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Effects of feeding a novel alfalfa leaf pellet product (ProLEAF MAX) and alfalfa stems (ProFiber Plus) on performance in the feedlot and carcass quality of beef steers

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ABSTRACT: Alfalfa is often included in the diets of beef animals; however, the nutrient content of alfalfa is variable depending on the region in which it is grown, climate, soil, and many other factors. The leaf portion of alfalfa has a less variable nutrient composition than the stem portion of the plant. The variability that is present in the alfalfa plant can make the development of total mixed rations of consistent nutrient content difficult. As such, the purpose of this study was to determine how the inclusion of fractionated alfalfa leaves and alfalfa stems impacts performance and carcass quality of finishing beef steers. Twenty-four steers were allocated to one of three treatments: a control group fed a typical finishing diet with alfalfa as the forage (CON; $n = 8$), a typical diet that replaced alfalfa with fractionated alfalfa leaf pellets and alfalfa stems (ProLEAF MAX™ + ProFiber Plus™; PLM+PFP; $n = 8$), or a typical diet that replaced alfalfa with alfalfa stems (PFP; $n = 8$) for 63 days. Steers were fed individually once daily, weighed every 14 days and ultrasound images were collected every 28 days. At the end of the feeding trial, steers were harvested at a commercial facility and carcass data was obtained. Analysis of dry matter intake demonstrated that steers receiving the PFP and CON diets consumed more feed ($P < 0.001$) than steers consuming the PLM+PFP diet. Steers receiving the PLM+PFP diet gained less ($P < 0.001$) weight than the steers receiving the other two dietary treatments. No differences ($P > 0.10$) in feed efficiency or carcass characteristics were observed. Steers receiving the PFP diet had improved ($P = 0.016$) cost of gain ($0.93 per kg) when compared with steers receiving PLM+PFP ($1.08 per kg) diet. Overall, our findings demonstrate that the inclusion of PFP in place of alfalfa hay in a finishing diet has the potential to improve cost of gain, without negatively affecting growth, performance, or carcass characteristics of finishing feedlot steers.

Key words: beef, carcass quality, finishing steers, fractionated alfalfa, growth

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INTRODUCTION

In a beef operation, feed accounts for the majority of total beef production costs (Hill, 2012). As such, the beef industry is continuously working

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to increase feed efficiency (FE) (Lines et al., 2018). Alfalfa is a common feedstuff included in the diets of many livestock species (Sen et al., 1998), including cattle. Alfalfa provides a source of protein, fiber, and other nutrients (Apostal et al., 2017). Alfalfa leaves have a high-protein content and alfalfa stems are high in fiber (Palmonari et al., 2014). Alfalfa ranges from 12 to 20% crude protein, depending on the stage of maturity (Balliette and Torell, 2015) with alfalfa leaf protein only slightly declining with maturity and alfalfa stem protein declining to a much greater extent (Sheaffer et al., 2000). Crude fiber content is also variable depending on maturity (Church, 1977), and can range anywhere between 20 and 28% (Balliette and Torell, 2015). Alfalfa leaf neutral detergent fiber (NDF) concentration and digestibility decreases slowly with maturity and stem NDF and acid detergent fiber (ADF) increases more rapidly with an increasing maturity (Fick and Onstad, 1988). The nutrient content variability that is present in alfalfa can make the process of formulating a total mixed ration (TMR) of consistent nutrient content difficult and impact forage palatability and voluntary intake (Ademosum et al., 1968). As such, it is important to determine how novel harvesting and processing techniques, such as fractionation of alfalfa, may impact performance of livestock when included in the diet. The objective of this study was to examine the effects of including a novel alfalfa leaf pellet product [ProLEAF MAX (Scoular, Omaha, NE); PLM; (Pratt and Jackson, 2018)] and a novel alfalfa stem byproduct [ProFiber Plus; (Scoular, Omaha, NE); PFP; (Pratt and Jackson, 2018)] in the diet on feedlot performance and carcass quality of finishing beef steers when compared with steers fed a typical alfalfa hay-based feedlot diet for the Intermountain West. We hypothesized that steers consuming diets that included alfalfa leaves would have improved growth and carcass characteristics when compared with steers consuming diets that included alfalfa hay.

MATERIALS AND METHODS

Steers

All experimental procedures were approved by the Institutional Animal Care and Use Committee of Utah State University, approval number IACUC-2821, and steers were cared for in accordance with the Live Animal Use guidelines (FASS, 2010). Twenty-four Angus influenced steers that were approximately one year of age and similar in weight (420.6 kg ± 4.7 kg) were selected from the Utah State University beef herd. Twenty-four steers was the maximum capacity of the University facilities that allowed for individual intake to be measured. Steers were housed in a covered barn in individual pens with free choice access to water. Steers were implanted at the start of the trial with Synovex Choice (Zoetis, Parsippany, NJ). Synovex Choice implants 100 contain 100 mg of trenbolone acetate and 14 mg of estradiol. Steers were initially stratified by weight so that there were no differences in starting weight and then randomly assigned to one of three treatment groups. Pre-trial, steers were subjected to a 14 d adjustment period. Over the course of the adjustment period, all steers were fed a typical alfalfa-based background diet that included the following ingredients (dry matter (DM) basis): alfalfa hay (26.9%), corn silage (38.5%), barley (16.2%), high-moisture corn (15.4%), and a feedlot mineral supplement (3%). After the adjustment period, steers were fed their assigned experimental diets for an additional 63 d before harvest. During the 63 d feeding period, the experimental diets were fed in a series of two step-up diets (step-up diet and final diet) to allow for an increase in concentrate (grain) levels in the diets. The step-up diet was fed for 22 d and the final diet was fed for the final 41 d (Table 2).

