Influence of *Megasphaera elsdenii* and feeding strategies on feedlot performance, compositional growth, and carcass parameters of early weaned, beef calves

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ABSTRACT: Simmental–Angus calves [n = 135; 72 steers and 63 heifers; body weight (BW) = 212.4 kg ± 36.1] were early weaned (~5 mo) to evaluate multiple feeding regimens (conventional vs. aggressive energy diets ± *Megasphaera elsdenii* NCIMB 41125 (*M. elsdenii* culture (MEC); Lactipro Advance; MS Biotec Inc., Wamego, KS) in order to elucidate the optimal development strategy. Objectives were measured by tracking the effects of caloric density and oral drenching of growing phase performance and subsequent carcass traits. The 72-d experiment featured three groups: 1) control (CON), fed exclusively a 35% roughage diet; 2) aggressive (AGR), fed a blend of a 10% and 35% roughage diets; 3) MEC, fed the same diet as AGR and drenched with 50 mL of *M. elsdenii* NCIMB 41125 on day 1. A subset of calves (n = 45) was equipped with wireless rumination tags (Allflex Flex Tag; SCR Engineers, Ltd; Netanya, Israel), which logged daily rumination and general activity. Skeletal growth variables were assessed by measuring wither and hip height pretrial and posttrial. Ultrasonography provided additional resolution concerning growing phase compositional gain, which was later verified by carcass data collection. Data were analyzed as a nested analysis of variance with BW and gender serving as blocking factors. The increased caloric density of the diets administered to MEC and AGR calves resulted in greater average daily gain and gain:feed values compared with CON even during the first 21 d of diet acclimation ($P \le 0.05$). Additional fiber concentration of CON diets led to increased rumination times in 9 of the 10 wk of trial ($P \le 0.10$). No differences amongst treatments were detected for skeletal variables or ultrasound 12th rib fat. Cattle fed CON diets posted 3.4% inferior BW at the end of the growing period trial and a 3.8% reduction in hot carcass weight (HCW), reinforcing the theory that intensifying caloric intake during the growing phase does not compromise future feedlot performance. Ultrasound marbling scores for MEC-treated cattle were 19° greater than AGR treated cattle ($P \le 0.05$) at the end of the growing phase trial. Nearly the exact same advantage (22°) was observed in the cooler 5 mo later ($P = 0.42$). Implying MEC metabolically imprinted cattle to favor marbling development. It appears that maximizing dietary caloric density in light-weight calves does not adversely affect the growth curve, while oral dosing of MEC during the growing period may be a precursor for enhanced quality grade.

Key words: early weaned calves, Lactipro, *Megasphaera elsdenii*, metabolic imprinting, roughage level, step-up strategies

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INTRODUCTION

Early weaning (3–5 months of age) is a practical option for cow–calf operations to preserve cow body condition scores when confronted with drought or limited forage resources (Peterson et al., 1987; Myers et al., 1999). Moreover, it is the most feasible option when managing the nutritional inputs of a confined cow–calf system. Generally, these calves are light weight (115–275 kg) and would be developed on a starter diet (30–40% roughage) prior to feedlot placement. Although a proven method to reduce digestive disturbances, roughages can be cost prohibitive. The bulky physical characteristics of roughages are subject to elevated shrink, prompting additional trips for diet delivery, and have a deleterious effect on feed mill flow and upkeep (Britton and Stock, 1986). When evaluated on a unit of caloric energy basis, roughages can be relatively expensive, which can be amplified by drought conditions (Miller, 2013). However, the failure of cattle to adapt to concentrate-dense diets can overwhelm ruminal buffering capabilities, prompting depression in ruminal pH and leading to acidosis (Owens, 1998).

A potential mediator of ruminal pH in acidotic conditions is the bacterium *Megasphaera elsdenii,* which is responsible for converting 60% to 80% of lactate to less acidic volatile fatty acids (Counotte et al., 1981). Lactipro Advance (*M. elsdenii* culture (MEC); MS Biotec Inc., Wamego, KS) is a commercially available strain (NCIMB 41125) of *M. elsdenii*, which has demonstrated an ability to avert ruminal acidosis in accelerated dietary step-up protocols (Kung and Hession, 1995; Klieve et al., 2003; Horn et al., 2009; McDaniel, 2009; Henning et al., 2010b; Muya et al., 2015). Application of MEC could be an option to promote ruminal health in rapid step-up protocols of early weaned calves. However, consideration must be given to the potential for undesirable early fat deposition, hastening the growth curve, and mitigating future feedlot efficiency and performance. Thus, the objective of this study was to evaluate the optimal development strategy for early weaned calves by comparing multiple feeding regimens (conventional vs. aggressive energy diets ± MEC). Given this hypothesis, compositional gain throughout the growing period and subsequent carcass composition will be captured to test the objectives.

MATERIALS AND METHODS

All procedures conducted in the current trial were approved by the Texas Tech University Institutional Animal Care and Use Committee (IACUC # 18067-08). The experiment was conducted at the Texas Tech University Beef Center Teaching and Research Unit located 9.7 km east of New Deal, TX.

