 965.17), potassium (AOAC International, 1999; procedure 956.01), and magnesium (AOAC International, 1999; procedure 956.01). Almond hulls were also analyzed for crude fiber as described by AOAC 962.09. Samples collected for ruminal volatile fatty acid (VFA) and ruminal ammonia analyses were centrifuged for 30 min at 17,000 × g at 4 °C. Volatile fatty acid concentrations of the supernatant were analyzed using gas-liquid chromatography as described by Vanzant and Cochran (1994). Ruminal ammonia concentrations of the supernatant were measured as described by Broderick and Kang (1980).

To estimate apparent diet digestibility, approximately 0.5 grams of dried fecal material were ground using a 1-mm screen and then placed in a muffle oven at 600°C for 2 h. Concentrations of chromium within each sample were determined by atomic absorption spectrophotometry as described by Williams et al. (1962). Chromium concentrations in fecal samples were used to estimate total fecal output and diet digestibility according to Cochran and Galyean (1994). Ruminal cobalt concentrations were determined by atomic absorption spectrophotometry. Liquid passage rate was calculated using the nonlinear procedure of SAS by regressing the natural logarithm of cobalt concentration from ruminal samples collected at 2, 4, 6, 8, 12, and 18 hours after feeding. Liquid passage rate was estimated from the negative slope of the regression.

Statistical analysis

All data were analyzed using the MIXED procedure in SAS (SAS 9.4, SAS Inst. Inc, Cary, NC). Experiment 1 was a randomized complete block design with each particle size reduction run serving as the experimental unit. Each treatment was replicated three times in three separate time periods. The model included a fixed effect of treatment and a random effect of time period. In Exp. 2, performance data was analyzed as a randomized block design with a fixed effect of treatment and random effect of block. In Exp. 3, the model for intake and apparent digestibility included fixed effects for treatment and period and a random effect for animal. Ruminal pH, ruminal ammonia concentration, and ruminal volatile fatty acid (VFA) concentrations were analyzed as repeated measures. The model contained fixed effects of treatment, period, hour, and treatment × hour and a random effect of animal. Hour served as a repeated measure and the subject was animal × period. The covariance structure was autoregressive as determined by AIC and BIC fit statistics. When protected by a significant *F*-test ($P \leq 0.05$), treatment means were separated using the method of Least Significant Difference. Significance was declared at $P \leq 0.05$ and tendencies at $0.05 \leq P$ 0.10.

Results and Discussion

Almond hull composition

The nutrient composition of the almond hulls is presented in Table 3.2. Almond hulls were obtained from a commercial grower in the California Central Valley. Almond hulls used in Exp. 1 and 3 were received in October 2021, and hulls used in Exp. 2 were received in January

2022. The California almond industry currently markets almond hulls based on crude fiber concentrations. Almond hulls containing ≤ 15% crude fiber (CF; AF basis) are marketed as "prime hulls" whereas almond hulls that contain more than 15% CF but less than 29% CF (AF basis) are marketed as "hulls and shells" (CDFA, 2022). The almond hulls used in our experiments contained between 15.6 to 18.6% CF (AF basis) and were considered hulls and shells.

Experiment 1: Almond hull processing

When processed through a hammermill, geometric mean particle size of almond hulls was greatest ($P < 0.01$; Table 3.3) when no screen was used, intermediate ($P < 0.01$) when a 19.1-mm screen or a 25.4-mm screen was used, and least ($P < 0.01$) when an 11.1-mm screen was used. Particle size standard deviation did not differ ($P = 0.13$) among processing treatments. When evaluated using the Penn State Particle Separator, the proportion of large particles (i.e., > 19 mm) was minor and did not differ ($P = 0.46$) among treatments; however, proportions of medium size particles (i.e., 8 to 19 mm) tended to be greater ($P = 0.07$) when no screen was used to grind almond hulls compared with an 11.1-mm screen or a 19.1-mm screen. Small particles (i.e., 4 to 8 mm) comprised 76.5 to 84.3% of ground almond hulls and did not differ ($P = 0.32$) between treatments. Conversely, proportions of fine particles (i.e., < 4 mm) increased when hammermill screen size was reduced. Proportions of fine particles were greater ($P \leq 0.02$) when a 11.1-mm screen was used compared with no screen, a 19.1-mm screen, and a 25.4-mm screen.

Bulk density of the initial non-ground almond hulls was 226.2 kg/m^3. Grinding almond hulls with a 11.1-mm screen, 19.1-mm screen, 25.4-mm screen, or no screen increased bulk density by 140, 115, 114, and 111%, respectively. In addition, bulk density tended ($P = 0.07$) to be greater when a 11.1-mm screen was used to grind almond hulls compared with when a 19.1-

mm screen, 25.4-mm screen, or no screen was used. Overall, comparisons of almond hull particle sizes and bulk densities are lacking in animal nutrition literature. Because grinding almond hulls with no screen minimized the proportion of fine particles but still achieved an increase of over 100% in bulk density, almond hulls ground with no screen were included as one of the four treatments in the following experiments.

Experiment 2: Growth performance

Growth performance data are presented in Table 3.4. Final body weights (BW) following the 56-d feeding period were greater ($P < 0.01$) for 13AH and 13GAH compared with 26AH and tended to be greater ($P = 0.10$) for 13GAH compared with CON. In addition, final BW tended to be greater ($P = 0.06$) for CON compared with 26AH. Beckett et al. (1992) reported no differences in growth performance or feed efficiency when ground almond hulls replaced portions of alfalfa and oat hay and were fed up to 15% of diet DM. In addition, final BW and ADG were similar in finishing lambs when almond hulls replaced proportions of chopped alfalfa and were fed up to 10% of diet DM (Phillips et al., 2015). In our experiment, replacing portions of dry-rolled corn with almond hulls reduced final BW; in contrast, Scerra et al. (2022) reported no differences in final BW or ADG when almond hulls replaced up to 30% of barley and maize in a commercial concentrate mix fed to lambs during the final 40 d of the finishing period. In their experiment, hay was provided for ad libitum intake and final almond-hull intake represented approximately 18% of total intake.

Average daily gains from d 0 to 56 were greater ($P \leq 0.05$) for 13GAH, 13AH, and CON compared with 26AH; however, ADG from d 14 to 56 were greater ($P = 0.03$) for 13GAH compared with CON and tended to be greater ($P = 0.09$) for 13AH compared with CON. Differences in ADG early in the feeding period may have been associated with diet adaptation and gut fill. Prior to the start of the experiment, all calves were fed CON including prairie hay at 13% of diet DM. On average, commercial nonpareil almond hulls contain approximately 33% nonstructural carbohydrates (DePeters et al., 2020). Specifically, almond hulls sampled from Northern California contained 10.4% glucose, 8.8% fructose, 5.3% sucrose, 4.6% sorbitol, and 2.5% inositiol (Sequeira and Lew, 1970). When beef cattle were transitioned from fiber-based diets to concentrate-based diets, proportions of fibrolytic bacteria decreased while proportions of nonstructural-carbohydrate fermenting bacteria increased (Fernando et al., 2010); therefore, cattle fed almond hulls in our experiment may have required time to adapt to greater concentrations of nonstructural carbohydrates in the diet compared with those not fed almond hulls.

In addition to diet adaptation, numerical differences in ADG early in the feeding period may have been associated with differences in gut fill. Because all cattle were fed the CON diet prior to trial initiation, calves fed 13AH and 13GAH may have had decreasing gut fill early in the feeding period compared with calves fed CON continuously. As a result, ADG during the first 14 d were numerically lower for 13AH and 13GAH compared with CON. After the initial 14 d, gut fill within treatment likely reached a new baseline and remained constant for the remainder of the experiment. Changes in ADG from d 14 to 56 likely reflected changes in BW independent of changes in gut fill.

Aguilar et al. (1984) and Williams et al. (2018) observed no differences in dry matter intake (DMI) when almond hulls replaced portions of alfalfa hay or alfalfa cubes in lactating dairy cattle diets. Conversely, Swanson et al. (2021) reported a cubic response where lactating cows consuming almond hulls at 7% of diet DM had greater DMI compared with those consuming almond hulls at 0, 13, and 20% of diet DM. Notably, when expressed as a percent of body weight, DMI were similar among treatments. In our experiment, DMI was greater for 13GAH, 13AH, and CON compared with 26AH. Differences in dry matter intake were likely associated with greater weight gains for steers fed 13GAH, 13AH, and CON. Pen weights were measured weekly and daily feed delivery was adjusted to 2.2% of pen BW (DM basis); therefore, greater ADG in 13GAH, 13AH, and CON resulted in greater pen weights and ultimately more feed delivered compared with 26AH. Although DMI was less for 26AH, no feed refusals were present the morning following feed delivery, suggesting almond hulls were readily consumed.

Gain-to-feed (G:F) ratio from d 0 to 56 was greater ($P \leq 0.02$) for 13GAH and 13AH compared with 26AH and tended to be greater for CON ($P = 0.10$) compared with 26AH. In addition, G:F from d 14 to 56 was greater ($P \leq 0.04$) for 13GAH and 13AH compared with CON and 26AH. Imani Rad et al. (2016) reported no differences in G:F when urea-treated almond hulls replaced alfalfa and were fed at 40% of diet DM to finishing lambs. Similarly, Beckett et al. (1992) and Phillips et al. (2015) reported no reductions in G:F when almond hulls replaced proportions of alfalfa or oat hay and were included in finishing beef cattle or finishing lamb diets. Reduced G:F in steers fed 26AH was likely associated with a reduction in energy intake that resulted from replacing proportions of dry-rolled corn with almond hulls; therefore, if almond hulls are going to be used as an alternative to dry-rolled corn, additional energy supplementation is necessary to achieve similar growth performance.

Experiment 3: Apparent digestibility and ruminal fermentation characteristics

Dry matter intake and organic matter intake did not differ ($P \geq 0.53$; Table 3.5) among treatments; however, NDF intake was greater ($P < 0.01$) for 26AH and CON compared with 13AH and 13GAH. In addition, ADF intake was greatest ($P < 0.01$) for 26AH, intermediate ($P < 0.01$) for CON, and least ($P < 0.01$) for 13AH and 13GAH. Differences in NDF and ADF intakes were associated with the nutrient composition of each diet. Neutral detergent fiber concentrations were 26.1, 26.4, 22.8, and 22.7% of diet DM, while ADF concentrations were 12.8, 11.0, 9.5, and 9.7% of diet DM for 26AH, CON, 13AH, and 13GAH, respectively.

Apparent total-tract DM, OM, NDF, or ADF digestibilities did not differ ($P \geq 0.15$) among treatments. Similarly, Can et al. (2007) and Yalchi (2011) reported no differences in DM or OM digestibility when almond hulls replaced portions of alfalfa or wheat straw and were fed to male goats or mature sheep.

Ruminal VFA concentrations are presented in Table 3.5, and VFA concentrations over the 24-hour sampling period are presented in Fig. 3.1. Total VFA concentrations were greater ($P \leq 0.03$) for calves fed 13GAH and 13AH compared with calves fed 26AH. In addition, total VFA concentrations tended ($P = 0.06$) to be greater for calves fed 13GAH compared with calves fed CON. No treatment × hour interactions were observed ($P \geq 0.37$) for ruminal concentrations of acetate, propionate, butyrate, or isobutyrate. In addition, concentrations of acetate and butyrate did not differ ($P \geq 0.16$) among treatments; however, propionate concentrations were greatest ($P < 0.01$) for 13GAH, intermediate ($P \leq 0.01$) for 13AH, and least ($P \leq 0.01$) for CON and 26AH. As a result, the acetate-to-propionate ratio was lower ($P \leq 0.03$) in 13GAH, intermediate ($P \leq 0.03$) in 13AH, and greatest ($P < 0.01$) in CON and 26AH. Greater concentrations of propionate in 13GAH and 13AH were likely associated with increased fermentation of non-structural carbohydrates from almond hulls compared with prairie hay.

Ruminal valerate concentrations were greater (treatment × hour: $P \leq 0.02$) from hours 2 to 6 post-feeding in 13AH, 13GAH, and 26AH compared with CON. As a result, overall concentrations of ruminal valerate were greater (diet effect: $P < 0.01$) in diets containing almond hulls compared with prairie hay. Rad et al. (2016) and Williams et al. (2018) observed no effect of almond hull inclusion on concentrations of ruminal valerate; however, in those experiments almond hulls replaced proportions of alfalfa cubes or alfalfa hay rather than prairie hay. Ruminal concentrations of isobutyrate and isovalerate were minor, but differences among treatments were observed. Concentrations of isobutyrate were greatest ($P \leq 0.01$) in CON compared with 13AH, 13GAH, and 26AH, whereas concentrations of isovalerate tended ($P = 0.08$) to be greater in CON compared with 13AH. Ruminal concentrations of branched-chain fatty acids increase as dietary protein increases (Dijkstra, 1994); therefore, numerically greater crude protein concentrations in CON may have contributed to increased concentrations of isobutyrate and isovalerate. In addition, greater non-structural carbohydrate fermentation in diets containing almond hulls may have led to greater uptake of isobutyrate and isovalerate by ruminal bacteria compared with diets containing prairie hay.