The three treatment diets included corn silage, barley, high-moisture corn, a feedlot mineral supplement, and either alfalfa hay (Table 1; control; CON; n = 8), alfalfa leaf pellets and alfalfa stems (PLM+PFP; n = 8) in place of alfalfa hay, or alfalfa stems (PFP; n = 8) in place of alfalfa hay. The PLM and PFP products were included in their respective diets at concentrations required to replace the alfalfa hay in the CON diet, thus, allowing all treatment diets to have similar amounts of forage. In the PLM diet, the alfalfa hay was simply substituted for alfalfa hay and crude protein levels were matched by adding in urea. The PLM+PFP diet was designed to essentially create an ideal hay with the two products. The PLM was not included as the sole forage in its own treatment diet because the amount of physically effective fiber would not have been adequate to maintain rumen health. Forage nutrient compositions are shown in Table 1. The nutrient compositions of the treatment diets can be seen in Table 2. Each of the three diets that were fed were formulated to be isocaloric and isonitrogenous using CowBytes (Government of Alberta, Canada). Of note, although all three treatment diets were balanced to be isocaloric and isonitrogenous, analyses of the diets provided to the steers

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Table 1. Nutrient composition of forage sources[1]

	Forage source			
Item	Alfalfa hay	PLM	PFP	Corn silage
DM, %	88.30	89.85	88.52	29.20
Analysis, DM basis				
Crude protein, %	14.40	24.05	12.07	9.90
ADF, %	41.60	26.40	50.05	25.40
aNDF, %	51.20	30.20	59.58	40.08
NFC, %	27.80	30.95	22.70	42.50
TDN, %	55.30	65.35	49.94	69.80
NE_m, Mcal/kg	0.24	0.30	0.22	0.34
NE_g, Mcal/kg	0.12	0.18	0.10	0.21
Ash, %	6.66	13.20	6.38	5.63
Calcium, %	1.24	2.17	0.70	0.24
Phosphorus, %	0.19	0.33	0.24	0.20
Magnesium, %	0.28	0.35	0.22	0.14
Potassium, %	1.85	3.25	2.26	1.40
Sodium, %	0.13	0.10	0.16	0.02
Iron, mg/kg	91.00	627.50	94.00	172.00
Manganese, mg/kg	23.00	57.00	17.50	75.00
Zinc, mg/kg	15.00	24.00	16.17	27.00
Copper, mg/kg	8.00	9.00	9.33	6.00

DM, dry matter; PLM, ProLEAF MAX (Scoular, Omaha, NE); PFP, ProFiber Plus (Scoular, Omaha, NE); ADF, acid detergent fiber; NDF, neutral detergent fiber; NFC, Non-fiber carbohydrates; TDN, total digestible nutrients; NE_m, net energy for maintenance; NE_g, net energy for gain; Mcal, megacalorie

[1]Treatment diets consisted of the following ingredients: corn silage, barley, high-moisture corn, a feedlot supplement, and either alfalfa hay (CON; *n* = 8), alfalfa leaf pellets (PLM) and alfalfa stems (PFP) (PLM+PFP; *n* = 8), or alfalfa stems (PFP; *n* = 8) and were fed to finishing feedlot steers for 63 d.

showed that nutrient content of the diets slightly differed from formulated nutrient densities, likely due to inconsistencies when mixing the ration or sampling feeds (Table 2). Diets were mixed every two d and fed twice daily at 08:00 and 16:00 h. All feed ingredients for the diets, except urea and mineral supplement, were loaded into a commercial mixer, weighed, and mixed together for approximately 15 min. Because of the small amount required, both urea and the mineral supplement were pre-weighed and top dressed daily. Feed offered and feed refused were measured daily in order to determine individual daily dry matter intake (DMI) using the clean-bunk management system as described previously (Pritchard and Bruns, 2003). In brief, each individual bunk was cleaned out and feed refusals were weighed daily so that the amount of feed that was consumed in that 24-hour period could be recorded and any adjustments to the amount of feed provided to ensure animals were being fed *ad libitum* could be made. Bunks were managed to have approximately 0.9 kg of refusals per day to ensure that animals were receiving feed *ad libitum*. Every 14 d, steers were weighed at approximately 07:00 h. On d 0 and d 28, carcass ultrasound imaging was performed by a trained ultrasound technician to obtain 12th rib fat thickness (FT) and ribeye area (REA) measurements using an EXAGO ultrasound (Universal Imaging, Bedford Hills, NY) to assess growth early on in the feeding trial. Feed efficiency, calculated as gain to feed (G:F), was determined from DMI and average daily gain (ADG). Although DMI was calculated daily as described above, DMI will be presented as 14 d averages instead of daily averages in order to align with the weight gain data and calculated G:F for 14 d periods throughout the feeding period.