Pretrial Animal Selection and Management

Cattle used in the early weaned study [n = 135; 72 steers and 63 heifers; body weight (BW) = 212.4 kg ± 36.1] were sourced from the Texas Tech Beef Teaching and Research Unit cow herd. These Simmental–Angus cross calves were born from January to March of 2018 in a semiconfined cow–calf system. Cows were calved on pasture, and pairs were moved to dry lots approximately 1 mo following parturition. Physical characteristics of the highly related calf crop includes: predominately black hided, muscle score 1s (majority) and 2s, and medium to large frame scores. These cattle were classified as top-end feeder calf prospects and most likely would have been rewarded a premium for their excellent growth potential. Calves were treated in April with: 1) a modified live vaccine to combat the pathogens often associated with bovine respiratory disease (Bovi-Shield Gold, One Shot; Zoetis, Parsippany, NJ); 2) a vaccine to prevent against common forms of clostridia (Ultrabac 7; Zoetis, Parsippany, NJ); and 3) a low-potency implant for suckling calves containing 100 mg of progesterone and 10 mg of estradiol benzoate (Synovex C; Zoetis, Parsippany, NJ). Subsequently, calves were administered preweaning booster vaccinations on July 7, 2018. On July 20, 2018, calves (n = 166; mean calving date February 13, 2018) were weaned. During processing procedures, individual BW was documented and a random subset of calves (n = 45) was equipped with a wireless rumination tag (Allflex Flex Tag; SCR Engineers, Ltd; Netanya, Israel). Following processing, calves were sorted into soil surface holding pens (27 × 37 m). These pens featured a soil surface mound and a shade structure designed to help alleviate heat stress. Concrete fence line bunks were fastened on top of a 3-m concrete apron. Calves were allocated approximately 24 m^2 of pen space and approximately 0.64 m of linear bunk space. Cattle were given 11 d prior to trial initiation to allow calves fitted with Allfex Flex tags to establish a baseline of daily rumination and activity characteristics. The data collected during the baseline period was stored in SCR Heatime Pro+ software system and used to model changes in rumination during the trial period. Calves were granted ad libitum access to native grass hay and were bunk delivered creep feed targeted at 2.0% of BW on an as-fed basis. Creep feed was delivered to bunk break calves and pulse treat cattle with chlortetracycline (Aureomycin; Zoetis; Parsippany, NJ) for 5 d at a rate of 4.54 mg/kg of BW.

Experimental Design

Calves (n = 135; 72 steers and 63 heifers) were organized into a completely randomized block design. Cattle were blocked by BW nested within gender and randomly assigned to one of three feeding strategies (3 calves/pen; 15 pens/treatment; and 45 total pens): 1) negative control (CON), exclusively fed a grower diet (35% roughage) with no probiotic; 2) positive control or aggressive (AGR), a blend of grower (35% roughage) and finisher (10% roughage) strategy with no probiotic; or 3) probiotic treatment (MEC), grower/finisher strategy and drenched with an oral gavage of 50 mL of Lactipro Advance (*M. elsdenii* NCIMB 41125, 2 × 10[8] cfu/mL). This dose level was established based on the prior work of (Henning et al., 2010b; Drouillard et al., 2012; Muya et al., 2015; Thieszan et al., 2015). The trial was conducted over a 72-d growing period.

Cattle Management

Cattle were weighed on consecutive days (July 29, 2018, day 0; July 30, 2018, day 1). During the second BW documentation, 1) calves were assigned a unique individual color-coded tag that corresponded with treatment; 2) steers were administered a progesterone/estradiol combination implant (Synovex S; Zoetis Inc., Parsippany, NJ) and heifers were given a testosterone/estradiol combination implant (Synovex H; Zoetis Inc., Parsippany, NJ); 3) skeletal wither height (height directly over the top of the shoulder), and hip height measurements were documented while calves were displaying natural posture and standing upright and restrained in the chute. Finally, calves designated to the MEC treatment were orally drenched with 50 mL of exogenous *M. elsdenii* NCIMB 41125 (2 × 10[8] cfu/mL; MS Biotec Inc., Wamego, KS). Cattle were sorted from the chute into designated groups of three and then moved into trial pens. Calves were housed in soil surface pens (3 × 15.2 m) and allocated one linear meter of bunk space. These pens featured concrete fence-line bunks secured on top of 3-m concrete aprons. Aprons were cleaned once every 2 wk. Each pen was fitted with an overhead mesh cloth canvas that provided approximately 16.7 m[2] of shade per pen at all times during the day. Pens were equipped with automatic water troughs, which were cleaned weekly and a daily log was maintained to monitor health status and heat stress.

Diets were formulated to meet or exceed the standards set forth by the National Research Council [NRC (2016)]. Ration composition and nutrient analyses of diets utilized during the trial are presented in Table 1. Both diets contained organic trace mineral (Availa 4; Zinpro Corp., Eden Prairie, MN) and monensin (Rumensin-90; Elanco, Greenfield, IN, formulated at a rate of 300 mg/animal/d). All daily rations were milled at the Texas Tech Burnett Center Feed Mill, including the

Table 1. Ingredient and analyzed chemical composition (DM basis) of diets fed during the trial period

Ingredient	Grower diet[a]	Finisher diet
Corn grain, steam flaked	17.5	40.0
Wet corn gluten feed[b]	40.0	40.0
Alfalfa hay, full bloom	20.0	10.0
Ground cotton burrs	15.0	0.0
Cottonseed meal—41% crude protein	4.0	6.0
Limestone	1.5	2.0
Texas Tech University supplement, % [c]	2.0	2.0
Analyzed composition[d]		
DM, % as fed	74.45	72.48
Crude protein, %	17.16	17.22
Net energy for maintenance, Mcal/kg	1.54	1.96
Net energy for gain, Mcal/kg	0.99	1.32
Effective NDF, %[e]	26.42	12.41
Calcium, %	0.99	0.85
Phosphorus, %	0.60	0.64
Potassium, %	1.53	1.05
Magnesium, %	0.36	0.34

[a]Calves were developed for 72 d: 1) control, fed grower diet exclusively; 2) aggressive, fed 2.0% of initial BW on an as-fed basis of grower diet at 0630 h and ad libitum finishing diet at 0930 h; 3) Lactipro, drenched with 50 mL of *M. elsdenii* (Lactipro Advance; MS Biotech, Inc., Wamego, KS) on day 0 of the trial, fed 2.0% of initial BW on an as-fed basis of grower diet at 0630 h and ad libitum finishing diet at 0930 h.

[b]Sweet bran (Cargill, Dalhart, TX).