Ruminal ammonia concentrations were greater ($P \leq 0.02$; Table 3.5) in CON compared with 13GAH and 26AH. In addition, ruminal ammonia concentrations were also greater ($P = 0.05$) in 13AH compared with 26AH but did not differ ($P = 0.37$) between 13GAH and 26AH. Differences in concentrations of ruminal ammonia may have been associated with dietary crude protein concentrations. Average crude protein concentrations were 4.3, 5.0, and 8.8% of DM for almond hulls, prairie hay, and dry-rolled corn, respectively. Diets were not formulated to be iso-nitrogenous which resulted in lower dietary crude protein when almond hulls replaced prairie hay and proportions of dry-rolled corn. Similar reductions in ruminal ammonia concentrations were observed in lactating dairy cows when almond hulls replaced proportions of alfalfa cubes (Williams et al., 2018). Schwab et al. (2005) indicated that 5 mM of ruminal NH_3-N is needed to support ruminal microbial growth; therefore, additional protein supplementation may be needed when replacing traditional feed ingredients with almond hulls.

Liquid passage rate did not differ ($P \leq 0.26$; Table 3.5) among treatments; however, ruminal pH was greater ($P \leq 0.04$; Table 5) in 26AH and CON compared with 13GAH. In addition, ruminal pH was greater ($P = 0.03$) in 26AH and tended ($P = 0.06$) to be greater in CON compared with 13AH. Reduced ruminal pH may have been a result of increased organic matter fermentation and VFA production in 13GAH and 13AH compared with CON and 26AH. Conversely, replacing proportions of dry-rolled corn with almond hulls decreased dietary starch which resulted in a similar ruminal ($P = 0.72$) pH between CON and 26AH. In addition, differences in particle size between almond hulls and prairie hay may have also influenced ruminal pH. Weiss et al. (2017) reported an increase in rumination time and ruminal pH with greater corn stalk particle size. Rumination stimulates saliva production which subsequently increases ruminal pH (Allen, 1997). Time spent ruminating may have been greater in calves consuming CON and 26AH compared with 13PAH and 13AH, which could have contributed to differences in ruminal pH among treatments. Regardless of diet, ruminal pH was within the normal range for beef cattle fed grain-based diets (Nagaraja and Titgemeyer, 2007); however, the reduction in ruminal pH observed when almond hulls replaced prairie hay should be considered when formulating higher-energy diets.

Conclusions

Replacing prairie hay and portions of dry-rolled corn with almond hulls reduced growth performance, ruminal VFA concentrations, and ruminal ammonia concentrations in limit-fed growing beef cattle diets. Reductions in growth performance were likely a result of reduced energy intake and numerically lower apparent diet digestibility. Conversely, replacing prairie hay with almond hulls at 13% of diet DM resulted in similar final BW and ADG following a 56-d feeding period. Greater ADG between d 14 to 56 when almond hulls replaced prairie hay might indicate that cattle may require time to adapt to almond hulls in the diet or that this dietary substitution alters gut fill. Processing almond hulls with a hammermill or grinder mixer increased bulk density and numerically improved diet digestibility and performance but does not appear to be required. Overall, our data demonstrate that almond hulls can be an alternative to prairie hay in limit-fed growing beef cattle diets.

Acknowledgments

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Tables

Table 3.1 Composition of experimental diets

	Diet			
Item,	Control	13AH	13GAH	26AH
Ingredient, % DM				
Dry-rolled corn	39.5	39.5	39.5	26.5
Supplement[1]	7.5	7.5	7.5	7.5
Sweet Bran[2]	40.0	40.0	40.0	40.0
Prairie hay	13.0	-	-	-
Almond hulls	-	13.0	-	26.0
Ground almond hulls	-	-	13.0	-
Experiment 2				
Nutrient composition[3], % DM				
Dry matter	75.9	75.1	75.2	74.7
Crude protein	14.2	14.2	14.2	13.6
Organic matter	94.2	94.4	94.4	94.0
Neutral detergent fiber	28.1	22.5	22.4	24.1
Acid detergent fiber	11.5	8.4	8.1	10.2
Experiment 3				
Nutrient composition[3], % DM				
Dry matter	75.0	74.8	75.0	75.0
Crude protein	14.9	14.8	14.8	14.2
Organic matter	94.8	94.8	94.8	94.1
Neutral detergent fiber	26.4	22.8	22.7	26.1
Acid detergent fiber	11.0	9.5	9.7	12.8
Calculated composition[4], Mcal/kg				
NE_m	1.95	2.00	2.00	1.89
NE_g	1.30	1.35	1.35	1.25

[1] Supplement pellet formulated to contain (dry matter basis) 9.2% Ca, 5.26% NaCl, and 360 mg/kg monensin. Supplement ingredients: 71.01% wheat middlings, 22.72% calcium carbonate, 5.26% NaCl, 0.39% soybean oil, 0.18% Rumensin 90 (Elanco; Greedfield, IN), 0.11% zinc sulfate, 0.08% manganese (Mn) sulfate (32% Mn), 0.06% vitamin E premix (500,000 IU/kg), 0.05% copper sulfate, 0.10% selenium premix (0.99% Se), 0.008% ethylenediamine dihydriodide (EDDI) premix (9.2% EDDI), and 0.043% vitamin A (600,000 IU/g).

[2] Sweet Bran (Cargill Corn Milling; Blair, NE).

[3] Nutrient analysis conducted by SDK Laboratories (Hutchinson, KS).

[4] Net energy of maintenance (NE_m) and net energy of gain (NE_g) were calculated using NASEM (2016) values of diet ingredients.

Table 3.2 Nutrient composition of almond hulls[1]

	Experiment	
Item, % DM	1 & 3	2
Dry matter	92.1	89.4
Crude protein	4.3	4.4
Organic matter	93.5	94.7
Ash	6.5	5.3
Crude fiber	20.2	17.4
Neutral detergent fiber	33.3	22.6
Acid detergent fiber	27.8	17.4
Calcium	0.31	0.18
Phosphorus	0.05	0.08
Potassium	3.36	2.70
Magnesium	0.15	0.09

[1] Nutrient analysis conducted by SDK Laboratories (Hutchinson, KS).

Table 3.3 Effects of grinding almond hulls with a hammermill on particle size and bulk density

	Hammermill screen hole diameter[1]					
Item,	11.1 mm	19.1 mm	25.4 mm	No screen	SEM[2]	*P*-value[3]
Particle size[4], µm	1324^{c}	1772^{b}	1777^{b}	2217^{a}	71.2	0.01
Standard deviation	2.53	2.47	2.45	2.18	0.138	0.13
Bulk density, kg/m[3]	542^{y}	486^{z}	484^{z}	476^{z}	23.3	0.07
Particle separator[5], %						
Large	0.00	0.08	0.09	0.33	0.208	0.46
Medium	0.44^{z}	2.81^{z}	5.12^{yz}	15.00^{y}	2.091	0.07
Small	79.59	84.25	83.68	76.50	4.581	0.32
Fine	19.92^{a}	12.55^{by}	11.66^{b}	7.92^{bz}	2.152	0.01

[1] Almond hulls were ground with a laboratory-scale 1.5 HP Bliss Hammermill (Model 6K630B) using a 11.1 mm, 19.1 mm, 25.4 mm, or no screen. For each screen size treatment, approximately 9 kg of almond hulls were ground at three separate time points to provide three replications per treatment.

[2] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[3] Treatment main effect.

[4] Particle size and standard deviation determined as described by ASABE 319.4 methods.

[5] Determined using the Penn State Particle Separator. Large = particles > 19 mm, medium particles 8 to 19 mm, small particles from 4 to 8 mm, and fine particles < 4 mm.

[a,b,c] Within row, means with unlike superscripts differ ($P \leq 0.05$).

[y,z] Within row, means with unlike superscripts tend to differ ($P \leq 0.10$).

Table 3.4 Effects of almond hull inclusion on growth performance of limit-fed growing steers

	Diet[1]					
Item,	Control	13AH	13GAH	26AH	SEM[2]	*P*-value[3]
No. of pens	10	10	10	10		
No. of animals	91	91	91	91		
Body weight, kg						
d 0	260	262	262	259	1.7	0.22
d 14	270^{y}	270^{y}	271^{y}	266^{z}	2.2	0.09
d 56	326^{aby}	330^{a}	333^{ax}	319^{bz}	3.8	< 0.01
ADG, kg/d						
0 to 14	0.72	0.55	0.68	0.46	0.121	0.15
14 to 56	1.35^{bcz}	1.44^{aby}	1.47^{a}	1.27^{c}	0.052	< 0.01
0 to 56	1.19^{a}	1.22^{a}	1.27^{a}	1.07^{b}	0.083	0.02
DMI, kg/d						
0 to 14	5.68	5.63	5.68	5.61	0.043	0.23
14 to 56	6.64^{a}	6.62^{a}	6.66^{a}	6.46^{b}	0.072	0.04
0 to 56	6.30^{a}	6.27^{a}	6.32^{a}	6.15^{b}	0.059	0.03
G:F						
0 to 14	0.129	0.101	0.119	0.083	0.0225	0.20
14 to 56	0.205^{b}	0.222^{a}	0.222^{a}	0.199^{b}	0.0078	< 0.01
0 to 56	0.191^{aby}	0.198^{a}	0.202^{a}	0.176^{bz}	0.0092	0.04

[1] Control: prairie hay fed at 13% of diet DM; 13AH: non-ground almond hulls fed at 13% diet DM; 13GAH: ground almond hulls fed at 13% of diet DM; 26AH: Non-ground almond hulls fed at 26% of diet DM.

[2] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[3] Treatment main effect.

^{a,b,c} Within row, means with unlike superscripts differ ($P \leq 0.05$).

^{x,y,z} Within row, means with unlike superscripts tend to differ ($P \leq 0.10$).

Table 3.5 Effect of almond hull inclusion on intake, apparent digestibility, and ruminal fermentation characteristics in limit-fed ruminally cannulated beef heifers

	Diet[1]					
Item,	Control	13AH	13GAH	26AH	SEM[2]	*P*-value[3]
Number of observations	8	7	8	8		
Intake, kg/d						
Dry matter	8.88	8.83	8.87	8.84	0.104	0.61
Organic matter	8.42	8.37	8.29	8.32	0.097	0.53
Neutral detergent fiber	2.34^{a}	2.01^{b}	1.98^{b}	2.30^{a}	0.032	< 0.01
Acid detergent fiber	0.97^{b}	0.85^{c}	0.85^{c}	1.14^{a}	0.024	< 0.01
Apparent total-tract digestibility, %						
Dry matter	70.1	72.4	73.3	67.8	2.79	0.21
Organic matter	72.8	74.6	75.5	69.8	2.61	0.15
Neutral detergent fiber	54.7	51.4	51.2	46.1	4.61	0.31
Acid detergent fiber	38.9	30.0	33.3	24.1	6.77	0.22
Volatile fatty acids[4], m*M*						
Acetate	50.2	49.3	49.1	46.5	1.80	0.16
Propionate	24.2^{c}	28.4^{b}	32.8^{a}	24.0^{c}	1.66	< 0.01
Butyrate	12.7	13.2	11.4	12.5	0.92	0.22
Valerate	1.8^{b}	2.7^{a}	3.0^{a}	3.0^{a}	0.32	< 0.01
Isobutyrate	0.8^{a}	0.7^{b}	0.7^{b}	0.6^{c}	0.05	< 0.01
Isovalerate	1.7^{y}	1.3^{z}	1.5^{yz}	1.6^{yz}	0.24	0.08
Acetate:Propionate	2.2^{a}	1.9^{b}	1.7^{c}	2.2^{a}	0.11	< 0.01
Total volatile fatty acids	91.5^{ab}	95.8^{ab}	98.4^{a}	87.7^{b}	3.80	< 0.01
Ruminal ammonia[4], m*M*	6.0^{a}	5.1^{ab}	4.4^{bc}	3.8^{c}	0.85	0.01
Liquid passage rate[5], %/h	6.3	5.1	5.8	6.2	0.61	0.26
Ruminal pH	5.96^{ab}	5.84^{bc}	5.83^{c}	5.99^{a}	0.065	0.03

[1] Control: prairie hay fed at 13% of diet DM; 13AH: non-ground almond hulls fed at 13% diet DM; 13GAH: ground almond hulls fed at 13% of diet DM; 26AH: Non-ground almond hulls fed at 26% of diet DM.

[2] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[3] Treatment main effect.

[4] Average of values collected at 0, 2, 4, 6, 8, 12, 18, and 24 h after feeding.

[5] Calculated from samples collected at 2, 4, 6, 8, 12, and 18 h after feeding.

[a,b,c] Within row, means with unlike superscripts differ ($P \leq 0.05$).

[y,z] Within row, means with unlike superscripts tend to differ ($P \leq 0.10$).