Harvest and Preparation of Fractionated Alfalfa Products

A self-propelled leaf combine (Pratt and Jackson, 2018) was used to fractionate the alfalfa plant into PLM, a pelleted alfalfa leaf product, and PFP, alfalfa stems. The leaf combine strips the alfalfa leaves from the standing alfalfa plant and the alfalfa leaf fraction was then transported by truck to a drying facility for curing and processing into pellets. The stem alfalfa fraction was cut, conditioned, and windrowed to be baled when dry.

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Table 2. Composition and nutrient composition of treatment diets[1]

Item	Step-up diet			Final diet		
	CON	PLM+PFP	PFP	CON	PLM+PFP	PFP
Composition of treatment diets						
Feed, % DM						
Alfalfa hay	16.5	–	–	14.0	–	–
PLM	–	16.3	–	–	13.8	–
PFP	–	6.0	16.6	–	5.8	14.0
Corn silage	24.6	21.2	24.6	13.2	10.3	13.2
Barley	27.7	26.8	27.6	35.8	34.8	35.8
High-moisture corn	27.7	26.9	27.7	33.4	32.4	33.4
Feedlot supplement[2]	2.8	2.7	2.8	2.9	2.8	2.9
Urea	0.7	–	0.7	0.3	–	0.6
Nutrient composition of treatment diets						
DM, %	59.75	63.35	63.55	72.10	70.95	73.30
Analysis, DM basis						
Crude protein, %	13.85	14.1	12.40	13.20	13.35	12.40
ADF, %	19.05	18.80	27.55	18.00	19.90	29.15
aNDF, %	28.95	28.10	27.55	27.60	29.60	40.30
NFC, %	50.10	52.40	41.85	52.70	50.95	40.65
TDN, %	73.60	73.80	67.65	74.45	72.75	65.30
NE_m, Mcal/kg	0.36	0.36	0.32	0.37	0.35	0.31
NE_g, Mcal/kg	0.23	0.23	0.20	0.24	0.23	0.18
Ash, %	7.10	6.91	7.51	6.48	6.15	6.65

DM, dry matter; PLM, ProLEAF MAX (Scoular, Omaha, NE); PFP, ProFiber Plus (Scoular, Omaha, NE); ADF, acid detergent fiber; NDF, neutral detergent fiber; NFC, Non-fiber carbohydrates; TDN, total digestible nutrients; NE_m, net energy for maintenance; NE_g, net energy for gain; Mcal, megacalorie

[1]Treatment diets consisted of the following ingredients: corn silage, barley, high-moisture corn, a feedlot supplement, and either alfalfa hay (CON; n = 8), alfalfa leaf pellets (PLM) and alfalfa stems (PFP) (PLM+PFP; n = 8), or alfalfa stems (PFP; n = 8) and were fed to finishing feedlot steers for 63 d (the step-up diet was fed for 22 d and the final diet was feed for the final 41 d).

[2]The guaranteed nutrient analysis for the feedlot supplement is as follows: 11.0% crude protein, 5.0% salt, 0.5% phosphorus, 8.0% calcium, 0.2% magnesium, 0.8% potassium, 0.5% sulfur, 2.0% sodium, 200.0 mg/kg copper, 400.0 mg/kg manganese, 650.0 mg/kg zinc, 2.0 mg/kg selenium, 22.0 mg/kg iodine, 9.0 mg/kg cobalt, 360.0 mg/kg Monensin.

Feed Sample Analysis

Samples of alfalfa hay, corn silage, barley, high-moisture corn, PLM, and PFP were collected pre-trial and analyzed for nutrient compositions at a commercial lab (Cumberland Valley Analytical Services, Waynesboro, PA). Samples of the PLM and PFP were collected each time a new batch was delivered. A sample of the TMR was collected three times weekly immediately after feed was delivered to the bunks and urea and mineral supplement were top-dressed to the appropriate diets and a composite sample of each week was sent for analysis at a commercial lab. All samples were frozen at −20°C and sent for analysis at the completion of the trial.

Carcass Data

All steers were harvested at a commercial harvest facility in Hyrum, UT once they reached approximately 550 kg and had approximately seven mm of ribeye fat thickness. This target weight and ribeye fat thickness were chosen to reflect the average weights of cattle harvested in the state of Utah, as well as ensuring that the animals did not have too much fat while also working within the constraints of scheduling with the commercial facility (Troxel and Gadberry, 2015; USDA, 2018). All carcass data was obtained from the harvest facility including, hot carcass weight (HCW), marbling score (MS), ribeye area (REA), 12th rib fat thickness (FT), dressing percentage (DP), USDA yield grade (YG) and USDA quality grade (QG). Quality grade is the evaluation of the distribution of marbling within the lean (MS) and the degree of maturity of the animal, which are both factors that affect palatability of the meat (Hale et al., 2013). Yield grade is an estimate of the boneless, closely trimmed retail cuts from parts of the carcass that are considered to be of high value and is assigned based on HCW, REA, FT, and kidney, pelvic, and heart fat (Hale et al., 2013). Marbling to backfat ratio (M:BF) was calculated using previously described equations (Mohrhauser et al., 2015).