[c]Supplement composition (DM basis): 67.755% cottonseed meal, 15.000% NaCl, 10.000% KCl, 3.760% urea, 0.986% zinc sulfate, 0.750% monensin (Rumensin-90; Elanco, Greenfield, IN), 0.506 Tylan40 (Elanco), melengesterol acetate (MGA 500, Pfizer, New York, NY; 0.4 mg/animal/d), 0.500% Endox (Kemin Industries, Des Moines, IA), 0.196% copper sulfate, 0.167% manganese oxide, 0.157% vitamin E (500 IU/g), 0.125% selenium premix (0.2% Se), 0.083% iron sulfate, 0.010% vitamin A (1,000,000 IU/g), 0.003% ethylenediamine dihydroiodide, and 0.002% cobalt carbonate.

[d]Composition of weekly composite samples (10 wk) analyzed at a commercial laboratory (Servi-Tech Laboratories, Amarillo, TX). DM calculated weekly (forced air oven for 24 h at 100 °C) using weekly ingredient sample DM records.

[e]Measure the physical characteristics of fiber (particle size) to stimulate chewing and saliva production.

supplemental premix that was blended in a commercial micromixer.

Calves were fed twice daily at 0630 and 0930 h. On day 1, each pen was delivered 2.0% of their initial BW of the grower diet on an as-fed basis during the first feed delivery. Cattle were delivered 0.5% of their BW on an as-fed basis at 0930 h, with CON pens receiving the grower diet and AGR and MEC treatments delivering the finisher diet. From day 2 to trial completion, calves received the grower diet at 0630 h, 2.0% of their initial BW on an as-fed basis, while the 0930 h delivery was administered on an ad libitum basis. This method allowed the AGR and MEC treatments to receive greater finisher diet consumption as the trial progressed. At approximately 0530 h each morning, feed bunks were evaluated to estimate orts and to predetermine daily feed deliveries. The goal of the slick bunk management utilized in the trial was for cattle to refuse ≤0.45 kg of feed on an as-fed basis. Cattle were required to clean their bunks for two consecutive days, prior to being offered an additional kilogram of feed on an as-fed basis. In instances when ≥5 kg was left in the bunk, refusals were removed and weighed and, to adjust dry matter intake (DMI) calculations, a sample of the residual was dried (forced-air oven at 100 °C for 24 h).

Roughage sources and sweet bran were loaded in a tractor-pulled mixer (Rotomix, Dodge City, KS) by a skid steer. The remaining dietary ingredients were batched in a paddle-type mixer and delivered to the mixer using a drag chain conveyor system. Prior to diet delivery, a 5-min stationary mix was applied. The mixer was equipped with a scale with a readability of ±0.45 kg. Feed samples were collected daily from the mixer and stored at −18 °C for further analysis. These samples were composited for each diet within a week. To establish representative composites, they were forced through a separator and vigorously shaken in a bucket for 1 min. The composites were sent to Servi-Tech Laboratories, (Amarillo, TX) for proximate analysis utilizing the standards established by Association of Official Analytical Chemists (1995; Table 1). Dry matter (DM) and dietary inclusion calculations were established weekly by drying diet and ingredient samples (forced-air oven at 100 °C for 24 h).

In concert with daily health logs, an acidosis intervention protocol was developed. Bloat scores were monitored daily and recorded 2, 4, and 6 h after feeding. The designation of bloat scores was in accordance with the previous standards established by Paisley and Horn (1998). A total of 14 calves were treated for bovine respiratory disease during the trial period. Calves that displayed signs of morbidity were pulled from pens, processed through a chute with the goal of recording calf body temperature. Calves with temperatures ≥40 °C were treated with flunixin meglumine (Banamine Transdermal; Merck Animal Health, Summit, NJ) and tulathromycin (Draxxin; Zoetis Animal Health, Kalamazoo, MI). The distribution of cattle treated for bovine respiratory disease were: two calves from the CON group; five calves from the AGR treatment; and seven cohorts from the MEC treatment. An additional three calves from the MEC treatment died on trial of pneumonia; these cattle were removed from all calculations.

Individual BW measurements were captured on days 0, 1, and 72 (Silencer chute; Moly Manufacturing, Lorraine, KS; mounted on Avery Weigh-Tronix load cells, Fairmount, MN; readability ± 0.45 kg) and pen BW measurements for interim calculations were recorded on day 21 and 42. Calves were weighed prior to feeding at 0630 h, with residual feed removed from the bunk, weighed, and sampled for DM analysis. On October 9, 2018 (day 72), cattle were processed and weighed off the trial. Additional documented measurements included: 1) measurement of skeletal length variables (wither and hip height) and 2) carcass ultrasonography used to estimate loin muscle area (LMA), 12/13th rib fat thickness, and intramuscular fat percentage.

Rumination Data Collection

Each pen of cattle had one randomly assigned calf that was equipped with an Allflex Flex Tag (SCR Engineers, Ltd, Netanya, Israel). Equipped with a 3-yr battery lifespan, the Flex Tag logs the head motions used during chewing to estimate daily rumination time and general animal activity. General activity was measured as the animal's movement around the pen. Each tag had the capability to store 24 h of data, with the compiled information sent to an SCR frequency base unit, and data was subsequently downloaded by a monitoring system (Heatime Pro+; SCR Engineers, Ltd., Netanya, Israel). The software package generated an output of daily activity and rumination used to monitor calves throughout the growing phase trial.

Posttrial Management and Data Collection

Following study completion, all cattle were loaded onto semitrucks and transported 126 km to a commercial feedlot at Happy, TX (Wrangler Feedyard; Cactus Feeder Inc., Amarillo, TX).

Despite MEC and AGR treatments being adapted to finisher diets, in accordance with Wrangler feedlot receiving protocols, all cattle were stepped up from a starter diet to a finisher diet over approximately a 3–4-wk period. All cattle were housed in treatment groups throughout the duration of the finishing phase and heifers were harvested on April 8, 2019, and the steers were harvested on April 22, 2019, at Tyson Fresh Meats (Amarillo, TX). Carcass information was collected by personnel from West Texas A&M University and subsequently shared with the principal investigators at Texas Tech University.