Figure

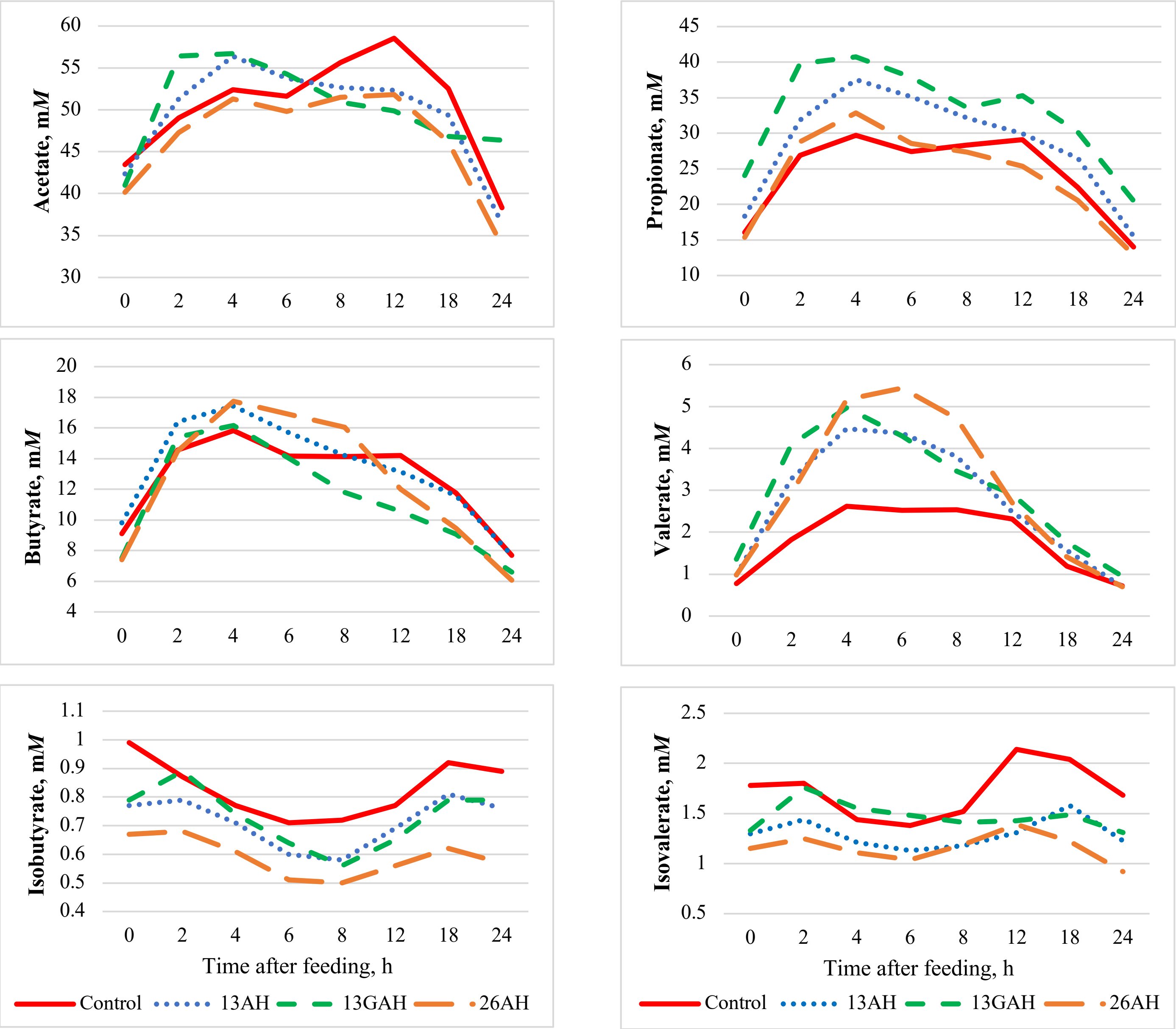

Figure 3.1. ***Effects of almond hull inclusion on ruminal volatile fatty acid concentrations in limit-fed growing beef cattle.*** Control: prairie hay fed at 13% of diet DM; 13AH: non-ground almond hulls fed at 13% diet DM; 13GAH: ground almond hulls fed at 13% of diet DM; 26AH: Non-ground almond hulls fed at 26% of diet DM. Acetate: diet ($P = 0.16$), diet × hour ($P = 0.54$), hour ($P < 0.01$), period ($P = 0.08$), SEM = 3.51. Propionate: diet ($P < 0.01$), diet × hour ($P = 0.85$), hour ($P < 0.01$), period ($P = 0.08$), SEM = 3.32. Butyrate: diet ($P = 0.22$), diet × hour ($P = 0.37$), hour ($P < 0.01$), period ($P = 0.20$), SEM = 1.47. Valerate: diet ($P < 0.01$), diet × hour ($P < 0.01$), hour ($P < 0.01$), period ($P = 0.20$), SEM = 0.47. Isobutyrate: diet ($P < 0.01$), diet × hour ($P = 0.39$), hour ($P < 0.01$), period ($P = 0.53$), SEM = 0.06. Isovalerate: diet ($P = 0.07$), diet × hour ($P = 0.05$), hour ($P < 0.01$), period ($P = 0.76$), SEM = 0.22.

Chapter 4 - Effect of wheat middling incorporation into wet distillers grains on apparent diet digestibility and ruminal fermentation characteristics in growing and finishing diets

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Abstract

Two separate cross-over experiments were conducted to evaluate the effects of incorporating wheat middlings (MIDDS) into wet distillers grains (WDGS) on apparent diet digestibility and ruminal fermentation characteristics in growing and finishing diets. In Exp. 1, 4 ruminally cannulated heifers (313 ± 42.9 kg) were limit fed a high-energy growing diet that included WDGS or WDGS+MIDDS at 40% of diet dry matter (DM). In Exp. 2, 4 ruminally cannulated Holstein steers (321 ± 17.4 kg) were fed a traditional finishing diet that included WDGS or WDGS+MIDDS at 30% of diet DM. Experiments consisted of two 15-d periods, were conducted concurrently, and all sampling procedures were identical. Each period included 10 d of diet adaption, 4 d of fecal collection, and 1 d of ruminal fluid sample collection. Fecal samples were collected on d 11 to d 14 of each period and composite samples were analyzed for marker concentrations of chromium oxide to determine apparent diet digestibility. On d 15, ruminal fluid samples were collected prior to feeding and again at 2, 4, 6, 8, 12, 18, and 24-h post-feeding. In Exp. 1, DM, organic matter (OM), neutral detergent fiber (NDF), and acid detergent fiber (ADF) intake did not differ ($P \geq 0.11$) between diets; however, starch intake was greater ($P = 0.03$) for heifers fed WDGS+MIDDS compared with WDGS. Apparent DM, OM, NDF, and starch digestibilities were similar between diets ($P \geq 0.13$), but feeding WDGS+MIDDS tended to decrease ($P = 0.06$) apparent ADF digestibility. Ruminal pH and total volatile fatty acid concentrations did not differ between diets ($P \geq 0.16$); however, ruminal ammonia concentrations tended to be lesser ($P = 0.09$) for WDGS+MIDDS compared with WDGS. In Exp. 2, DM intake did not differ ($P = 0.65$) between diets. Apparent DM digestibility was greater ($P = 0.01$) for WDGS+MIDDS compared with WDGS, but the difference was small. Intake and apparent digestibility of OM, NDF, ADF, and starch did not differ ($P \geq 0.25$) between diets.

Ruminal butyrate concentrations were greater ($P < 0.01$) whereas ruminal ammonia concentrations were lesser ($P = 0.03$) in diets containing WDGS+MIDDS compared with WDGS. Ruminal pH was less acidic for WDGS+MIDDS compared with WDGS. Overall, incorporation of MIDDS into WDGS had minimal impacts on feed intake, diet digestibility, and ruminal fermentation characteristics when fed to growing and finishing cattle.

Key words: wet distillers grains, wheat middlings, starch, volatile fatty acids, apparent digestibility, ruminal pH

Introduction

Production of food and beverages for human consumption or ethanol from cereal grains generates by-products that can be incorporated into livestock diets (Stock et al., 2000). A survey of feedlot consulting nutritionists indicated that grain by-products were included in 95.8% and 97.1% of receiving and finishing diets, respectively (Samuelson et al., 2016). In addition, wet corn distillers grains (WDGS) were the most commonly used grain by-product in both receiving and finshing cattle diets (Samuelson et al., 2016). Corn contains approximately two-thirds starch and when starch is removed during the dry-milling process, the remaining protein, fat, fermentable fiber, and phosphorus are concentrated three-fold (Stock et al., 2000). Because WDGS are relatively low in starch but high in digestible fiber, they can be used to increase dietary crude protein and energy concentrations with low risk of ruminal acidosis.

An additional co-product that may be incorporated into livestock diets is wheat middlings (MIDDS). Wheat middlings are a by-product of flour milling and are defined as fine particles of wheat bran, germ, flour, and the offal from the "tail of the mill" (AFFCO, 2022). Similar to WDGS, MIDDS contain greater concentrations of crude protein, fermentable fiber, and minerals compared with wheat grain. Previous research demonstrated that MIDDS can replace small portions of dry-rolled corn or alfalfa in finishing beef cattle diets (Dalke et al., 1997); however, the physical characteristics of MIDDS can make them difficult to handle. Wheat middlings contain fine particles that have a low bulk density. As a consequence, MIDDS are often pelleted to make them easier to store and handle.

One potential alternative to pelleting MIDDS is to incorporate them into WDGS and generate a new co-product. An initial concern associated with integrating MIDDS into WDGS is that MIDDS will increase the starch concentration of the new co-product. A high-starch co-product could potentially increase the risk of ruminal acidosis if fed at high inclusion rates. Therefore, the objective of this experiment was to measure the effects of feeding WDGS or WDGS+MIDDS at relatively high inclusion rates on apparent diet digestibility and ruminal fermentation characteristics in growing and finshing diets.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee reviewed and approved all animal handling and animal care practices used in our experiments. All animal procedures were conducted in accordance with the Guide for the Care and Use of Animals in Agricultural Research and Teaching (FASS, 2020).

In Exp. 1, four ruminally cannulated crossbred Angus heifers (initial body weight = 313 ± 42.9 kg) were limit fed a high-energy growing diet that included WDGS or WDGS+MIDDS at 40% of diet dry matter (DM; Table 4.1). Diets also contained 39.5% dry-rolled corn, 7.5% supplement, and 13% prairie hay and were offered at 2.2% of body weight (DM basis). In Exp. 2, four ruminally cannulated Holstein steers (initial body weight = 321 ± 17.4 kg) were fed a traditional finshing diet that included WDGS or WDGS+MIDDS at 30% of diet DM. Diets also contained 60.33% dry-rolled corn, 2.67% supplement, and 7% prairie hay and were fed for ad libitum intake. Diets were mixed using a Marion Mixer (model 2030; Marion, IA) and were fed once daily at 1000 h. Animals were housed individually in soil-surfaced pens. Experiments were conducted simultaneously and the following procedures were identical.

Treatments were arranged in a cross-over design utilizing two consecutive 15-d periods. Each period consisted of 10 d of diet adaption, 4 d of fecal collection, and 1 d of ruminal fluid sample collection. On d 4 through d 14, 10 g of chromium oxide (Cr_2O_3) were administered intra-ruminally using a 1.5 oz. TORPAC® gel capsule (Leedstone; Melrose, MN). On d 11 through d 14, fecal samples were collected from the rectum of each animal at 8-h intervals. Collection time advanced 2 h each day, so that each 2 h interval over 24 h was represented. Following collection, fecal samples were composited for each animal within period. Individual feed ingredient samples were collected on d 10 through d 14 of each period. At the completion of the experiment, feed ingredient samples were composited within period.

On d 15, digesta samples were collected from 4 separate locations in the rumen prior to feeding. Following 0-h sampling, 3 g of cobalt-EDTA dissolved in 200 mL of water was dosed via the ruminal cannula. Animals were fed, and ruminal digesta samples were collected again at 2, 4, 6, 8, 12, 18, and 24 h post-feeding. Following each collection, samples were strained through 8 layers of cheesecloth and ruminal pH was measured using a portable pH meter (Pinpoint; American Marine Inc., Ridgefield, CT). Strained rumen fluid (1 mL) was subsequently pipetted into four 2-mL micro-centrifuge tubes containing 250 µL of m-phosphoric acid. In addition, 15 mL of strained rumen fluid was retained for cobalt analysis to determine liquid passage rate. After collection, ruminal fluid samples were immediately frozen at -20°C until analysis.

Prior to the start of the experiment, a 3-axial sensory accelerometer ear tag (Allflex Livestock Intelligence; Madison, WI) was applied in the right ear of each calf. Tags continuously measured rumination and activity and data was summarized in 2-h increments. Rumination time included time spent masticating and ruminating. Activity was defined as all other movement excluding rumination and mastication. Data from d 10 to d 14 was used in the analysis. All data from one calf in Exp. 2 was removed due to tag failure.

Laboratory analysis

At the completion of the experiment, feed ingredient and fecal samples were sent to a commercial laboratory (SDK Laboratories; Hutchinson, KS) for nutrient analysis. Samples were analyzed for dry matter (DM), crude protein (N × 6.25; AOAC International, 1999), neutral detergent fiber (NDF; Van Soest et al., 1991), acid detergent fiber (ADF; Van Soest et al., 1991), starch (Richards et al., 1995), calcium (Bowers and Rains, 1988), and phosphorus (AOAC International, 1999).

To determine apparent diet digestibility, dried fecal material was ground using a 1-mm screen. Approximately 0.5 g of ground fecal material was subsequently placed in a muffle oven at 600°C for 2 h. Chromium concentrations were then measured by atomic absorption spectrophotometry following preparation as described by Williams et al. (1962). Fecal chromium concentrations were used to estimate total fecal output and determine apparent diet digestibility according to Cochran and Galyean (1994).

Ruminal fluid samples collected for volatile fatty acid (VFA) and ammonia analysis were centrifuged for 30 min at 17,000 × g at 4 °C. The supernatant was collected, and VFA concentrations were measured using gas-liquid chromatography (Vanzant and Cochran, 1994). Ruminal ammonia concentrations of the supernatant were measured as described by Broderick and Kang (1980). Samples retained for ruminal cobalt analysis were centrifuged at 25,000 × g for 25 min at 4 °C. Cobalt concentrations of the supernatant were measured using atomic absorption spectrophotometry and were used to estimate liquid passage rate. Liquid passage rates were calculated using the nonlinear procedure of SAS. The natural logarithms of cobalt concentration from ruminal samples collected at 2, 4, 6, 8, 12, and 18 hours after feeding were regressed on time and liquid passage rate was estimated from the negative slope of the regression.