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Table 3. Effects of feeding fractionated alfalfa on weights of finishing feedlot steers

	Treatment[1]				
Day[2]	CON	PLM+PFP	PFP	SEM	*P*-value[3]
0	420.3	420.8	420.7	4.7	
14	438.6	435.6	439.3	4.9	
28	459.7	458.1	460.6	5.8	
42	489.9	482.9	497.8	7.1	
56	515.7	513.1	523.9	6.4	
63	539.2	531.0	545.7	6.5	
Treatment × day					0.97
Time					<0.001
Treatment					0.10

PLM, ProLEAF MAX (Scoular, Omaha, NE); PFP, ProFiber Plus (Scoular, Omaha, NE).

[1]Treatment diets consisted of the following ingredients: corn silage, barley, high-moisture corn, a feedlot supplement, and either alfalfa hay (CON; n = 8), alfalfa leaf pellets (PLM) and alfalfa stems (PFP) (PLM+PFP; n = 8), or alfalfa stems (PFP; n = 8) and were fed to finishing feedlot steers for 63 d. Values represent the least square mean ± SEM.

[2]Weights are displayed in kg.

[3]*P*-values for Treatment × day, Time, and Treatment when steer body weights were analyzed over time with repeated measures.

Marbling to backfat ratio is a measure of the degree of marbling compared to the degree of backfat thickness and a smaller M:BF value represents more marbling that is present in the product, which is often favored by consumers of beef products.

Economic Comparison

To make an economic comparison of the treatments, partial budgets were developed using the total feed costs (TFC), feedlot cost of gain (COG), feed cost per kilogram of hot carcass weight (FC/kg HCW), and the feed cost per marbling score (FC/MS). TFC were calculated for each steer as the summed product of total feed (kg as-fed) and the weighted cost ($/kg) of each individual feed component where the weights were equal to the percentage of each feed component in the total diet. Five-year historical average prices (LMIC, 2020) were used for all feed components other than the alfalfa leaf pellets, alfalfa stems, urea, and feedlot supplement for which actual prices were used. Total feed costs were then divided by total gain, hot carcass weight, and marbling score to calculate COG, FC/kg HCW, and FC/MS, respectively. Total feed cost is intuitively understood, greater relative TFC indicates additional expenses associated with feeding. Cost of gain estimated for this study considers marginal changes to the cost of feed only and represents the FC in dollars that could be anticipated by the feedlot to achieve one additional kg of weight gain. Feed cost/kg HCW represents the FC in dollars that are required to increase the hot carcass weight by one kg, while FC/MS represents the FC in dollars that are required to increase the MS by one MS.

Statistical Analyses

A completely randomized block design was used in this study. Steers were initially stratified by weight so that there were no differences in starting weight and then assigned to one of three blocks based on weight and randomly allocated to one of three treatment groups. All data were analyzed using the MIXED procedure of SAS® (version 9.4; SAS Institute Inc., Cary, NC). Treatment was the main effect and individual steer was included as a random variable in the model. The variables that were analyzed include total weight gain, ADG, HCW, MS, REA, FT, DP, YG, QG, M:BF, TFC, COG, FC/kg HCW, and FC/MS. Repeated measures were used to analyze the following variables over time: weight, G:F, and DMI. A Tukey–Kramer adjustment was used in determining significant treatment differences by separation of the least square means. A $P \leq 0.05$ was considered significant and a $P > 0.05$ and $P \leq 0.10$ was considered a tendency.

RESULTS

Feedlot Performance

Analysis of body weight between the different treatment groups demonstrated that the steers increased in body weight over time ($P < 0.001$), and there was a tendency ($P = 0.10$) for treatment to have an effect on body weight such that steers that received the PFP diet tended to have increased body weight gain over the 63 d feeding period compared to the steers that received the PLM+PFP diet (Table 3). Average daily gain over the 63 d feeding period showed a tendency for an effect of treatment ($P = 0.058$) where the steers receiving the PFP diet had increased ($P = 0.047$) ADG compared to the PLM+PFP diet, but was not different ($P > 0.10$) from the CON (Figure 1).