Statistical Analysis

Data were analyzed as a nested analysis of variance with BW and gender serving as blocking factors using SPSS Statistics 25.0 (IBM, Armonk, NY). Pen was designated as the experimental unit for performance, ultrasound, and skeletal parameters, while animal served as the experimental unit for rumination and carcass data. Diet and MEC application were treated as fixed effects, whereas block was treated as a random effect in the model. Model assumptions were tested using: 1) Shapiro Wilk's, 2) Bartlett's, and 3) Mauchely's tests.

Individual weights were, respectively, shrunk 1% and 3% for initial and interim/final measurements. Initial trial weights were established by averaging measurements recorded on days 0 and 1. Ratio's for skeletal measurements were established by computing the quotient of BW by height. Rumination and activity characteristics were averaged over each week to establish daily values. The resulting weekly composite measurements were subtracted from the value generated during the baseline period. As such, the delta (Δ) of these values is utilized to quantify the effect of dietary transition on rumination and general activity. Yield-grade values presented in carcass characteristics were derived using the method established by the USDA (1997). Empty body fat percentage, empty BW, and empty BW adjusted to a 28% empty body fat were calculated as outlined by Guiroy et al. (2002). Pertaining to the results and discussion of the current study, significance is declared at $P \leq 0.05$, while all values in the range $0.05 < P \leq 0.10$ are considered tendencies.

RESULTS AND DISCUSSION

Feedlot Performance

Performance parameters of early weaned calves are presented in Table 2. In concert with the variation observed in diet caloric density (Table 1), feeding strategy led to significant differences. For the trial duration, cattle fed a blend of finisher and grower diets (AGR and MEC) posted 10.7% greater average daily gain (ADG; 1.59 vs. 1.74 and 1.78 kg, $P < 0.01$), while no differences in DMI led to an 11.4% enhancement of gain:feed (G:F; 0.185 vs. 0.203 and 0.209 units, $P = 0.02$) compared with calves exclusively consuming grower ration. Cattle fed CON diets documented the poorest G:F and ADG values during the first and second interim period compared with AGR and MEC treatments ($P \leq 0.05$). Despite early weaned calves consuming ad libitum hay and modest levels of creep feed prior to the trial, the increased roughage concentration of CON-fed diets did not influence DMI during any period in the trial. It is possible that the limited ruminal capacity of immature early weaned calves was quickly satiated by the bulkier nature of the grower diet (additional 25% roughage). The physical fill response of the grower diet may have served as an equalizer to the additional organic acid production potential of the blended finisher and grower strategy (NRC, 2016). It is also worth noting that the early weaned calves utilized in the current study were raised in a semiconfined cow–calf system and may have developed a level of concentrate adaptation, consuming bunk-delivered diets alongside their dams prior to weaning. Furthermore, calves were delivered creep feed for 11 d prior to the trial, which may have partially muted the acidosis potential of all cattle. Partial concentrate acclimation may also explain the lack of statistical difference observed between MEC and AGR treatments for any performance parameter.

Our findings are congruent with Fluharty et al. (1996), who evaluated four different diet approaches for early weaned calves. A 17.4% improvement was documented for ADG for cattle consuming a 90% concentrate diet compared with calves delivered a 60% concentrate diet over the 105-d trial. Similar findings were reported by Meteer et al. (2013) who published a 13% improvement in feed efficiency for early weaned calves on a starch-dense diet compared with a fiber diet.

The dearth of bloating or other clinical acidosis signs exhibited by the AGR treatment was perplexing given the immature age and ruminal development of the early weaned calves on trial. It is possible that the confined cow–calf system programmed the microbiome of AGR calves or that the diets employed in the study lacked the caloric intensity needed to trigger ruminal acidosis. However, numerical improvements of

Table 2. Effects of feeding strategy*a* and *M. elsdenii**b* on feedlot performance parameters of early weaned calves during a 72-d growing phase

Item	Treatment[a] CON	AGR	MEC[b]	SEM[c]	P
Initial BW, kg[d]	213.1	212.6	211.6	5.44	0.99
Final BW, kg[d]	327.5	338.0	339.5	6.14	0.69
Days 1–21					
ADG, kg	1.82[b]	1.98[a]	2.08[a]	0.049	0.05
DMI, kg	6.58	6.5	6.53	0.126	0.96
Gain:feed	0.278[b]	0.306[a]	0.320[a]	0.0064	0.03
Days 21–42					
ADG, kg	1.40[b]	1.63[a]	1.66[a]	0.037	0.01
DMI, kg	8.64	8.73	8.79	0.173	0.94
Gain: feed	0.166[b]	0.187[a]	0.193[a]	0.0054	0.02
Days 42–72					
ADG, kg	1.56	1.65	1.65	0.034	0.42
DMI, kg	10.18	10.08	10.17	0.186	0.97
Gain:feed	0.154	0.166	0.166	0.0045	0.49
Entire trial					
ADG, kg	1.59[b]	1.74[a]	1.78[a]	0.02	<0.01
DMI, kg	8.68	8.64	8.65	0.159	0.99
Gain:feed	0.185[b]	0.203[a]	0.209[a]	0.0035	0.02

[a]Calves were developed for 72 d: 1) control (CON), fed grower diet exclusively; 2) aggressive (AGR), fed 2.0% of initial BW on an as-fed basis of grower diet at 0630 h and ad libitum finishing diet at 0930 h; 3) *M. elsdenii* culture (MEC), drenched with 50 mL of *M. elsdenii* (Lactipro Advance; MS Biotech, Inc., Wamego, KS) on day 0 of the trial, fed 2.0% of initial BW on an as-fed basis of grower diet at 0630 h and ad libitum finishing diet at 0930 h.

[b]Calves were drenched with no *M. elsdenii* or 50 mL of *M. elsdenii* (Lactipro; MS Biotech, Inc., Wamego, KS) on day 1 of the trial.

[c]Pooled standard error of treatment means (n = 15 pens/treatment).