Statistical Analysis

All data were analyzed using the MIXED procedure in SAS (SAS 9.4, SAS Inst. Inc, Cary, NC). For nutrient intake and apparent digestibility, the model contained fixed effects of diet and period and a random effect of animal. Ruminal pH and concentrations of VFA and ruminal ammonia were analyzed as repeated measures. The model contained fixed effects of treatment, period, hour, and treatment × hour and a random effect of animal. Hour was the repeated term and the subject was animal × period. The covariance structure was spatial power for ruminal pH and autoregressive for ruminal ammonia concentrations and ruminal VFA concentrations as determined by Akaike information criterion fit statistics.

Rumination and activity data was also analyzed as repeated measures. The model included fixed effects of treatment, period, hour, and treatment × hour and random effects of animal and day. Hour served as the repeated term, and the subject was animal × period × day. The covariance structure was spatial power as determined by Akaike information criterion fit statistics. When protected by a significant *F*-test ($P \leq 0.05$), treatment means were separated using the method of Least Significant Difference. Significance was declared at $P \leq 0.05$ and tendencies at $0.05 \leq P$ 0.10.

Results and Discussion

Co-product composition

The nutrient composition of WDGS and WDGS+MIDDS is presented in Table 4.2. Incorporation of MIDDS into WDGS increased DM, starch, and phosphorus concentrations and reduced crude protein concentrations. Differences in nutrient composition between co-products were associated with the nutrient composition of the initial feed ingredients. Cromwell et al. (2000) reported that MIDDS contain on average 89.6% DM, 16.2% crude protein, and 0.97% phosphorus (DM basis) whereas Buckner et al. (2011) indicated that WDGS contain on average 32.5% DM, 31% crude protein, and 0.84% phosphorus (DM basis). In addition, MIDDS contain approximately 19.5% more starch than WDGS (NASEM, 2016). Because the initial nutrient concentrations of WDGS and MIDDS differ slightly, blending the two feed ingredients generated a product that contained more DM, starch, and phosphorus but less crude protein; however, concentrations of organic matter (OM), NDF, ADF, and calcium were similar between WDGS and WDGS+MIDDS.

Experiment 1 Growing Diet

Dry matter, OM, and ADF intake did not differ ($P \geq 0.47$; Table 4.3) between WDGS and WDGS+MIDDS. Intake of NDF was numerically greater ($P = 0.11$) for heifers consuming WDGS compared with WDGS+MIDDS. In addition, intake of starch was greater ($P = 0.03$) for WDGS+MIDDS compared with WDGS. Differences in starch and NDF intake reflect differences in nutrient composition of the two co-products. Apparent DM, OM, NDF, and starch digestibility did not differ ($P \geq 0.13$; Table 4.3) between treatments in Exp. 1; however, apparent ADF digestibility tended to be lesser ($P = 0.06$) for WDGS+MIDDS compared with WDGS, likely due to a difference in ADF digestibility of the two co-products. Although NDF digestibility was not affected by treatment, it should be noted that NDF digestibility followed a pattern similar to ADF digestibility, being lower for WDGS+MIDDS than for WDGS. When comparing MIDDS and corn gluten feed, Zhu et al. (1997) observed similar apparent total tract ADF digestibilities when lactating dairy cattle were fed diets formulated to provide equal amounts of NDF from MIDDS or a mix of dried distillers grains and hominy.

Ruminal VFA concentrations for Exp. 1 are presented in Table 4.3, and ruminal VFA concentrations over the 24-hour sampling period are presented in Fig. 4.1. Total VFA concentrations averaged across the 24-h sampling period did not differ ($P = 0.70$) between diets. Previous research demonstrated that limit-fed cattle consume their daily feed allotment within 6 to 7 hours of feed delivery (Schmidt et al., 2005; Duncan et al., 2022). In our experiment, ruminal VFA concentrations increased after feeding but began to decline approximately 6 hours post-feeding. Heifers consumed a large portion of their daily feed allotment within 6 hours of feeding which is reflected by ruminal VFA concentrations decreasing after this time. Conversely, no diet × hour interactions ($P \geq 0.18$) or effect of diet ($P \geq 0.13$) was observed for ruminal concentrations of acetate, propionate, butyrate, valerate, or isobutyrate.

No diet × hour interactions ($P = 0.15$; Fig. 4.2) were observed for concentrations of ruminal ammonia; however, average ruminal ammonia concentrations tended to be greater ($P = 0.09$; Table 4.3) for WDGS compared with WDGS+MIDDS. Differences in ruminal ammonia concentrations were associated with the nutrient composition of the co-products. Crude protein concentrations were 31.8 and 24.7% (DM basis; Table 4.2) for WDGS and WDGS+MIDDS, respectively. As a result, dietary crude protein concentrations were 2.9% (DM basis; Table 4.1) less for WDGS+MIDDS compared with WDGS. Although starch intakes were greater for heifers fed WDGS+MIDDS, ruminal pH did not differ ($P = 0.16$; Table 4.3) between diets. Ruminal pH declined immediately after feeding, remained low for approximately 4 to 6 h, and began to increase thereafter (Fig. 4.4). There was no effect of diet ($P \geq 0.52$; Table 4.3) on liquid passage rate, time spent ruminating, and heifer activity.

Experiment 2 Finishing Diet

Dry matter, OM, NDF, ADF, and starch intake did not differ ($P \geq 0.27$; Table 4.4) between WDGS and WDGS+MIDDS. Despite dietary starch concentrations being 2.5% greater in WDGS+MIDDS compared with WDGS, starch intake was similar ($P = 0.66$) between steers fed WDGS or steers fed WDGS+MIDDS. Dry matter intake was numerically greater for steers consuming WDGS compared with steers consuming WDGS+MIDDS which ultimately led to the similar intake of starch. VanderPol et al. (2006) reported that DM intake responded quadratically when WDGS inclusion was increased from 0 to 50% of diet DM and was maximized when WDGS were included at 30% of diet DM. When incorporated at 30% of diet DM in our experiment, DM intake was 0.32 kg less for steers fed WDGS+MIDDS compared with steers fed WDGS.

Apparent DM digestibility was greater ($P = 0.01$; Table 4.4) for WDGS+MIDDS compared with WDGS; however, the difference in apparent DM digestibility was small (i.e., 0.38 %) and likely not biologically important. Conversely, apparent digestibility of OM, NDF, ADF, and starch did not differ ($P \geq 0.25$) between treatments. Apparent starch digestibility was 90.0 and 91.0% for WDGS and WDGS+MIDDS, respectively and is in agreement with results published by Owens and Zinn (2005) for feedlot steers consuming diets based on dry-rolled corn.

Ruminal VFA concentrations for are presented in Table 4.4, and ruminal VFA concentrations over the 24-hour sampling period are presented in Fig. 4.4. Similar to Exp. 1, total VFA concentrations averaged across the 24-h sampling period were lower than expected for grain-based finshing diets, but they did not differ ($P = 0.91$) between diets. The pattern in total VFA concentrations was not typical for steers fed for ad libitum intake. Total VFA concentrations declined for the first 6 h after feeding, increased thereafter, and peaked 18 h post-feeding. Our experiment was conducted between August and September 2021 and average maximum temperatures were 30.9 °C (Kansas Mesonet, 2021). Steers were housed outside and were fed once daily at 1000 h. As a result, feed was likely consumed later in the day when ambient temperatures were lower and is reflected by increased ruminal VFA concentrations 10 to 20 h post-feeding.

No diet × hour interactions were observed ($P \geq 0.43$) for ruminal concentrations of acetate, propionate, butyrate, valerate, isobutyrate, or isovalerate. In addition, there was no effect of diet ($P \geq 0.13$) on average concentrations of ruminal acetate, valerate, isobutyrate, or isovalerate; however, ruminal propionate concentrations tended to be greater ($P = 0.07$) in WDGS compared with WDGS+MIDDS. As a result, acetate-to-propionate ratio tended to be lesser ($P = 0.07$) for WDGS compared with WDGS+MIDDS.

The trend for greater ruminal propionate concentrations in WDGS than WDGS+MIDDS was somewhat unexpected. Ruminal propionate concentrations generally increase as dietary starch concentrations increases (Coe et al., 1999); however, in our experiment, dietary starch concentrations were greater for WDGS+MIDDS compared with WDGS but starch intake did not differ between treatments. Conversely, ruminal butyrate concentrations were greater for WDGS+MIDDS compared with WDGS. Dalke et al. (1997) also observed a linear increase in ruminal butyrate concentrations when MIDDS replaced portions of dry-rolled corn in finishing diets. Ruminal butyrate concentrations were also numerically greater for WDGS+MIDDS compared with WDGS in Exp. 1 suggesting that incorporation of MIDDS into WDGS may increase ruminal butyrate concentrations.

No diet × hour interactions (*P* = 0.24; Fig. 4.5) were observed for concentrations of ruminal ammonia; however, average ruminal ammonia concentrations were greater (*P* = 0.03; Table 4.4) for WDGS compared with WDGS+MIDDS. Similar to Exp. 1, differences in ruminal ammonia concentrations were associated with the nutrient composition of the co-products. Dietary crude protein concentrations were 2.1% (DM basis; Table 4.1) less for WDGS+MIDDS compared with WDGS. In contrast to Exp. 1, ruminal pH in Exp. 2 was greater (*P* = 0.02; Table 4, Fig. 4.6) for steers consuming WDGS+MIDDS compared with steers consuming WDGS. Differences in ruminal pH in Exp. 2 may have been associated with feed intake. Rumsey et al. (1970) observed a decrease in ruminal pH as feed intake increased. In our experiment, feed intake was numerically greater for steers consuming WDGS compared with steers consuming WDGS+MIDDS which may have contributed to the reduction in ruminal pH. There was no effect of diet on liquid passage rate, time spent ruminating, and steer activity did not differ (*P* ≥ 0.16; Table 4.4).

Implications

Overall, incorporating MIDDS into WDGS generated a co-product that contained more dry matter, starch, and phosphorus and less crude protein compared with WDGS. When included in a limit-fed growing diet, WDGS+MIDDS did not influence DM intake but did increase starch intake. Despite this, ruminal pH did not differ between diets. Feeding WDGS+MIDDS for ad libitum intake to finishing steers caused a numeric reduction in DM intake which ultimately led to similar starch intake; however, ruminal pH was more acidic for steers fed WDGS. Overall, ruminal pH in both experiments was within the normal range for beef cattle fed grain-based diets and suggest that WDGS+MIDDS can be fed at relatively high inclusion rates in a growing or finshing diet without inducing ruminal acidosis (Nagaraja and Titgemeyer, 2007).

Apparent DM, OM, and starch digestibilities were similar for growing and finishing calves fed WDGS and WDGS+MIDDS. Conversely, apparent NDF digestibility was numerically lesser for growing heifers fed WDGS+MIDDS compared with WDGS. Apparent ADF digestibility also tended to be lesser for growing heifers fed WDGS+MIDDS compared with WDGS; however, there was no effect of diet on apparent fiber digestibility when WDGS+MIDDS were fed to finishing steers. Feeding WDGS+MIDDS to growing heifers did not influence ruminal VFA concentrations and but did cause minor shifts in ruminal propionate and butyrate concentrations when fed to finishing steers. Ruminal ammonia concentrations in both experiments were lower in diets containing WDGS+MIDDS compared with WDGS, reflecting the lower crude protein content of WDGS+MIDDS compared to WDGS. Taken together, it appears that WDGS+MIDDS can be incorporated into growing and finshing diets without negatively influencing diet digestibility or ruminal fermentation characteristics.

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Tables

Table 4.1. Composition of experimental diets

	Exp. 1 (growing)		Exp. 2 (finishing)	
	WDGS[1]	WDGS+MIDDS[1]	WDGS[2]	WDGS+MIDDS[2]
Ingredient, % of DM				
Dry rolled corn	39.50	39.50	60.33	60.33
Supplement 1	7.50	7.50	-	-
Supplement 2	-	-	2.67	2.67
WDGS[3]	40.00	-	30.00	-
WDGS+MIDDS[3]	-	40.00	-	30.00
Prairie hay	13.00	13.00	7.00	7.00
Nutrient composition[4], % of DM				
Dry matter	67.1	69.2	72.4	74.0
Crude protein	17.4	14.5	14.7	12.6
Organic matter	94.7	94.6	95.0	94.9
Ash	5.3	5.4	5.0	5.1
Neutral detergent fiber	23.1	22.3	16.8	16.2
Acid detergent fiber	9.2	9.2	6.1	6.0
Total starch	30.7	34.0	44.0	46.5
Calcium	0.74	0.75	0.68	0.68
Phosphorus	0.48	0.59	0.45	0.54

[1] Supplement pellet formulated to contain (DM basis) 11.4% crude protein, 7% calcium, 0.65% phosphorus, 2.0% fat, and 307 g/ton monensin (Rumensin; Elanco, Greenfield IN).

[2] Supplement formulated to contain (DM basis) 23.6% calcium, 2% phosphorus, 20.5% salt, 1,000 g/ton monensin (Rumensin; Elanco, Greenfield IN).

[3] PureField Ingredients; Russell, KS

[4] Nutrient analysis conducted by SDK Laboratories (Hutchinson, KS).