Average daily DMI between the different treatment groups demonstrated that intake increased over time ($P < 0.001$) and treatment had an effect ($P < 0.001$) on average daily DMI such that steers receiving the PFP and CON diets consumed more ($P < 0.001$) than steers receiving the PLM+PFP

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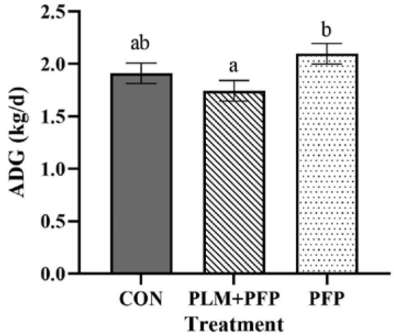

Figure 1. Average daily gains (ADG) of steers fed finishing diets consisting of corn silage, barley, high-moisture corn, a feedlot supplement, and either alfalfa hay (control; CON; n = 8), alfalfa leaf pellets [ProLEAF MAX (Scoular, Omaha, NE)] and alfalfa stems [ProFiber Plus (Scoular, Omaha, NE)] (PLM+PFP; n = 8), or alfalfa stems (PFP; n = 8) for 63 d. Values represent the least square mean ± SEM and bars with different letters indicate differences ($P \leq 0.05$) in ADG.

diet up until d 42 and the steers consuming the PFP diet consumed more ($P < 0.001$) than the steers consuming the other two diets from d 42 to d 63 of the feeding period (Figure 2). Analysis of G:F showed that treatment had no effect ($P > 0.10$) on G:F throughout the 63 d trial (Figure 3). While the steers that consumed the PFP diet gained the most weight and had the highest DMI, there was no difference in G:F between the treatment groups.

No differences ($P > 0.10$) were found between the different treatment groups in REA or FT measured by ultrasound on d 0 or d 28 of the feed trial. These data demonstrate that REA and FT are not affected when PFP or PLM+PFP are included in a diet for finishing feedlot steers.

Carcass Characteristics

Analysis of carcass characteristics at harvest demonstrated that there were no differences ($P > 0.10$) in HCW, MS, REA, FT, YG, QG, DP, or M:BF (Table 4). It is important to note that although the animals consuming PFP had increased weight gain, they did not have an increased HCW and there were no differences in DP indicating that the extra weight gained did not yield more consumable product.

Economic Analysis

Analysis of estimated economic metrics demonstrated that there were no differences ($P > 0.10$) in TFC, FC/kg HCW, or FC/MS between treatments (Table 5). However, COG over the 63 d feeding trial was affected ($P = 0.016$) by treatment such that the steers receiving the PFP diet had a lower COG ($P = 0.016$) than the PLM+PFP treatment,

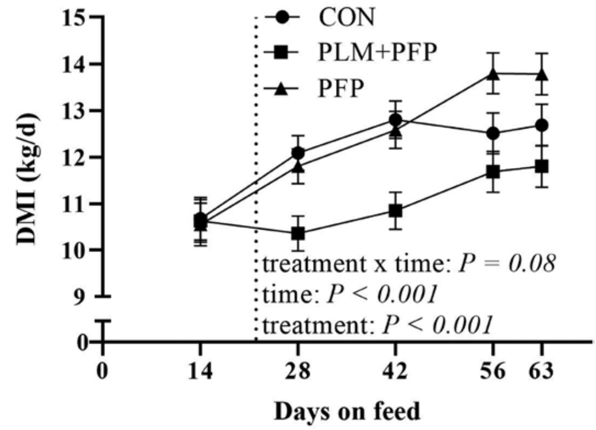

Figure 2. Average daily dry matter intake (DMI) of steers fed finishing diets consisting of corn silage, barley, high-moisture corn, a feedlot supplement, and either alfalfa hay (control; CON; n = 8), alfalfa leaf pellets [ProLEAF MAX (Scoular, Omaha, NE)] and alfalfa stems [ProFiber Plus (Scoular, Omaha, NE)] (PLM+PFP; n = 8), or alfalfa stems (PFP; n = 8) for 63 d. Values represent the least square mean ± SEM. Dotted vertical line denotes the end of feeding the step-up diet and the beginning of feeding the final diet.

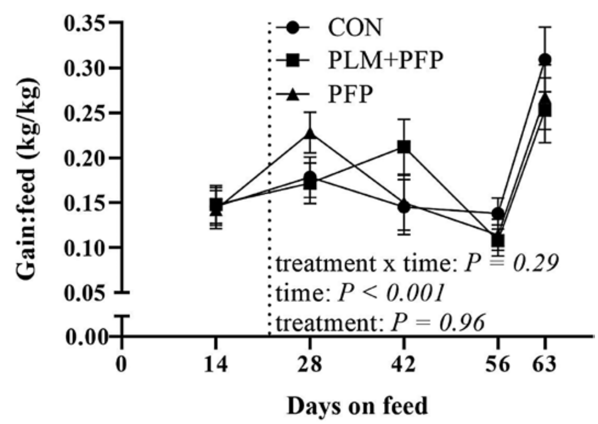

Figure 3. Average feed efficiency (gain to feed, G:F) of steers fed finishing diets consisting of corn silage, barley, high-moisture corn, a feedlot supplement, and either alfalfa hay (control; CON; n = 8), alfalfa leaf pellets [ProLEAF MAX (Scoular, Omaha, NE)] and alfalfa stems [ProFiber Plus (Scoular, Omaha, NE)] (PLM+PFP; n = 8), or alfalfa stems (PFP; n = 8) for 63 d. Values represent the least square mean ± SEM. Dotted vertical line denotes the end of feeding the step-up diet and the beginning of feeding the final diet.

but were not different ($P > 0.10$) from the CON (Table 5). The estimated COG for PLM+PFP was \$1.08/kg while the COG for PFP was \$0.93/kg.