[d]Initial and interim/final weights were applied a 1% and 3% shrink, respectively.

[a–c]Row means that do not have common superscripts differ (P < 0.05).

MEC appear to suggest the vitality and success of ruminal colonization of exogenous *M. elsdenii.* Principally, calves administered the probiotic posted numerical increases for ADG and G:F ratios during the first and second interim periods, resulting in improved outcomes throughout the entire trial; however, all values were nonsignificant. Additional resolution pertaining to the numerically upgraded G:F efficiencies of MEC calves compared with the AGR treatment may be provided by the work of Muya et al. (2015). The authors observed increased papillae area in 42-d-old concentrate-fed dairy calves and greater circulating β-hydroxybutyrate levels following MEC drenching at 14 d of age. The study found no difference in total ruminal volatile fatty acid (VFA) production, but calves dosed with *M. elsdenii* NCIMB 41125 had greater proportion of butyrate than controls. This suggests that improvements in animal gain and efficiency of MEC-drenched cattle are most likely an outgrowth of superior epithelial surface area and subsequent enhanced VFA absorption. Failing to achieve significant power despite numerical improvements in ADG echoes the conclusions of previous researchers (Drouillard et al., 2012; Thieszen et al., 2015).

Rumination and Activity Characteristics

A summary of rumination and general activity treatment means are presented in Table 3. Given that each week value denotes the (Δ) change from baseline value when cattle were granted ad libitum access to native grass hay, the decline of rumination values for all cattle during week 1 of the trial was anticipated. Naturally, the finer particle size of the bunk-delivered diet required less mastication to enable passage of the substrate to the lower gastrointestinal tract. Additionally, the relative naivety of calves to rapidly fermentable carbohydrates most likely depressed intake leading to further rumination abetment. Considering the disparity between neutral detergent fiber (NDF) concentrations of the grower and finisher diets (Table 1), elevated rumination times for CON calves is not surprising. Relative to cattle fed a blend of diets, CON cattle documented a significant increase in rumination time during 7 different weeks ($P \leq 0.05$) and displayed

Table 3. Effects of feeding strategy*a* and *M. elsdenii**b* on rumination and general activity characteristics of early weaned calves during a 72-d growing phase

	Rumination[c]				Activity[c]				*P* values	
Period, min	CON	AGR	MEC[b]	SEM[d]	CON	AGR	MEC[b]	SEM[d]	Rumination	Activity
Baseline[e]	451.9	455.7	468.5	8.7	336.9	330.7	337.9	2.79	0.73	0.69
Week 1[f]	−100.61[a]	−154.3[b]	−166.5[b]	9.15	−73.1	−79.8	−74.5	2.98	0.01	0.64
Week 2	−23.4[a]	−115.9[b]	−132.7[b]	11.27	−57.8[a]	−81.4[b]	−79.5[b]	3.60	<0.01	0.01
Week 3	57.9[a]	−12.8[b]	−21.9[b]	10.27	−21.7[a]	−45.9[b]	−39.8[b]	4.45	<0.01	0.05
Week 4	50.3[a]	4.3[b]	−12.9[b]	10.00	−20.1	−31.2	−30.9	4.48	0.03	0.53
Week 5	−39.7[x]	−38.6[x]	−76.3[y]	10.52	−52.3	−60.6	−75.1	6.27	0.10	0.33
Week 6	5.8[a]	−70.4[b]	−65.1[b]	10.50	−25.5	−34.4	−42	4.81	<0.01	0.39
Week 7	5.3[a]	−74.8[b]	−81.8[b]	11.03	−26.6[x]	−39.4[y]	−47.8[y]	4.73	<0.01	0.10
Week 8	−73.0[x]	−104.7[y]	−115.5[y]	9.22	−71.5	−86.3	−85.2	4.38	0.09	0.32
Week 9	−16.0[a]	−106.3[b]	−95.6[b]	11.07	−42.8	−51.5	−53.3	4.49	<0.01	0.60
Week 10	−18.8[a]	−83.2[b]	−66.0[b]	11.64	−40.1	−44.8	−48.7	4.35	0.05	0.73

[a]Calves were developed for 72 d: 1) control (CON), fed grower diet exclusively; 2) aggressive (AGR), fed 2.0% of initial BW on an as-fed basis of grower diet at 0630 h and ad libitum finishing diet at 0930 h; 3) *M. elsdenii* culture (MEC), drenched with 50 mL of *M. elsdenii* (Lactipro Advance; MS Biotech, Inc., Wamego, KS) on day 0 of the trial, fed 2.0% of initial BW on an as-fed basis of grower diet at 0630 h and ad libitum finishing diet at 0930 h.

[b]Calves were dosed with no *M. elsdenii* or 50 mL of *M. elsdenii* (Lactipro; MS Biotech, Inc., Wamego, KS) on day 1 of the trial.

[c]Cattle were fitted with rumination tags (Allflex Flex Tag; SCR Engineers, Ltd.; Netanya, Israel) to track daily time in minutes ruminating and general activity.

[d]Pooled standard error of treatment means (n = 15 animals/treatment).

[e]Cattle were fitted with rumination tags and given 10 d to establish a baseline level of rumination and activity while consuming a hay-based diet.

[f]Weekly computations were established by establishing the delta (Δ) between each week and the baseline period.

[a–c]Row means that do not have common superscripts differ ($P < 0.05$).

[x–y]Row means that do not have common superscripts have a tendency to differ ($0.05 < P \leq 0.10$).

an increased tendency for an additional 2 wk in the 10-wk trial ($P \leq 0.10$). The more conservative diet adaptation approach most likely improved ruminal ecology, enabling DMI to reach bulk fill limits even at the onset of the trial (NRC, 2016). Since AGR and MEC treatments were exclusively challenged with the more calorically dense finisher diet, as DMI increased throughout the experiment, it is possible that the difference observed during the final weeks of the trial was a product of NDF concentration of the diets.