Table 4.2 Composition of WDGS and WDGS+MIDDS

	Co-product	
	WDGS[1]	WDGS+MIDDS[1]
Nutrient composition, % DM		
Dry matter	34.0	39.3
Crude protein	31.8	24.7
Organic matter	94.7	94.3
Ash	5.3	5.7
Neutral detergent fiber	24.2	22.2
Acid detergent fiber	7.9	7.8
Total Starch	3.2	11.6
Calcium	0.14	0.15
Phosphorus	0.82	1.11

[1] PureField Ingredients; Russell, KS

Table 4.3 Effects of WDGS or WDGS+MIDDS inclusion on intake, apparent digestibility, and ruminal fermentation characteristics of limit-fed growing heifers (Exp. 1)

	Diet			
Item	WDGS	WDGS+MIDDS	SEM[1]	*P*-value[2]
Intake, kg/d				
Dry matter	6.98	7.00	0.100	0.87
Organic matter	6.61	6.62	0.094	0.94
Neutral detergent fiber	1.64	1.58	0.023	0.11
Acid detergent fiber	0.66	0.65	0.011	0.64
Starch	2.14	2.39	0.050	0.03
Apparent total tract digestibility, %				
Dry matter	74.19	74.08	2.432	0.97
Organic matter	77.65	77.51	1.508	0.94
Neutral detergent fiber	60.22	54.27	2.794	0.17
Acid detergent fiber	61.53	51.35	2.580	0.06
Starch	93.37	96.43	1.201	0.13
Ruminal VFA[3], m*M*				
Acetate	39.91	36.56	2.196	0.13
Propionate	21.31	21.82	3.977	0.90
Butyrate	6.94	7.62	1.000	0.50
Valerate	1.50	1.92	0.644	0.51
Isobutyrate	0.62	0.65	0.066	0.59
Isovalerate	1.89	1.60	0.300	0.54
Acetate:propionate	2.08	2.00	0.384	0.86
Total VFA	72.16	70.17	8.744	0.70
Ruminal ammonia[3], m*M*	6.68	3.87	1.356	0.09
Ruminal pH[3]	5.88	6.01	0.097	0.16
Liquid passage rate[4], %/h	3.34	3.12	1.071	0.79
Rumination, min	20.2	19.9	1.13	0.75
Activity, min	11.8	11.7	0.23	0.52

[1] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[2] Treatment main effect.

[3] Average of values collected at 0, 2, 4, 6, 8, 12, 18, and 24 h post-feeding.

[4] Determined using values collected at 2, 4, 6, 8, 12, and 18 h post-feeding.

Table 4.4 Effects of WDGS or WDGS+MIDDS inclusion on intake, apparent digestibility, and ruminal fermentation characteristics of finishing steers (Exp. 2)

	Diet			
Item	WDGS	WDGS+MIDDS	SEM[1]	*P*-value[2]
Intake, kg/d				
Dry matter	10.80	10.48	0.595	0.65
Organic matter	10.25	9.94	0.564	0.64
Neutral detergent fiber	1.85	1.72	0.092	0.27
Acid detergent fiber	0.67	0.64	0.038	0.48
Starch	4.74	4.88	0.282	0.66
Apparent total tract digestibility, %				
Dry matter	78.06	78.44	0.027	0.01
Organic matter	79.42	79.83	0.253	0.25
Neutral detergent fiber	59.31	63.45	5.579	0.54
Acid detergent fiber	58.06	62.25	5.666	0.65
Starch	90.00	90.97	1.733	0.63
Ruminal VFA[3], m*M*				
Acetate	40.35	42.77	1.572	0.13
Propionate	31.77	24.98	3.676	0.07
Butyrate	6.57	9.44	0.577	< 0.01
Valerate	2.24	2.24	0.887	0.99
Isobutyrate	0.56	0.64	0.047	0.18
Isovalerate	0.95	1.88	0.731	0.21
Acetate:propionate	1.28	1.95	0.260	0.07
Total VFA	82.44	81.94	5.048	0.91
Ruminal ammonia[3], m*M*	4.62	2.61	0.879	0.03
Ruminal pH[3]	5.53	5.71	0.071	0.02
Liquid passage rate[4], %/h	4.36	5.16	0.716	0.36
Rumination, min	21.5	21.0	1.75	0.57
Activity, min	16.0	16.5	0.38	0.16

[1] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[2] Treatment main effect.

[3] Average of values collected at 0, 2, 4, 6, 8, 12, 18, and 24 h post-feeding.

[4] Determined using values collected at 2, 4, 6, 8, 12, and 18 h post-feeding.


Acetate, mM
50
45
40
35
30
25
0
2
4
6
8
12
18
24
Propionate, mM
30
25
20
15
10
0
2
4
6
8
12
18
24
Butyrate, mM
11
10
9
8
7
6
5
4
0
2
4
6
8
12
18
24
Valerate, mM
3
2.5
2
1.5
1
0.5
0
0
2
4
6
8
12
18
24
Isobutyrate, mM
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
2
4
6
8
12
18
24
Isovalerate, mM
2.5
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
0.5
0
2
4
6
8
12
18
24
Total VFA, mM
90
85
80
75
70
65
60
55
50
45
40
0
2
4
6
8
12
18
24
Time after feeding, h
WDGS
WDGS+MIDDS
Acetate-to-Propionate
3.0
2.5
2.0
1.5
1.0
0.5
0
2
4
6
8
12
18
24
Time after feeding, h
WDGS
WDGS+MIDDS

Figure 4.1. ***Effects of WDGS or WDGS+MIDDS inclusion on ruminal VFA concentrations in limit-fed growing heifers.*** Acetate: diet ($P = 0.13$), diet × hour ($P = 0.18$), hour ($P < 0.01$), period ($P < 0.01$), SEM = 5.02. Propionate: diet ($P = 0.90$), diet × hour ($P = 0.31$), hour ($P < 0.01$), period ($P = 0.39$), SEM = 4.58. Butyrate: diet ($P = 0.50$), diet × hour ($P = 0.54$), hour ($P < 0.01$), period ($P = 0.75$), SEM = 1.47.Valerate: diet ($P = 0.51$), diet × hour ($P = 0.51$), hour ($P < 0.01$), period ($P = 0.94$), SEM = 0.52. Isobutyrate: diet ($P = 0.59$), diet × hour ($P = 0.45$), hour ($P < 0.01$), period ($P = 0.85$), SEM = 0.01. Isovalerate: diet ($P = 0.54$), diet × hour ($P = 0.07$), hour ($P < 0.01$), period ($P = 0.72$), SEM = 0.43. Total VFA: diet ($P = 0.71$), diet × hour ($P = 0.19$), hour ($P < 0.01$), period ($P = 0.04$), SEM = 10.06. Acetate-to-Propionate: diet ($P = 0.86$), diet × hour ($P = 0.99$), hour ($P < 0.01$), period ($P = 0.49$), SEM = 0.44

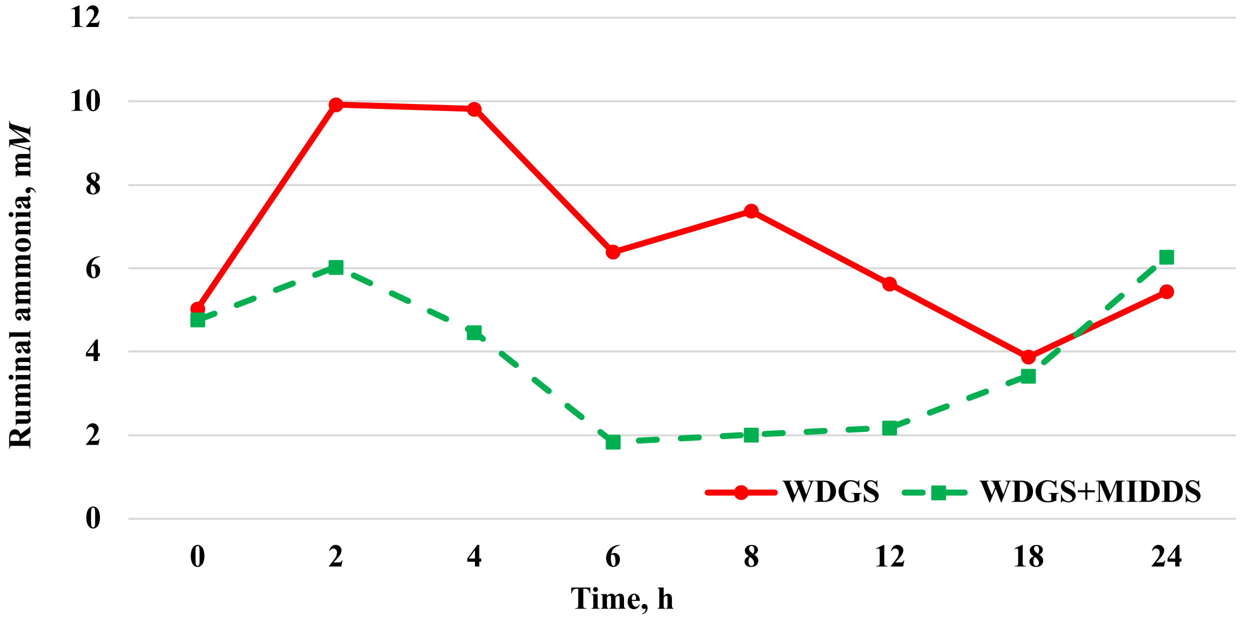

Figure 4.2. ***Effects of WDGS or WDGS+MIDDS inclusion on ruminal ammonia concentrations of limit-fed growing heifers*.** Diet ($P = 0.09$), Diet × hour ($P = 0.15$), hour ($P < 0.01$), period ($P = 0.44$), SEM = 0.959.

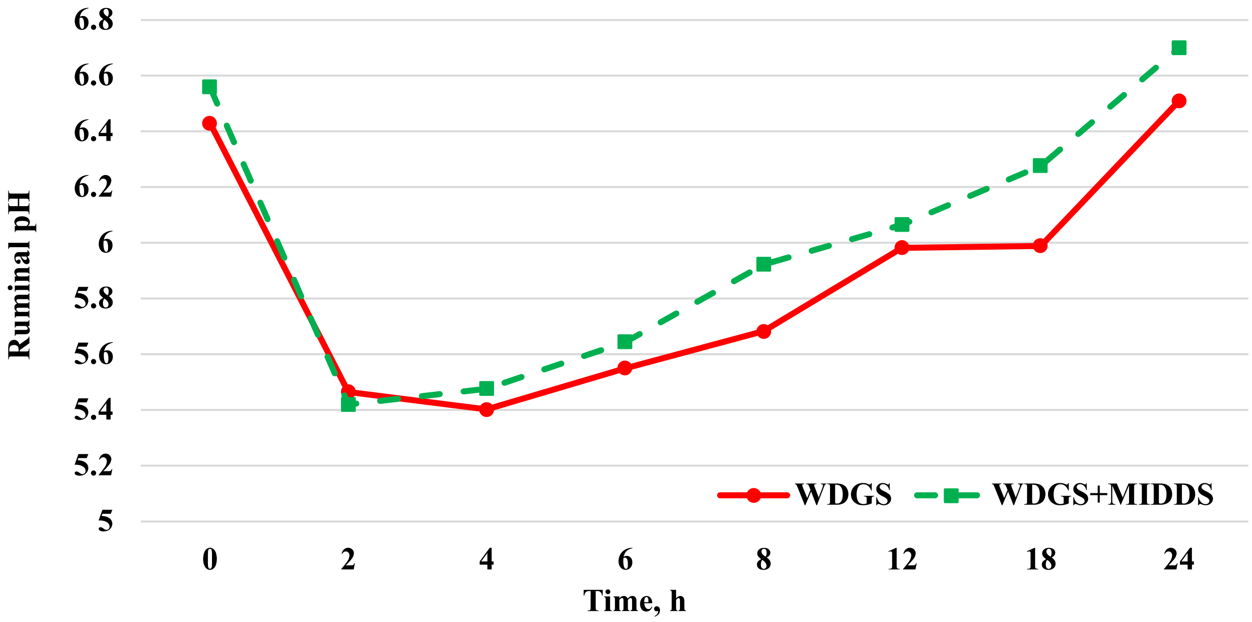

Figure 4.3. ***Effects of WDGS or WDGS+MIDDS inclusion on ruminal pH of limit-fed growing heifers.*** Diet ($P = 0.16$), Diet × hour ($P = 0.91$), hour ($P < 0.01$), period ($P = 0.01$), SEM = 0.169.


Acetate, mM
55
50
45
40
35
30
25
Propionate, mM
45
40
35
30
25
20
15
10
Butyrate, mM
13
12
11
10
9
8
7
6
5
4
Valerate, mM
3.5
3
2.5
2
1.5
1
0.5
0
Isobutyrate, mM
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
Isovalerate, mM
2.7
2.2
1.7
1.2
0.7
0.2
Total VFA, mM
105
100
95
90
85
80
75
70
65
60
Acetate-to-Propionate
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0
2
4
6
8
12
18
24
Time after feeding, h
WDGS
WDGS+MIDDS

Figure 4.4 Effects of WDGS or WDGS+MIDDS inclusion on ruminal VFA concentrations in finishing steers. Acetate: diet ($P = 0.13$), diet × hour ($P = 0.43$), hour ($P < 0.01$), period ($P < 0.01$), SEM = 5.02. Propionate: diet ($P = 0.07$), diet × hour ($P = 0.59$), hour ($P < 0.01$), period ($P = 0.14$), SEM = 4.18. Butyrate: diet ($P = 0.01$), diet × hour ($P = 0.57$), hour ($P = 0.02$), period ($P = 0.55$), SEM = 1.15.Valerate: diet ($P = 0.99$), diet × hour ($P = 0.75$), hour ($P < 0.01$), period ($P = 0.04$), SEM = 0.76. Isobutyrate: diet ($P = 0.12$), diet × hour ($P = 0.83$), hour ($P < 0.01$), period ($P = 0.09$), SEM = 0.01. Isovalerate: diet ($P = 0.21$), diet × hour ($P = 0.97$), hour ($P < 0.06$), period ($P = 0.39$), SEM = 0.55. Total VFA: diet ($P = 0.91$), diet × hour ($P = 0.48$), hour ($P < 0.01$), period ($P = 0.03$), SEM = 7.33. Acetate-to-Propionate: diet ($P = 0.07$), diet × hour ($P = 0.26$), hour ($P = 0.36$), period ($P = 0.58$), SEM = 0.30.