DISCUSSION

To the best of our knowledge, this study is the first to investigate feeding pelletized alfalfa leaves or alfalfa stems to livestock species, however, many studies have examined the effects of feeding alfalfa leaf meal (ALM) or alfalfa leaf concentrate to livestock species. Similar to our alfalfa leaf pellet product, ALM provides a source of energy and protein, as it has similar energy content to that of a

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Table 4. Effects of feeding fractionated alfalfa on carcass characteristics of finishing feedlot steers

	Treatment[1]				
Carcass Characteristic	CON	PLM+PFP	PFP	SEM	*P*-value
Hot carcass weight, kg	302.7	299.5	309.4	5.02	0.38
Marbling score[2]	332.1	381.1	324.5	25.44	0.26
Cold camera ribeye area, (cm^2)[3]	69.68	70.89	70.89	1.93	0.88
12th rib fat thickness, (mm)[3]	7.40	7.14	7.62	2.40	0.39
Dressing percent	56.00	56.40	56.60	0.57	0.75
Yield grade[3]	2.10	2.00	1.86	0.10	0.25
Quality grade[3]	2.38	2.25	2.13	0.22	0.73
Marbling to backfat ratio[4]	-0.19	0.82	-0.63	0.52	0.15

PLM, ProLEAF MAX (Scoular, Omaha, NE); PFP, ProFiber Plus (Scoular, Omaha, NE).

[1]Treatment diets consisted of the following ingredients: corn silage, barley, high-moisture corn, a feedlot supplement, and either alfalfa hay (CON; n = 8), alfalfa leaf pellets (PLM) and alfalfa stems (PFP) (PLM+PFP; n = 8), or alfalfa stems (PFP; n = 8) and were fed to finishing feedlot steers for 63 d. Values represent the least square mean ± SEM.

[2]Marbling score is assessed visually by a USDA grader at the harvest facility.

[3]As measured by the camera at the commercial harvest facility.

[4]Marbling to backfat ratio identified in carcasses calculated using previously described equations (Mohrhauser et al., 2015). A lower number indicates more intramuscular fat deposition compared to 12th rib fat deposition.

high-quality hay or small grain silage (DiCostanzo et al., 1999) and has been reported to have 22–28% crude protein (Jorgensen et al., 1997; DiCostanzo et al., 1999), and two to three times the crude protein of alfalfa stems (Mowat et al., 1965; Mowat and Wilton, 1984; Albrecht et al., 1987). Additionally, ALM is more digestible and has a lower fiber content than whole alfalfa or alfalfa stems (Buxton and Brasche, 1991; Titgemeyer et al., 1992; Bourquin and Fahey, 1994), making it a favorable supplement to low-quality roughages (Gossett and Riggs, 1956). Alfalfa stems, on the other hand, can serve as an alternative to fiber sources such as straw (Su et al., 2017); however, alfalfa stems have more than twice the protein content of straw (Su et al., 2017), which is especially beneficial for growing animals. Gossett and Riggs (1956) performed a study similar to the present study in which they supplemented a diet for finishing beef steers that consisted of low-quality prairie hay, cottonseed meal, and ground milo grain with varying amounts (7–21% of the diet DM) of ALM in which all diets were, overall, isocaloric and isonitrogenous. In contrast to our study, Gossett and Riggs (1956) observed improved daily weight gains in steers consuming the diets supplemented with three different amounts of ALM (7%, 14%, and 21%, DM basis) when compared with steers consuming the control diet, which consisted of low-quality prairie hay, cottonseed meal, and ground milo grain. The contrasting results could be due, in part, to our study having supplemented alfalfa leaves (PLM) at approximately 14% DM (Table 2), while Gossett and Riggs (1956) observed the highest total weight gain and daily weight gains in steers consuming the treatment that consisted of 21% ALM (DM). Additionally, unlike the present study, Gossett and Riggs (1956) did not include alfalfa in their control diet, which could be another source of variation. In the present study, the animals that consumed the PFP diet gained more weight throughout the feeding trial when compared with steers that consumed the other two treatment diets. These results are likely due to the improved DMI observed in animals consuming the PFP treatment diet. While our study did not result in improved weight gain or ADG in animals that were supplemented with PLM, the findings of Gossett and Riggs (1956) and Klosterman et al. (1953) demonstrate that supplementation of ALM in diets consisting of low-quality forages has the potential to result in improved weight gain in cattle. However, more research needs to be done to determine the effects of including pelletized alfalfa leaves, such as PLM, in the ration of feedlot steers.