Oral drenching of MEC failed to provoke significant improvements in rumination compared with their AGR-fed counterparts. Contrasting the numerical advantages in DMI and G:F observed in Table 2, numerical improvements were observed for AGR cattle compared with MEC-drenched calves. In fact, a tendency during week 5 was detected for greater rumination times for AGR cattle compared to MEC calves ($P < 0.10$). A decline in general activity that coincided with the decline in rumination values amongst all treatments during week 5 implies that calves may have been experiencing stress. With the ability of *M. elsdenii* to metabolize ruminal lactate (Meissner, 2010; Henning et al., 2010a), the probiotic should be suited to better equip the microbiome to cope with stress. However, logged rumination values appear to suggest the opposite in this study. It is possible that the diets employed in the trial lacked the caloric density to trigger the lactate proliferation required to incite digestive upset and depress DMI and rumination at the onset of the trial. The limited number of calves (n = 15/treatment) and the lack of difference of DMI between treatments consuming the same diets appear to undermine these rumination values.

General activity characteristics detected a significant improvement amongst CON-fed cattle during weeks 2 and 3 of the trial. This suggests a more seamless dietary transition, enabling CON cattle to return to normal activity patterns compared with AGR and MEC treatments experiencing some level of digestive discomfort. A tendency was detected during week 7 for CON cattle to post increased activity duration compared with the AGR and MEC treatments.

Skeletal Growth Traits

Skeletal growth traits are presented in Table 4. Treatment elicited no effect on any parameter measured prior to or following the growing phase ($P \geq 0.28$). Adipose accumulation at the expense of skeletal growth is often cited as a caveat of early weaned programs. This topic was studied by Day et al. (2001) who noted that despite early weaned concentrate-fed heifers reaching puberty faster, they posted 72-kg lighter BW, suggesting that energy-rich diets hastened the growth curve. Supporting these findings, a 2% reduction in hip height at the terminal endpoint of early weaned calves was noted by Schoonmaker et al. (2004), collectively suggesting that the trade-off for rapid accretion during the growing phase is a reduction in harvest weight.

However, the data presented herein suggest that alteration of skeletal growth was not modified by increasing caloric density in early weaned calves, despite the AGR and MEC treatments achieving greater ADG during the growing phase trial. Skeletal values when considered in concert with performance outcomes appear to suggest that increasing caloric density of early weaned diets during the growing phase can reduce calf age at harvest without compromising compositional terminal weights.

Ultrasound Composition

Means characterizing the composition of early weaned calves following the growing phase trial are presented in Table 5. Corresponding with grower-fed CON calves documenting lower ADG, a 3.1% numerical reduction of LMA was observed compared with the average of the MEC and AGR treatments (60.6 vs. 62.0 and 63.0 cm^2, P = 0.46).

Table 4. Effects of feeding strategy*a* and *M. elsdenii**b*** on skeletal growth traits of early weaned calves at the beginning and end of a 72-d growing phase

	Treatment[a]				
Item	CON	AGR	MEC[b]	SEM[c]	*P*
Initial shoulder height, cm	96.9	96.7	96.8	0.74	0.99
Initial hip height, cm	101.2	100.7	101.0	0.72	0.96
Final shoulder height, cm	105.3	104.2	103.8	0.51	0.46
Final hip height, cm	113.8	113.8	113.4	0.54	0.94
Shoulder growth, cm	8.4	7.5	6.8	0.51	0.47
Hip growth, cm	12.7	13.1	12.2	0.50	0.78
Initial BW: shoulder	2.17	1.97	2.18	0.059	0.28
Final BW: shoulder	2.91	3.00	3.03	0.044	0.52
Initial BW: hip height	2.09	2.08	2.07	0.044	0.99
Final BW: hip height	3.14	3.28	3.30	0.049	0.36

[a]Calves were developed for 72 d: 1) control (CON), fed grower diet exclusively; 2) aggressive (AGR), fed 2.0% of initial BW on an as-fed basis of grower diet at 0630 h and ad libitum finishing diet at 0930 h; 3) *M. elsdenii* culture (MEC), drenched with 50 mL of *M. elsdenii* (Lactipro Advance; MS Biotech, Inc., Wamego, KS) on day 0 of the trial, fed 2.0% of initial BW on an as-fed basis of grower diet at 0630 h and ad libitum finishing diet at 0930 h.

[b]Calves were dosed with no *M. elsdenii* or 50 mg of *M. elsdenii* (Lactipro; MS Biotech, Inc., Wamego, KS) on day 1 of the trial.

[c]Pooled standard error of treatment means (n = 15 pens/treatment).

[a–c]Row means that do not have common superscripts differ (P < 0.05).

[x–y]Row means that do not have common superscripts tend to differ (0.05 < P ≤ 0.10).

Table 5. Effects of feeding strategy*a* and *M. elsdenii**b*** on ultrasound traits of early weaned calves at the end of the 72-d growing phase

	Treatment[a]				
Item	CON	AGR	MEC[b]	SEM[c]	*P*
LMA, cm[b]	60.6	63.0	62.0	0.811	0.46
12th rib fat, cm	0.35	0.33	0.33	0.008	0.47
Intramuscular Fat, %	3.54[b]	3.67[b]	3.90[a]	0.068	0.05
Marbling score[d]	3.38[b]	3.48[b]	3.67[a]	0.054	0.04

[a]Calves were developed for 72 d: 1) control (CON), fed grower diet exclusively; 2) aggressive (AGR), fed 2.0% of initial BW on an as-fed basis of grower diet at 0630 h and ad libitum finishing diet at 0930 h; 3) *M. elsdenii* culture (MEC), drenched with 50 mL of *M. elsdenii* (Lactipro Advance; MS Biotech, Inc., Wamego, KS) on day 0 of the trial, fed 2.0% of initial BW on an as-fed basis of grower diet at 0630 h and ad libitum finishing diet at 0930 h.

[b]Calves were dosed with no *M. elsdenii* or 50 ml of *M. elsdenii* (Lactipro; MS Biotech, Inc., Wamego, KS) on day 1 of the trial.