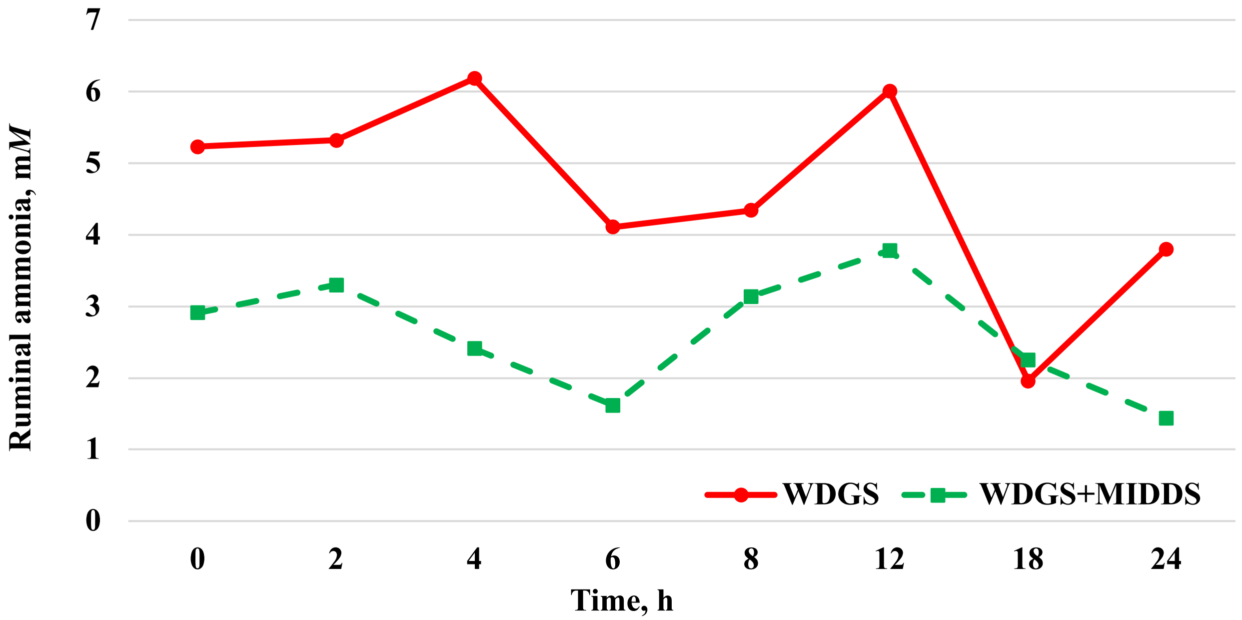

Figure 4.5. ***Effects of WDGS or WDGS+MIDDS inclusion on ruminal ammonia concentrations in finishing steers*****.** Diet ($P = 0.03$), Diet × hour ($P = 0.24$), hour ($P = 0.01$), period ($P = 0.95$), SEM = 1.196.

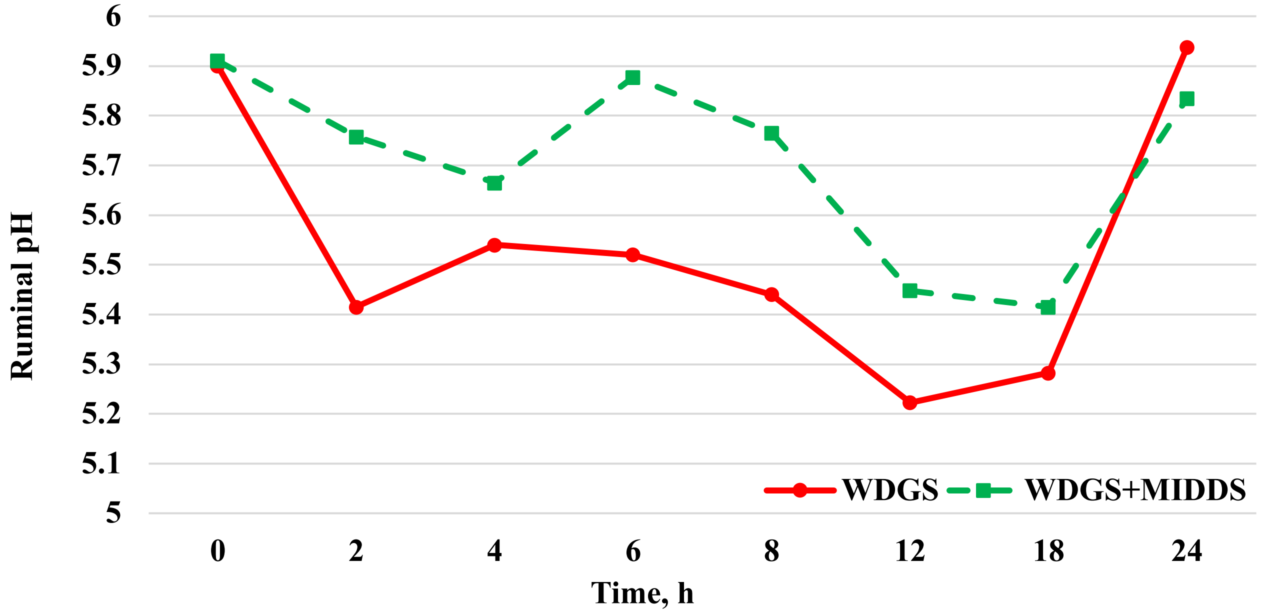

***Figure 4.6 Effects of WDGS or WDGS+MIDDS inclusion on ruminal pH in finishing steers*.** Diet ($P = 0.02$), Diet × hour ($P = 0.68$), hour ($P < 0.01$), period ($P = 0.12$), SEM = 0.060.

Chapter 5 - A six-year evaluation of prescribed-fire timing on yearling cattle growth performance and plant community dynamics on native tallgrass prairie in the Kansas Flint Hills

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Lay Summary

Cost-effective, comprehensive, and enduring solutions for noxious weed control on native range have been difficult to identify. Alexander et al. (2021) recently compared conventional spring prescribed fire with prescribed fire conducted in late summer for noxious weed control in tallgrass prairie. They reported that routine use of summer prescribed fire produced improved control of sericea lespedeza (a non-native forb) and woody-stemmed plant species with positive effects on native forb diversity compared with spring prescribed fire. Similarly, Reemts et al. (2019) indicated that a single, summer-season prescribed fire conducted on two mixed-grass prairie sites in central Texas provided control of yellow bluestem three years post treatment. Land managers, while welcoming the potential benefits of summer prescribed fire, have expressed concern that the substantial growth-performance advantage documented for grazing cattle (≈14 kg of bodyweight) following application of spring-season prescribed fire would be lost if prescribed fire application was moved to late summer. Our six-year evaluation of plant community dynamics and growth rate of yearling beef steers grazing native, tallgrass prairie provided evidence that summer-season prescribed fire resulted in positive to neutral effects on native plant populations and equivalent final body weights for grazing yearling cattle compared to spring-season prescribed fire.

Teaser Text

A six-year experiment was conducted to evaluate the effects of unconventional applications of prescribed fire on growth performance of grazing yearling beef cattle and plant community composition in native tallgrass prairie. We present evidence that summer-season prescribed fire allowed similar final body weights for grazing yearling cattle and produced positive to neutral effects on native plant populations compared to conventional spring-season prescribed fire.

Abstract

A six-year experiment was conducted to determine the effects of prescribed-fire season on stocker cattle growth performance and rangeland plant community characteristics in the Kansas Flint Hills. Eighteen pastures were grouped by watershed and each watershed was randomly assigned to 1 of 3 prescribed-fire treatments: spring (11 April ± 5.7 d), summer (25 August ± 6.2 d), or autumn (2 October ± 9.0 d). All burns were applied prior to grazing in years 1, 2, 3, and 5; however, no burns were applied in year 4 because of unfavorable burn conditions. Over 5 consecutive grazing seasons, 1,939 yearling stocker calves (initial BW = 281 ± 58.9 kg) were grazed from May to August at a targeted stocking density of 280 kg live-weight $\cdot$ ha^{-1}. Beginning in June of 2018 (pretreatment), a permanent 100-m transect was established in each pasture and was used to determine plant-species composition using a modified step-point method. Forage biomass accumulation and root carbohydrate concentrations of 4 native tallgrass plant species were also measured. All data was analyzed as a completely randomized design using a mixed-model. Average daily gain (ADG) was 0.05 to 0.07 kg greater ($P = 0.02$) for calves grazing spring-burned pastures compared with calves grazing summer- or autumn-burned pastures; however, ADG did not differ ($P \geq 0.55$) between calves assigned to the summer or autumn prescribed-fire treatments. Basal cover of all graminoids and all forbs did not differ ($P \geq 0.30$) among prescribed-fire treatments; however, basal cover of C3 grasses tended ($P = 0.06$) to be greater while basal cover of C4 grasses tended ($P = 0.08$) to be less in autumn-burned pastures compared with spring-burned pastures. Forage biomass accumulation did not differ ($P = 0.58$) among treatments. In addition, root starch or root water-soluble carbohydrate concentrations in big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), or purple prairieclover (*Dalea purpurea*) did not differ ($P \geq 0.26$) among prescribed-fire treatments. Overall, we interpreted these data to suggest that prescribed-fire timing had small influences on yearling stocker cattle growth performance and rangeland plant composition but did not influence forage biomass accumulation or root carbohydrate concentrations of key native tallgrass plant species in the Kansas Flint Hills.

Key words: grazing, *Lespedeza cuneata,* prescribed fire, rangeland plant composition, stocker cattle growth performance

Introduction

The Kansas Flint Hills are the largest intact remnant of tallgrass prairie in the world (Samson and Knopf, 1994). During Euro-American settlement, the shallow, rocky soils made the area unsuitable for cultivation; however, ranchers in the mid-1800s realized that cattle grazing native warm-season grasses in the region could achieve weight gains of 90 to 136 kg during the growing season. In addition, cattle that grazed burned pastures had greater weight gains compared with those that grazed non-burned pastures (Anderson, 1953). Early research evaluating prescribed-fire timing led to the almost-exclusive recommendation that fire should be applied in mid- to late April because of improvements in stocker cattle weight gains (Smith and Owensby, 1978), increased native warm-season grass production (Anderson et al., 1970; Towne and Owensby, 1984), and reductions in invasive woody-stemmed plant species (Owensby et al., 1973).

Today, approximately 850,000 ha of native Flint Hills rangeland are burned annually between mid-March and early May (KDHE, 2022). Fires applied in March and April accounted for 74 to 93% of annual prescribed-fire detections in the Flint Hills between 2007 and 2018

(Baker et al., 2019). Although spring-season prescribed fire is widely practiced in the Flint Hills, smoke management during this period can be difficult. Strong spring-season winds and low relative humidity typically reduce the number of days available to safely conduct a burn to the extent that up to 40,000 ha can be burned in a single day (Baldwin et al., 2022). Smoke produced from burning large amounts of rangeland can travel to urban areas downwind of the Flint Hills and reduce air quality. Smoke contains fine particulate matter and precursors for ozone which can negatively impact human health (KDHE, 2010).

Another challenge associated with spring-season prescribed fire is the inability of spring fire to control sericea lespedeza (*Lespedeza cuneata*). Sericea lespedeza is a perennial legume that was originally brought to southeast Kansas in the 1930s (Ohlenbusch et al., 2007). Soon after its introduction, sericea lespedeza expanded into Kansas and has degraded approximately 190,000 ha of native rangeland, most of which is located in the Flint Hills (KDA, 2022). The Flint Hills are predominantly grazed by beef cattle and attempts to manage sericea lespedeza infestations via grazing have been ineffective because high concentrations of condensed tannins in the plant discourage herbivory by cattle (Preedy et al., 2013; Sowers et al., 2019). In addition, spring-season prescribed fire may stimulate sericea lespedeza germination which further promotes its establishment in native rangelands (Wong et al., 2012).

Currently, Flint Hills ranchers typically apply a spring-season prescribed fire in April and then graze yearling beef cattle at a high relative stocking density (i.e., intensive-early stocking) for 75 to 100 days. Intensively grazing mature ewes for 60-days after cattle grazing reduced basal cover of sericea lespedeza, reduced sericea seed production, and appeared to be a sustainable strategy for sericea control (Lemmon et al., 2023); however, this practice has not been widely adopted in the Flint Hills. Herbicide application temporally reduced basal cover of sericea lespedeza; however, routine use of herbicides can have negative impacts on non-target native forbs (Gatson, 2018).

When prescribed fire application was shifted from April to August or September, sericea lespedeza basal cover, biomass, and seed production were sharply reduced compared with traditional spring-season prescribed fire. In addition, native forb diversity was greater in plots burned in August or September compared with those burned in April (Alexander et al., 2021). Similar experiments have also reported improved forb diversity, reduced cover of woody plants (Weir and Scasta, 2017) and reduced cover of yellow bluestem (*Bothriochloa ischaemum*; Reemts et al. 2019) when fire was applied in late summer or early autumn (i.e., September – October). Widespread adoption of growing season prescribed fires in the Kansas Flint Hills have met resistance because of perceived effects of fire applied later in the year on stocker cattle growth performance and possible protracted stress on warm-season forage grasses. Therefore, the objectives of this experiment were to document the effects of prescribed fires applied in spring, summer, or autumn on stocker cattle growth performance, rangeland plant composition, forage biomass accumulation, and root carbohydrate concentrations in key native tallgrass plant species over a six-year period.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee reviewed and approved all animal handling and animal care practices used. All animal procedures were conducted in accordance with the Guide for the Care and Use of Animals in Agricultural Research and Teaching (FASS, 2010).