Additionally, few studies have been conducted on the inclusion of alfalfa stems in the diets of cattle, however, Su et al. (2017) investigated the effects of feeding alfalfa stem haylage on the performance of Holstein dairy heifers. Su et al. (2017) diluted a basal diet consisting of corn silage and alfalfa haylage with either alfalfa stem haylage or wheat straw and found that heifers consuming a diet diluted with alfalfa stem haylage had decreased weight gain and growth (as measured by heart girth, hip height, wither height, and BCS) when compared with heifers consuming the other two treatment diets (corn silage and alfalfa haylage; corn silage, alfalfa haylage, and wheat straw), which

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Table 5. Effects of feeding fractionated alfalfa on total feed costs, cost of gain, feed cost per kilogram of hot carcass weight, and feed cost per marbling score of finishing feedlot steers

	Treatment[1]				
Item	CON	PLM+PFP	PFP	SEM	*P*-value
TFC[2]	\$120.43	\$118.40	\$116.11	3.52	0.69
COG[3]	\$1.02[ab]	\$1.08[a]	\$0.93[b]	0.03	0.02
FC/kg HCW[4]	\$0.40	\$0.40	\$0.38	0.01	0.29
FC/MS[5]	\$0.37	\$0.32	\$0.36	0.01	0.09

PLM, ProLEAF MAX (Scoular, Omaha, NE); PFP, ProFiber Plus (Scoular, Omaha, NE); TFC, total feed costs, COG, cost of gain, FC/kg HCW, feed cost per kilogram of hot carcass weight; FC/MS, feed cost per marbling score.

[1]Treatment diets consisted of the following ingredients: corn silage, barley, high-moisture corn, a feedlot supplement, and either alfalfa hay (CON; $n = 8$), alfalfa leaf pellets (PLM) and alfalfa stems (PFP) (PLM+PFP; $n = 8$), or alfalfa stems (PFP; $n = 8$) and were fed to finishing feedlot steers for 63 d. Values represent the least square mean ± SEM. Different letters (a and b) are significantly different ($P < 0.10$) within each row.

[2]TFC (\$) is the total cost associated with feeding each treatment for the 63 d feeding period.

[3]COG is equal to the TFC/total weight gain.

[4]FC/kg HCW is equal to the TFC/hot carcass weight.

[5]FC/MS is equal to TFC/marbling score.

contrasts the findings of the present study. The ADF and TDN of the alfalfa stems (PLM) used in the present study was higher than that of the alfalfa stemlage used by Su et. al. (2017), which could be a reason for the difference in results between the two studies. Additionally, this study analyzed finishing feedlot steers, whereas Su et al. (2017) analyzed growth of heifers.

After completion of the feeding trial, the nutrient composition of all treatment diets was analyzed. Although all treatment diets were initially balanced to be isocaloric and isonitrogenous, post-trial analyses showed small differences in nutrient content between the different treatment diets (Table 2). Forages tend to vary more in their nutrient composition than concentrates and the variation that was present between the different forage sources in our treatment diets (Table 1) was most likely the main cause of the nutrient composition variation between the formulated nutrient content and actual nutrient content treatment diets. In addition, as with all large-scale feeding operations, there could have been variation in mixing and delivering the ration daily that contributed to differences in nutrient composition of the ration. Of note, for finishing feedlot diets, our treatment diets had a higher proportion of forage than is typical. However, treatment diets were balanced this way to ensure that enough of the PLM and PFP products were included in the diets to analyze their impact on feedlot performance. Variations that were present in nutrient composition between the different treatment diets included the PFP diet containing more ADF and NDF and less CP and TDN when compared with the other two treatment diets. The lower CP content that was present in the PFP diet could be due, in part, to the fact that the urea was top-dressed in this diet, therefore, samples of the PFP diet that were collected might not have been representative of the true CP content of this diet. These variations between the different treatment diets could have influenced our observed results.

In our study, the steers receiving the PLM+PFP diet had the lowest DMI throughout the trial; however, there is not a good explanation for this trend. The nutrient compositions of the different treatment diets were fairly similar, as such, the only explanation for the depressed DMI observed in steers receiving the PLM+PFP diet is that something about the PLM product in the diet caused decreased DMI. The inclusion of PLM in the PLM+PFP diet could have affected physically effective fiber content, which may be responsible for the decreased DMI observed in steers receiving the PLM+PFP diet. On days 56 and 63, steers consuming the PFP diet had numerically increased DMI compared to steers consuming the other two diets. The ADF of the PFP diet was higher than that of the other two diets (Table 2), indicating that perhaps the diet was not as digestible and the steers needed to consume more feed to get a proper amount of nutrients. Alternatively, the large amount of fiber present in the PFP diet could have stimulated microbial fermentation and the presence of rumen microbes, which could then result in decreased fermentation and increased DMI. Nonetheless, more research needs to be completed to determine how rumen characteristics change when PLM or PFP is included in the ration. In contrast to the present study, Su et al. (2017) did not observe improved DMI when

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alfalfa stem haylage was used to dilute a basal diet consisting of corn silage and alfalfa haylage when compared with wheat straw. Zehnder et al. (2010) observed similar results to the present study in that they did not observe improved DMI in beef heifers that were fed a diet that replaced soybean meal with ALM in a corn-based diet. However, DiCostanzo et al. (1999) observed improved DMI in finishing steers that were fed a diet that substituted ALM for hay and soybean meal, demonstrating that DMI has the potential to be improved when ALM is included in the diet. Although this study did not result in improved weight gain or DMI with supplementation of alfalfa leaves (PLM), it is important to note that inclusion of PFP, which is a cheaper alternative to alfalfa hay, even with the added costs of processing, in the diet of finishing steers results in similar performance when compared with the inclusion of alfalfa hay or PLM in the diet, and thus, may be an economically viable alternative forage for producers to use.