[c]Pooled standard error of treatment means (n = 15 pens/treatment).

[d]3.00 = slight^{00}, 4.00 = small^{00}, 5.00 = modest^{00}.

[a–c]Superscripts in the same row are significantly different (P ≤ 0.05).

Considering increasing diet caloric density (MEC and AGR vs CON) led to a 10.7% improvement in ADG and merely a 3.1% improvement in LMA, all treatments posting comparable 12th rib fat thickness and skeletal growth variables, is somewhat perplexing. Regardless, similar 12th rib fat thickness (0.35 vs. 0.33 and 0.33 cm, P =0.47) strengthens the hypothesis that increasing caloric density of diets did not further alter the growth curve in early weaned calves during the growing period.

Parameters associated with quality grade appeared to be altered by MEC application. Early weaned calves drenched with MEC documented enhanced intramuscular fat percentage and marbling scores compared with AGR and CON treatments ($P \leq 0.05$). The consensus amongst available literature suggests that MEC administration fails to alter carcass composition (Leeuw et al., 2009; McDaniel et al., 2009; Drouillard et al., 2012; Ellerman et al., 2017). Admittedly, these investigators were evaluating carcass traits of traditional feedlot cattle compared to the early weaned calves employed in the current study. Most lactate-utilizing bacteria appear to be favorable for propionate production (Rinttilä et al., 2009). Despite in vitro studies documenting *M. elsdenii* strain NCIMB 41125 showing little affinity to the acrylate pathway (Aikman, 2008; Kettunen et al., 2008; Rinttilä et al., 2009; Aikman et al., 2009; Hagg et al., 2010; Henning et al., 2010a), more recent studies conducted by Muya et al. (2015) and Thieszen et al. (2015) reported elevated propionate concentrations due to inoculation with the probiotic. A noted precursor of marbling development, and the only VFA that is gluconeogenic in nature, elevated propionate production may have triggered insulin secretions improving cellular uptake of glucose, manifesting in enhanced intramuscular fat deposition (Wan et al., 2009). Inconsistent results from studies, as to the primary VFA end-product created by MEC, may be due to the probiotic indirectly promoting acetate production by safeguarding fibrolytic microflora against acidotic pH levels, although the bacterium itself may be proliferating propionate. Therefore, the intrinsic diet and, thus, the resulting pH specific to a study (depending on fiber levels) may result in varying levels of indirect acetate production that would correspond to shifts in VFA ratios. We would hypothesize that the ratio is not as critical as the total abundance of added propionate produced.

Perhaps, more peculiar was the lack of statistical differences between AGR and CON treatments in ultrasonography quality-grade assessments. Given the similar levels of DMI throughout the study, and the caloric difference between the finisher and grower diets, the lack of contrast in marbling values is puzzling. This data contradict previous early weaned calf studies where increased starch concentrations enhanced marbling scores (Myers et al., 1999; Retallick et al., 2013; Scheffler et al., 2014) perhaps achieved by propagation of preadipocytes (Gorocica-Buenfil et al., 2007). Failure of elevated starch levels to metabolically imprint AGR calves suggests that subclinical digestive upsets may have limited microbial communities' ability to produce propionate. However, the lack of difference in DMI observed in AGR and CON calves may contradict this theory.

Harvested Carcass Parameters

Treatment means for carcass characteristics are summarized in Table 6. Following the completion of the growing phase trial, cattle remained in treatment groups and were finished at a commercial yard. Among the numerous benefits of early weaning calves is a reduction of cattle age at harvest if managed continuously in a dry lot. This is particularly true for spring-born calves, where extending the finishing phase to the heat of the summer can depress feed efficiency and elevate the risk of sudden death disease, especially in black-hided cattle (Lees et al., 2019). To contextualize the data presented in Table 6, steers and heifers were approximately 14 mo and 9 d of age at the time of harvest (433 d).

Although only a numerical difference, cattle fed a blend of grower and finisher diets (AGR and MEC treatments) in the growing phase had a 3.4% numerical advantage in live BW, which translated to a 3.8% increased HCW (374.4 vs. 389.4 and 388.0 kg, P = 0.35) and 3.6% greater harvest empty BW (525.0 vs. 544.8 and 542.9 kg, P = 0.35) compared with controls. Considering that all cattle were transitioned to a finisher diet over the same period at the Wrangler feedyard and that AGR and MEC treatments were already accustomed to calorically dense diets, it is cogent to suggest that the observed numerical difference in HCW and feedlot performance would have been amplified if these treatments were allowed to immediately start on a finisher ration.

Early weaned calves administered MEC maintained their growing phase ultrasonography quality-grade advantage, harvesting with an additional 22° of marbling compared with AGR-fed cattle and 12° compared with controls (4.54 vs. 4.44 vs. 4.66 units, P = 0.42). This echoes the 19° and 29° advantages at the end of the

Table 6. Effects of feeding strategy*a* and *M. elsdenii**b* on harvested carcass parameters

Item	Treatment[a] CON	AGR	MEC[b]	SEM[c]	*P*
HCW, kg	374.4	389.4	388.0	4.78	0.35
Marbling score[d]	4.54	4.44	4.66	0.064	0.42
Calculated yield grade	2.64[y]	2.62[y]	2.88[x]	0.058	0.10
LMA, cm[b]	92.3[y]	96.0[x]	92.5[y]	0.906	0.09
12th rib fat, cm	1.2	1.25	1.34	0.039	0.34
Kidney pelvic heart fat, %	2.01	1.97	1.97	0.017	0.56
Liver score[e]	2.04	2.26	1.44	0.155	0.15
Empty body fat, %[f]	28.9	29.1	30.0	0.24	0.22
Empty BW, kg[g]	525.0	544.8	542.9	6.32	0.35
28% adjusted final BW, kg[h]	510.0	526.7	511.5	5.50	0.39

[a]Calves were developed for 72 d: 1) control (CON), fed grower diet exclusively; 2) aggressive (AGR), fed 2.0% of initial BW on an as-fed basis of grower diet at 0630 h and ad libitum finishing diet at 0930 h; 3) *M. elsdenii* culture (MEC), drenched with 50 mL of *M. elsdenii* (Lactipro Advance; MS Biotech, Inc., Wamego, KS) on day 0 of the trial, fed 2.0% of initial BW on an as-fed basis of grower diet at 0630 h and ad libitum finishing diet at 0930 h.