Our experiment was conducted at the Kansas State University Beef Stocker Unit between June 2018 and August 2023. Eighteen pastures were grouped by watershed and each watershed was assigned randomly to 1 of 3 prescribed-fire treatments: spring (11 April ± 5.7 d), summer (25 August ± 6.2 d), or autumn (2 October ± 9.0 d). Pastures ranged in size from 16 to 30 ha and had previously been managed using annual spring-season prescribed fire followed by a 90-day intensive-early grazing season. Burn treatments were applied prior to grazing in years 1, 2, 3, and 5; however, no burn treatments were applied in year 4 due to unfavorable burn conditions. A more detailed description of the study location and burn conditions used to conduct the experiment is described by Duncan et al. (2021).

Animal performance

A total of 1,939 yearling beef calves (initial BW = 281 ± 58.9 kg) were grazed over 5 consecutive growing seasons. Calves were grazed for 90 d from May to August at a targeted stocking density of 280 kg live weight $\cdot$ ha^{-1}. Based on cattle availability, heifers were grazed in year 1 and steers were grazed in years 2 to 5. Initiation and termination of grazing varied slightly from year to year based on cattle availability. At receiving, calves were individually weighed using a hydraulic squeeze chute (Silencer, Moly Manufacturing Inc., Lorraine, KS). Initial body weights (BW) were recorded, visual identification tags were applied, and calves were stratified by weight and randomly assigned to pasture and treatment. All cattle were fed a high-roughage growing diet at 2.0% of BW for a minimum of 14 d until turnout for grazing. The day grazing began, calves were reweighed individually to determine initial BW. In addition, all calves received a growth-promoting implant (Ralgro, Merck Animal Health, Rahway, NJ). At the completion of the grazing season, each pasture was gathered and individual weights were immediately measured. The livestock scale used to measure individual weights was validated annually in April (Salina Scale, Inc. Salina, KS).

Botanical composition

In 2018 (pretreatment), a permanent 100-m transect was established in each pasture. Transects were established exclusively on Benfield-Florence complex soils in areas with less than 2% slope. Each transect point (i.e., endpoints and center) was marked with orange survey stakes (Forestry Suppliers, Inc., Jackson, MS) and GPS coordinates were recorded (Garmin eTrex 20x, Olathe, KS). Soil cover and botanical composition was evaluated annually in June along each transect using a modified step-point technique (Owensby, 1973; Farney et al., 2017). Using a step-point device, a point was randomly selected on the ground at 2-m intervals along both sides of each transect (i.e., 100 total points per transect; Owensby, 1973). Each point was first characterized as a hit on bare soil, litter, or live basal plant matter to determine soil cover. Next, the closest rooted plant (i.e., grass, forb, or shrub) in a 180° arc in front of the selected point was recorded. If the closest rooted plant was a grass, then the closest rooted forb or shrub was recorded. Plant species composition was then calculated as described by Farney et al. (2017). Common and scientific names were those recommended by Haddock (2005).

Plant species were grouped into categories based on their growth form as described by Hickman et al. (2004). Categories included total C4 grasses, C4 perennial tall grasses, C4 perennial mid-grasses, C4 perennial short grasses, C3 perennial grasses and sedges, annual forbs, perennial forbs, and shrubs. In addition, plant species were also categorized as native graminoids, introduced graminoids, native forbs, introduced forbs, leguminous forbs, nectar-producing forbs, increaser shrubs (i.e., shrubs that tend to proliferate in response to grazing; Vesk and Westoby, 2001), and nectar-producing shrubs.

Forage biomass

Forage biomass accumulation was evaluated in late June to early July in 2018, 2020, and 2022. Ten 50 × 50-cm clipping frames were randomly placed alongside each transect at 10-m intervals beginning at the south or east end. Once placed, litter from the previous growing season was removed and all remaining vegetation was clipped 1 cm above the soil surface. All samples were weighed, dried in a forced-air oven (50ºC; 96 h), and reweighed to estimate standing forage dry matter · ha^{-1}.

Root carbohydrate reserves

Root starch and root water-soluble carbohydrate concentrations of big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), and purple prairieclover (*Dalea purpurea*) were measured in mid-June from 2018 to 2021. A steel spading fork (Bully Tools, Steubenville, OH) was used to collect approximately 60 g of roots and rhizomes to a depth of 20 cm from each targeted species within each pasture. Following collection, samples were placed in bags within individual plant species and stored in coolers. Subsequently, samples were washed with tap water, separated from the aerial portion of the plant, and dried in a forced-air oven (50ºC; 96 h). Once dry, samples were sent to a commercial laboratory (Dairy 1, Ithaca, NY) for root starch and water-soluble carbohydrate analysis. Water-soluble carbohydrate concentrations were determined as described by Hall et al. (1999) using a Thermo Scientific Genesys 10s Vis Spectrophotometer. Root starch concentrations were determined by incubating samples in a water bath at 40ºC and filtering them through Whatman no. 41 filter paper. Residues were then autoclaved, incubated with a glucoamyalse enzyme, and analyzed using a YSI 2700 SELECT Biochemistry Analyzer (YSI Inc. Life Sciences, Yellow Springs, OH).

Statistical analysis

All data were analyzed as a completely randomized design using a mixed-model (PROC MIXED; SAS 9.4, SAS Inst. Inc, Cary, NC). Class variables included burn treatment, year, and pasture. The initial model contained fixed effects for treatment, year, and treatment × year and a random effect for pasture within treatment. No treatment × year interactions were significant (*P* > 0.10) for yearling growth performance, forage biomass accumulation, root carbohydrate concentrations, or major classifications of range plants; therefore, the final models relevant to those data categories contained a term for treatment only as a fixed effect and year and pasture within treatment as random effects. In the case of individual range plant species, occasional treatment differences or tendencies (treatment × time - *P* ≤ 0.10) in basal cover were observed over time. As these phenomena were not associated with temporal trends in basal cover and appeared to be ephemeral, main-effect means of basal cover were reported for hairy grama (*Bouteloua hirsuta*), Indiangrass, Kentucky bluegrass (*Poa pratensis*), prairie junegrass (*Koeleria macrantha*), sideoats grama (*Bouteloua curtipendula*), leadplant (*Amorpha canescens*), and New Jersey tea (*Ceanothus americanus*).

When protected by a significant *F*-test (*P* ≤ 0.05), treatment means were separated using the method of Least Significant Difference. Significance was declared at *P* ≤ 0.05 and tendencies at 0.05 ≤ *P* ≤ 0.10.

Results and Discussion

Animal performance

After 5 consecutive grazing seasons total BW gains and ADG were greater (*P* = 0.02; Table 5.1) for calves grazing spring-burned pastures compared with calves grazing summer- or autumn-burned pastures; however, total BW gains and ADG were similar (*P* ≥ 0.55) among calves grazing summer- and autumn-burned pastures. Total BW gains during the 90-day grazing period averaged 96.6, 91.5, and 90.3 kg for the spring, summer, and autumn prescribed-fire treatments, respectively. Initial BW did not differ (*P* = 0.23) among treatments; moreover, final BW did not differ (*P* = 0.36) between spring and summer prescribed-fire treatments but both were greater (*P* = 0.02) than that of the autumn prescribed-fire treatment.

Previous reports indicated that yearling stocker cattle weight gains were greater for cattle grazing burned pastures compared with non-burned pastures (Woolfolk et al., 1975; Svejcar, 1989; McCollum et al., 1992). Early research in the Kansas Flint Hills suggested that ranchers should apply prescribed fire during mid- to late April to maximize growth performance under intensive-early stocking management (Anderson et al., 1970; Smith and Owensby, 1978). In our experiment, total BW gains were 5.1 to 6.3 kg less for calves grazing summer- and autumn-burned pastures compared with calves grazing spring-burned pastures, respectively. McMillan et al. (2022) observed a 24 kg reduction in BW gain in yearling cattle grazing pastures burned in August-September compared with pastures burned in March-April. In that experiment, calves were grazed from April to September and burn treatments were applied to one-third of the pasture each year; growing-season burns were not applied prior to grazing in year 1 but were subsequently applied during the grazing season throughout the remainder of the three-year experiment. In our experiment, grazing was always preceded by fire application. Differences in study design likely contributed to the difference in weight gains observed for stocker cattle grazing pastures burned during the growing season.

Soil cover

Differences in cattle growth performance among prescribed-fire treatments may have been associated with diet quality. Proportions of litter on the soil surface were greatest ($P \leq 0.04$;

Table 5.2) in the summer prescribed-fire treatment, intermediate ($P \leq 0.04$) in the autumn prescribed-fire treatment, and least ($P \leq 0.01$) in the spring prescribed-fire treatment. Overall, litter on the soil surface was 6.5 and 11.6% greater in autumn- and summer-burned pastures, respectively, compared with spring-burned pastures. Diets selected by calves assigned to the autumn or summer prescribed-fire treatments may have contained small amounts of dead plant material from the previous growing season which could have contributed to the slightly reduced growth performance we observed.

Conversely, proportions of bare soil were greater ($P \leq 0.01$; Table 5.2) in the spring prescribed-fire treatment compared with the summer or autumn prescribed-fire treatments. Soil cover was measured annually in June; therefore, as the length of time between fire application and sample collection increased, proportions of litter on the soil surface increased while proportions of bare soil decreased. Despite this observation, basal vegetation cover did not differ ($P = 0.19$) among pastures burned in spring, summer, or autumn and accounted for 12 to 13.3% of total area.

Botanical composition

Basal cover of total graminoids represented 86 to 89% of total basal plant cover and did not differ ($P = 0.30$; Table 5.3) among prescribed-fire treatments. Similarly, basal cover of native and introduced graminoids did not differ ($P \geq 0.24$) among spring-, summer-, or autumn-burned pastures; however, prescribed-fire season tended to influence relative basal cover of C3 and C4 grasses. Basal cover of C3 grasses tended to be greater ($P = 0.06$) in the autumn prescribed-fire treatment, intermediate in the summer prescribed-fire treatment, and least in the spring prescribed-fire treatment.

The trend toward increased basal cover of C3 grasses in autumn-burned pastures was associated with temporal changes to Kentucky bluegrass (non-native) and prairie junegrass (native) populations. Kentucky bluegrass basal cover was greater ($P < 0.02$; Table 5.3) in pastures burned in autumn compared with pastures burned in spring; summer-burned pastures were intermediate to and not different from those burned in spring or autumn. A similar trend was observed for basal cover of prairie junegrass where it tended ($P = 0.08$) to be greater in autumn-burned pastures compared with spring-burned pastures.

Towne and Owensby (1984) and Towne and Kemp (2008) reported a reduction in basal cover of Kentucky bluegrass following fire application in March, April, July, or December. Conversely, basal cover of prairie junegrass and sedges increased when fire was applied in February or November (Towne and Craine, 2014). In addition, basal cover of sedges was 19.7% greater in watersheds burned in late July or early August every other year compared with watersheds burned annually in April (Towne and Kemp, 2008). Overall, it appears that shifting prescribed fire from April to August or October resulted in minor changes to basal cover of certain C3 graminoid species. Sedge species, the predominant C3 graminoids in the region (Table 3), accounted for 1.9 to 3.4% of grazed yearling-steer diets in the Kansas Flint Hills (Sowers et al., 2019), indicating that stocker cattle will consume C3 forages, including sedges, if they are available. In addition, increased presence of C3 grasses could potentially extend the current Flint Hills grazing season outside of the traditional May to August period.

Total basal cover of C4 grasses tended ($P = 0.08$; Table 5.3) to be greatest in spring-burned pastures, intermediate in summer-burned pastures, and least autumn-burned pastures. Within C4-grass growth forms, basal cover of total C4 tallgrasses did not differ ($P = 0.35$) among prescribed-fire treatments; however, prescribed-fire season appeared to influence basal cover of Indiangrass. Basal cover of Indiangrass was greater ($P < 0.01$) in the summer prescribed-fire treatment compared with the spring or autumn prescribed-fire treatments. Alexander et al. (2021) observed a similar trend where basal cover of Indiangrass was greatest in plots burned in August, intermediate in plots burned in April, and least in plots burned in September. Indiangrass produces biannual tillers and the percentage of 1st-year tillers are greatest towards the end of the growing season (McKendrick et al., 1975). Fire applied in September or October could potentially damage 1st-yr tillers and reduce the propagation potential of Indiangrass populations.

Basal cover of C4 mid- and shortgrasses was greater ($P \leq 0.03$; Table 5.3) in spring-burned pastures compared with summer- or autumn-burned pastures. Within C4 mid-grasses, basal cover of little bluestem was less ($P < 0.01$) in the summer prescribed fire treatment compared with the spring prescribed-fire treatment. Conversely, basal cover of sideoats grama was greatest ($P = 0.04$) in summer-burned pastures, least in autumn-burned pastures, and intermediate in spring-burned pastures. Reemts et al. (2019) reported that cover of yellow bluestem, a non-native C4 mid-grass, was reduced in plots treated with late-summer prescribed fire compared with non-burned plots. Basal cover yellow of bluestem did not differ ($P = 0.45$) among prescribed-fire regimes evaluated in our experiment likely due to small relative cover values; however, it was present within all pastures at the initiation of our prescribed-fire treatments in 2018 (data not shown). After repeated prescribed-fire applications, yellow bluestem remained along transects treated with spring fire but was not detected along transects treated with summer or autumn fire. Within C4 shortgrasses, basal cover of hairy grama tended ($P = 0.08$) to be greatest in spring-burned pastures, intermediate in summer-burned pastures, and least in autumn-burned pastures. Overall, these data demonstrated that prescribed fire timing was associated with minor changes to basal cover of certain C4 graminoid plant species.