On day 63, G:F was higher for all three treatments when compared with the rest of the feeding period. The exact reasons for the increase in G:F towards the end of the feeding period as the steers approached their mature size are unknown. It is also important to point out that the steers had a sharp increase in weight gain the last week of the trial, without a change in DMI which is likely the reason why G:F increased. However, there is no good explanation as to why the steers had such a sharp increase in weight gain during the last week of the feeding trial. Gossett and Riggs (1956) observed results that contrasted our FE data and observed improved FE in steers that consumed the diets that were supplemented with ALM, whom required 484 kg of feed to gain 45.4 kg of weight when compared with the steers consuming the diet that was not supplemented with ALM, which required 571.1 kg of feed for 45.4 kg of weight gain.

To our knowledge, the present study is the first to investigate the effects of feeding fractionated alfalfa on carcass characteristics of beef steers. However, there is one other study that examines the effects of feeding different forages to beef steers on carcass characteristics. Swanson et al. (2017) performed a study that investigated the effects of feeding a dry-rolled corn-based diet that included one of four different forage sources (alfalfa, corn silage, wheat straw, or corn stover) on carcass characteristics of beef steers. In agreement with our results, Swanson et al. (2017) observed no difference in HCW, MS, FT, or longissimus muscle area between the different treatments. However, Swanson et al. (2017) did observe a tendency for the steers consuming the diets including wheat straw or corn stover to have greater DP than alfalfa or corn silage treatments. In our study, although not statistically significant, MS was increased by approximately 13% and 15% in steers that consumed the PLM+ PFP diet when compared with the steers that consumed the CON or PFP diets, respectively. Additionally, the steers that consumed the PLM+PFP diet had numerically increased M:BF when compared with the steers in the other two treatment groups. These results indicate that the steers that consumed PLM+PFP were more efficient at depositing intramuscular fat than steers that received the other two treatments. However, it is important to note that these differences were not significant and this trial needs to be replicated with a larger number of animals to determine whether fractionated alfalfa impacts fat deposition in the carcass when fed during the finishing period.

The economic analysis in the present study showed that the COG difference of \$0.15/kg greater for the PLM+PFP diet when compared with the PFP diet. This COG difference has the potential to significantly alter return per head. The average total weight gain across all treatments was 118 kg. This would result in an average decrease in net return per head of \$17.70 (118 kg × \$0.15/kg) for PLM+PFP steers as compared to PFP. Additionally, while not statistically significant, PFP had a lower FC/kg HCW while PLM+PMP was shown to have a relatively lower FC/MS ratio. These results highlight trends within the data from this current study and demonstrate that the cost to produce hot carcass weight tends to be cheapest when feeding a PFP diet while the cost to produce better quality grade (i.e., increased marbling) tends to be cheapest when feeding the PLM+PFP diet.

In summary, our findings showed that replacing alfalfa hay with PFP in a finishing feedlot steer diet results in increased DMI and weight gain when compared with steers consuming the PLM+PFP diet. However, no differences were observed in G:F or carcass characteristics between the three treatment groups (CON, PLM+PFP, and PFP). Economic analysis demonstrated that steers receiving the PFP diet had improved cost of gain when compared with steers receiving PLM+PFP diet. Other studies have observed improved weight gain, DMI, and/or FE when animal diets are supplemented with ALM or alfalfa leaf protein concentrate, but we did not observe these differences in the present study. If we were able to have more

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than eight animals per treatment in our study, we may have observed similar trends to the previous studies. Additionally, our feeding period took place over 63 d and while we realize this is a limitation of the present study, it is an adequate amount of time to observe differences between the treatment groups with the parameters that we measured. As such, additional research needs to be completed to determine how including fractionated alfalfa in the diet impacts feedlot performance and carcass quality of beef steers.

CONCLUSION

As the population continues to grow exponentially and the amount of land available for food production decreases (Mayo, 2016), it is necessary to maximize the efficiency of beef production. Feed accounts for the majority of costs associated with beef production (Archer et al., 1999; Hill, 2012; Lines et al., 2018) and, therefore, it is essential to develop nutrition regimes that will decrease cost of production without impacting efficiency of production. Overall, our findings demonstrate that inclusion of PFP in place of alfalfa hay in a finishing diet has the potential to improve COG and inclusion of alfalfa hay, PLM, or PFP in a finishing diet results in similar growth, performance, and end-product quality and quantity. Additionally, producers can purchase PFP for a lower price than alfalfa hay or PLM and improved COG when compared with animals receiving the PLM+PFP diet. However, more research needs to be completed on these products with a larger number of animals and also on how inclusion of different amounts of the products might impact production.

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*Conflict of Interest Statement***.** C. Pratt is co-owner of Green Leaf Global, the company that produces and holds the patent for the fractionated alfalfa products that were tested in this manuscript. All of the other authors declare no conflicts of interest with the research presented in this manuscript. All authors declare that the research that is presented in this manuscript depicts the results of the study and was not biased towards the products that were tested in any way.

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