[b]Calves were dosed with no *M. elsdenii* or 50 ml of *M. elsdenii* (*M. elsdenii* culture; MS Biotech, Inc., Wamego, KS) on day 1 of the trial.

[c]Pooled standard error of treatment means (control, $n = 45$; aggressive, $n = 45$; Lactipro, $n = 42$).

[d]3.00 = slight^{00}, 4.00 = small^{00}, 5.00 = modest^{00}.

[e]1= normal liver; 2 = A− (1–2 small abscesses); 3 = A (2–4 small active abscesses); 4 = A+ (>4 small active abscesses).

[f]Empty body fat (%) = 17.76207 + (4.68142 × 12th rib fat) + (0.01945 × HCW) + (0.81855 × quality grade) − (0.06754 × LMA). The numerical quality grade value was assigned on the basis of the marbling score quality grade such that standard = 3–4, select = 4–5, low choice = 5–6, average choice = 6–7, high choice = 7–8, low prime = 8–9, and average prime = 9–10; Guiroy et al. (2002).

[g]Empty BW = (1.316 × HCW) + 32.29; Guiroy et al. (2002).

[h]Shrunk BW adjusted to a 28% empty body fat = empty BW + [(28 – empty body fat) × 14.26]/0.891; Guiroy et al. (2002).

[a–c]Superscripts in the same row are significantly different ($P \leq 0.05$).

[x–y]Superscripts in the same row tend to differ ($0.05 < P \leq 0.10$).

growing phase revealed by ultrasound in Table 5. It is conceivable that MEC improved ruminal health during a pivotal development stage, promoting papillae growth and enabling augmented propionate absorption. A plausible theory is that MEC, working in concert with a calorically dense diet, elevated the flux of glucose being exposed to progenitor cells within skeletal tissues. Johnson and Chung (2007) have outlined how these mesenchymal stem cells can transdifferentiate into preadipocytes if provided the proper environmental signaling, especially in younger animals. This may explain why this early weaned model study is the first to demonstrate a marbling advantage of MEC, while studies with more traditional placement weights (>318 kg) have not seen the same response. This hypothesis would coincide with the observation that the MEC cattle had a tendency for reduced LMA versus the AGR group at the time of harvest ($P < 0.10$), even though there was no difference in LMA at the end of the 72-d growing phase. Redirection of progenitor cells would have limited the inventory of muscle satellite cells in the MEC cattle, which could have increased muscle fiber diameter over time, especially with anabolic steroid and beta-agonist usage during the finishing phase (Johnson and Chung, 2007). Further studies elucidating these cellular mechanisms would be warranted.

Considering the extent of marbling improvement created by MEC drenching, it is not surprising that these carcasses also displayed greater 12th rib fat, empty body fat percentage, and a tendency for higher calculated yield grades compared with AGR and CON treatments. In tandem with the AGR cattle tending to have greater LMA at harvest than both of the other treatments ($P = 0.09$), this translated to a numerically heavier adjusted empty BW value, and final BW adjusted to 28% empty body fat for AGR cattle, although these values were nonsignificant. Despite MEC and AGR calves receiving the same diets and posting comparable performance parameters during the growth phase, clear delineation in compositional growth exists between treatments. The direct comparison of CON calves fed exclusive grower diets versus AGR cattle fed a blend of grower and finisher lends credibility to the inference that intensifying caloric density in early weaned diets did not compromise subsequent feedlot gain and closeout weights. However, presented means for final empty BW adjusted to 28% empty body fat for MEC-treated cattle convolute this theory, most likely due to growing phase metabolic imprinting, favoring adipose development.

Finally, a numeric reduction in liver scores that approached a tendency (P = 0.15) was observed amongst cattle drenched with MEC. Typically, introducing highly processed grains to young, concentrate naïve cattle increases the prevalence of liver abscesses as prolonged acid insults enable phylogenic bacteria to escape the rumen and colonize the liver. This is often observed in calf-fed Holsteins finished in the high plains, which have documented a 48% liver abscess rate (Elanco, 2014). Additionally, the stress of the summer heat results in a 4% national seasonal uptick of abscess rates, which coincides with when most calf-fed beef cattle are traditionally marketed (Elanco, 2014). Additional early weaned studies with greater animal inventory may be able to evaluate if the use of MEC can promote favorable microbial communities, strengthening gut integrity, and limiting liver abscesses.

IMPLICATIONS

Traditionally, pushing light-weight calves to achieve greater ADG during their growing period was not recommended due to fears of hastening their growth curve. Nevertheless, genetics within the North American beef system have changed drastically and the potential for efficient growth is more superior than ever before. The current study demonstrates that early weaned, light-weight, SimAngus beef calves fed a calorically dense diet during the growing phase can generate improved feed efficiency and gain without altering skeletal or compositional growth. In fact, the differences between treatment HCW data mirroring trial BW (at day 72) suggests that cattle fed more calorically dense diets were able to sustain performance advantages throughout the finishing phase. Expedited weaning and development strategies should reduce cattle age at harvest and prompt a reduction in carbon footprint per animal (Capper, 2012).

MEC appears to have a profound impact on compositional growth. Trial ultrasound marbling advantages were sustained until harvest validating the ability of MEC to enhance lipogenesis, while numeric improvements in liver score data suggest that the probiotic was able to foster ruminal health without the aid of elevated fiber levels. In concert with early weaned protocols, it appears that high-growth potential calves may be the best model to exploit the apparent ability of MEC to augment marbling scores.

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