Basal cover of total, native, introduced, annual, perennial or leguminous forbs did not differ ($P \geq 0.12$; Table 5.4) among spring-, summer-, or autumn-burned pastures; however, basal cover of nectar-producing forbs was greater ($P = 0.02$) in the autumn prescribed-fire treatment compared with the spring and summer prescribed-fire treatments. Similar trends have been observed in previous reports. Weir and Scasta (2017) reported that fires applied in September-October increased forb cover compared with fire applied at other times during the year, whereas Alexander et al. (2021) indicated that forb diversity was greater in plots burned in August or September compared with plots burned in April. Duncan et al. (2021) noted also that annual forbs and nectar-producing forbs were present in greater proportions in autumn-burned pastures compared with those burned in spring or summer. The consistency of these reports may indicate a potential habitat benefit of late summer or autumn prescribed burning to grassland-obligate invertebrates and the native birds that feed upon them (Ogden et al., 2019).

In our final analysis, sericea lespedeza basal cover was not different ($P = 0.43$; Table 5.4) between prescribed fire treatments. It was present in small amounts on all pastures before fire treatments were applied in 2018; however, it decreased to levels below detection by our third year of data collection on pastures burned in summer or autumn. Sericea lespedeza remained through the end of the experiment on pastures burned exclusively in the spring.

Basal cover of total shrubs tended ($P = 0.06$; Table 5.4) to be greater in summer- and autumn-burned pastures compared with spring-burned pastures. The trend for increased basal cover of shrubs in the autumn and summer prescribed-fire treatments was associated with changes in basal cover of leadplant and New Jersey tea. At the end of our experiment, basal cover of leadplant tended (*P* = 0.10) to be greatest in the autumn-fire treatment, intermediate in the summer-fire treatment, and least in the spring-fire treatment. In addition, basal cover of New Jersey tea was numerically greater (*P* = 0.14) in summer-burned pastures compared with spring- or autumn-burned pastures. The slight increase in basal cover of leadplant and new jersey tea, both desirable shrubs for livestock forage and wildlife habitat, contributed a minimum of 85% to total basal cover of all shrubs. Basal cover of increaser shrubs (i.e., shrubs that tend to proliferate in response to grazing) tended (*P* = 0.08) to be greater in autumn-burned pastures compared with spring-pastures; however, basal cover of increaser shrubs was small and accounted for less than 0.25% of total basal cover in autumn-burned pastures.

Forage biomass accumulation

Towne and Owensby (1984) reported that prescribed-fire timing influenced forage biomass production in the Kansas Flint Hills. Between 1968 and 1982, average forage biomass measured in October was greater in plots burned in mid-spring (10 April) or late spring (1 May) compared with plots burned in early spring (20 March) or winter (1 December). In our experiment, forage biomass accumulation measured in late June to early July did not differ (*P* = 0.58; Table 5.1) among prescribed-fire treatments. Similarly, Towne and Craine (2014) reported no differences in grass production at the end of the growing season among pastures burned in February, April, or November over a 20-year period. In addition, July standing forage biomass did not differ between plots burned in April, August, or September (Alexander et al., 2021) or in pastures burned in April, August, or October (Duncan et al., 2021). We interpreted these data to suggest that prescribed fire applied at different time points throughout the growing season had minimal impact on forage biomass accumulation in the Kansas Flint Hills.

Root carbohydrate reserves

According to the report by Sowers et al. (2019), big bluestem, little bluestem, Indiangrass, and purple prairie clover made up a large portion (i.e., 46 to 69%) of the diets of grazing yearling cattle in the Flint Hills. These plant species represented a significant amount of pre-treatment plant cover at our study site (Duncan et al., 2021). Following prescribed-fire application, root starch and root water-soluble carbohydrate concentrations of big bluestem, little bluestem, Indiangrass, and purple prairie clover did not differ ($P \geq 0.26$; Tables 5.5 and 5.6) among pastures burned in April, August, or October. Owensby et al., (1970) observed a rapid decline in available carbohydrates in rhizomes and stem bases of big bluestem from April to mid-May; however, when plant growth slowed, carbohydrate concentrations began to increase and peaked for non-grazed, burned plots in mid-June. We interpreted similar root starch and root water-soluble concentrations measured in mid-June to suggest that prescribed-fire timing in our experiment had minimal impacts on the ability of big bluestem, little bluestem, Indiangrass, or purple prairie clover to resynthesize root carbohydrates following periods of rapid growth.

Conclusions

Shifting prescribed-fire timing from April to August or October reduced yearling stocker cattle weight gains by 5.1 to 6.3 kg over a 90-day grazing period and was associated with small but benign changes in rangeland plant composition. Conversely, prescribed fire timing did not influence forage biomass accumulation or root carbohydrate concentrations in key native tallgrass plant species. Overall, Flint Hills ranchers are encouraged to consider the costs associated with sericea lespedeza and yellow bluestem control using herbicides, as opposed to summer or autumn prescribed burning, versus the income sacrifice associated with small reductions in stocker-cattle growth performance.

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Tables

Table 5.1 Effects of prescribed-fire season on yearling stocker cattle growth performance and forage biomass accumulation in the Kansas Flint Hills.

	Prescribed fire season[1]				
Item	Spring	Summer	Autumn	SEM[2]	*P*-value[3]
Initial bodyweight, kg	287	290	285	2.7	0.23
Final bodyweight, kg	384^a	382^a	376^b	2.5	0.01
Total bodyweight gain[4], kg	96.6^a	91.5^b	90.3^b	2.10	0.02
Average daily gain[5], $kg \cdot d^{-1}$	1.07^a	1.02^b	1.00^b	0.023	0.02
Forage biomass[6], $kg \cdot ha^{-1}$	1968	2151	2210	240.4	0.58

[1] Eighteen pastures were grouped by watershed and randomly assigned to 1 of 3 prescribed-fire treatments: spring (11 April ± 5.7 d), summer (25 August ± 6.2 d), or autumn (2 October ± 9.0 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight $\cdot$ ha^{-1} following prescribed fire application.

[2] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[3] Treatment main effect.

[4] Calculated as final body weight – initial body weight.

[5] Calculated as total body weight gain ÷ total grazing days.

[6] Measured in late June to early July in 2018, 2020, and 2022.

[a, b] Within rows, means with unlike superscripts differ ($P \leq 0.05$).

Table 5.2 Effects of prescribed-fire season on proportions of bare soil, litter on the soil surface, and basal plant cover on native tallgrass prairie measured annually in June.

	Prescribed fire season[1]				
Item, % total area	Spring	Summer	Autumn	SEM[2]	*P*-value[3]
Bare soil	66.0[a]	55.7[b]	59.8[b]	2.40	< 0.01
Litter cover	20.7[c]	32.3[a]	27.2[b]	2.33	< 0.01
Basal vegetation cover	13.3	12.0	13.0	0.70	0.19

[1] Eighteen pastures were grouped by watershed and randomly assigned to 1 of 3 prescribed-fire treatments: spring (11 April ± 5.7 d), summer (25 August ± 6.2 d), or autumn (2 October ± 9.0 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight ∙ ha^{-1} following prescribed fire application.

[2] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[3] Treatment main effect.

[a, b, c] Within rows, means with unlike superscripts differ ($P \leq 0.05$).

Table 5.3 Effects of prescribed-fire season on graminoid composition in native tallgrass prairie measured annually in June.

	Prescribed fire season[1]				
Item, % basal plant cover	Spring	Summer	Autumn	SEM[2]	*P*-value[3]
Total graminoid cover	89.4	89.3	85.8	2.53	0.30
Native graminoids	85.0	85.2	80.0	3.41	0.24
Introduced graminoids	4.3	4.1	5.8	2.46	0.74
C3 grasses	19.2^{z}	26.1^{yz}	27.2^{y}	3.44	0.06
Sedges	13.9	19.6	16.3	2.80	0.15
Kentucky bluegrass	2.0^{b}	4.1^{ab}	5.8^{a}	1.25	0.02
Prairie junegrass	0.9^{z}	1.3^{yz}	2.5^{y}	0.69	0.08
C4 grasses	70.1^{y}	63.2^{yz}	58.7^{z}	4.79	0.08
Tallgrasses	33.8	37.3	35.1	2.37	0.35
Big bluestem	20.5	19.9	22.1	1.59	0.62
Indiangrass	12.5^{b}	15.9^{a}	11.5^{b}	1.19	< 0.01
Mid-grasses	33.1^{a}	25.0^{b}	22.3^{b}	3.73	0.02
Little bluestem	14.5^{a}	7.9^{b}	10.7^{ab}	2.15	0.03
Sideoats grama	13.0^{ab}	14.9^{a}	7.8^{b}	2.68	0.04
Yellow bluestem	2.2	0.0	0.0	2.06	0.45
Shortgrasses	3.1^{a}	0.8^{b}	1.2^{b}	0.83	0.03
Hairy grama	2.3^{y}	0.6^{yz}	0.5^{z}	0.79	0.08

[1] Eighteen pastures were grouped by watershed and randomly assigned to 1 of 3 prescribed-fire treatments: spring (11 April ± 5.7 d), summer (25 August ± 6.2 d), or autumn (2 October ± 9.0 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight $\cdot$ ha^{-1} following prescribed fire application.

[2] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[3] Treatment main effect.

[a, b] Within rows, means with unlike superscripts differ ($P \leq 0.05$).

[y, z] Within rows, means with unlike superscripts tended to differ ($P \leq 0.10$).

Table 5.4 Effects of prescribed-fire season on forb and shrub composition in native tallgrass prairie measured annually in June.

	Prescribed fire season[1]				
Item, % basal plant cover	Spring	Summer	Autumn	SEM[2]	*P*-value[3]
Total forb cover	10.11	9.55	12.59	2.526	0.47
Native forbs	9.97	9.47	12.58	2.401	0.40
Introduced forbs	0.14	0.07	0.01	0.131	0.58
Annual forbs	0.39	0.56	0.98	0.258	0.12
Perennial forbs	9.77	9.01	11.66	2.386	0.53
Leguminous forbs	1.37	0.29	0.68	1.047	0.57
Nectar-producing forbs	1.46^{b}	1.64^{b}	2.66^{a}	0.414	0.02
Sericea lespedeza	0.14	0.00	0.00	0.129	0.43
Total shrub cover	0.50^{z}	1.20^{y}	1.58^{y}	0.438	0.06
Leadplant	0.48^{z}	0.87^{yz}	1.33^{y}	0.376	0.10
New Jersey tea	0.01	0.21	0.01	0.112	0.14
Increaser shrubs[4]	0.02^{z}	0.12^{yz}	0.24^{y}	0.092	0.08
Nectar-producing shrubs	0.48	1.09	1.34	0.400	0.11

[1] Eighteen pastures were grouped by watershed and randomly assigned to 1 of 3 prescribed-fire treatments: spring (11 April ± 5.7 d), summer (25 August ± 6.2 d), or autumn (2 October ± 9.0 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight $\cdot$ ha^{-1} following prescribed fire application.

[2] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[3] Treatment main effect.

[4] Shrubs that tend to proliferate in response to grazing (Vesk and Westoby, 2001).

[a, b] Within rows, means with unlike superscripts differ ($P \leq 0.05$).

[y, z] Within rows, means with unlike superscripts tended to differ ($P \leq 0.10$).

Table 5.5 Effects prescribed-fire season on root starch concentrations (% DM) in big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), and purple prairie clover (*Dalea purpurea*) during mid-June from 2018 to 2021.

	Prescribed fire season[1]				
Item	Spring	Summer	Autumn	SEM[2]	*P*-value[3]
Big bluestem	2.25	2.78	1.89	0.685	0.44
Little bluestem	1.44	1.52	1.19	0.427	0.73
Indiangrass	2.65	1.83	1.64	0.920	0.51
Purple prairie clover	4.39	3.45	3.50	0.899	0.50

[1] Eighteen pastures were grouped by watershed and randomly assigned to 1 of 3 prescribed-fire treatments: spring (11 April ± 5.7 d), summer (25 August ± 6.2 d), or autumn (2 October ± 9.0 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight ⋅ ha^{-1} following prescribed fire application.

[2] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[3] Treatment main effect.

Table 5.6 Effects prescribed-fire season on root water-soluble carbohydrate concentrations (% DM) in big bluestem (*Andropogon gerardii*), little bluestem (*Schizachyrium scoparium*), Indiangrass (*Sorghastrum nutans*), and purple prairie clover (*Dalea purpurea*) during mid-June from 2018 to 2021.

	Prescribed fire season[1]				
Item	Spring	Summer	Autumn	SEM[2]	*P*-value[3]
Big bluestem	3.33	4.29	3.93	0.585	0.26
Little bluestem	3.16	4.11	3.14	0.728	0.33
Indiangrass	4.83	3.59	4.02	0.991	0.45
Purple prairie clover	4.37	3.61	4.91	0.809	0.30

[1] Eighteen pastures were grouped by watershed and randomly assigned to 1 of 3 prescribed-fire treatments: spring (11 April ± 5.7 d), summer (25 August ± 6.2 d), or autumn (2 October ± 9.0 d). Yearling beef cattle were grazed on all pastures from May to August at a targeted stocking density of 280 kg live-weight • ha^{-1} following prescribed fire application.

[2] Mixed-model standard error of the mean (SEM) associated with comparison of treatment main-effect means.

[3] Treatment main effect.