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Utilization of canola and sunflower meals as replacements for soybean meal in a corn silage-based stocker system[1]

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ABSTRACT: Two experiments were conducted to evaluate 3 silage-based stocker diets. In Exp. 1, diets were fed to a total of 276 animals over a period of 3 yr and performance data was collected. In Exp. 2, the same diets were subjected to in vitro digestion for 5 time periods: 0, 6, 12, 24, and 48 h, to evaluate IVDMD, production of fermentation end products, and efficiency of transformation of energy. The experimental diets were similar, except for their protein supplements. They were composed of: 1) 74% corn silage, 15.2% ground ear corn, and 10.8% soybean meal (SBM); 2) 74.4% corn silage, 9.8% ground ear corn, and 15.8% canola meal (CAN); 3) 74.5% corn silage, 9.8% ground ear corn, and 15.7% sunflower meal (SUN). Results from Exp. 1 showed that DMI was similar across all treatments ($P = 0.167$), but ADG was greater ($P = 0.007$) for animals fed either SBM or CAN than for animals fed SUN (1.29, 1.28, and 1.20 kg/d, respectively). Both CAN and SUN significantly reduced ($P < 0.001$) daily feeding cost per animal in comparison to SBM. Exp. 2 revealed that total VFA production was similar for all treatments ($P = 0.185$), and greatest molar proportions of propionate were observed for SBM and CAN ($P = 0.02$). Additionally, IVDMD was highest for SBM ($P < 0.001$). Regression analysis showed that most of the evaluated traits followed a quadratic trend for incubation times ($P \leq 0.02$). On average, the in vitro technique used in this study was able to account for 97.03% of the caloric transformations suffered by DE throughout the different incubation times. Overall, our findings revealed that although animals receiving SUN had the cheapest daily feeding cost, important traits like ADG and feed conversion rate were negatively affected by this treatment. In contrast, data showed that CAN was an effective replacement for SBM for it maintained similar animal performance while decreasing feed costs. Therefore, from a producer standpoint, CAN is a viable alternative to replace the more costly SBM diet in silage-based stocker operations.

Key words: canola meal, corn silage, cost of gain, stockers, sunflower meal

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INTRODUCTION

Recent changes in the feedstuff market have created a new scenario for beef cattle producers. Feeds traditionally used in beef cattle operations have reached unprecedented prices in recent years.

The feedstuff market is very volatile. As an illustration, the national average price of corn grain has suffered a variation of 139% in the last 5 yr. This same trend was observed for soybean prices, as they varied 90.4% in the same period (USDA, 2017). This market volatility has highlighted the need for continued research on alternative feeds. Practically, alternative feeds must be able to reduce costs while yielding similar or even improved animal performance (Segers et al., 2013).

Canola and sunflower meals are co-product feeds classified as protein supplements (Conrad et al., 1982). They both result from the oil extraction process of their respective seeds. Canola meal

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typically contains less gross energy, less protein, and more fiber when compared to soybean meal; nonetheless, it is higher than soybean meal in several essential vitamins and minerals (Bell, 1993).

The nutritional value of sunflower meal is greatly influenced by the amount of hull in its composition. The proportion of the hull removed before processing differs among processing facilities. In some cases, a portion of the hulls may be added back to the meal after crushing. This variation in processing may result in meals ranging from 25 to over 40% CP for products containing all the hulls or completely de-hulled, respectively (Anderson and Lardy, 2012).

The purpose of this study was to evaluate the replacement of soybean meal with canola or sunflower meals as protein supplements in a corn silage-based stocker operation. Additionally, to evaluate the digestibility and formation of fermentative end products related to feed efficiency, in vitro assays were performed on the experimental diets.

MATERIALS AND METHODS

All procedures involving animals were verified and approved by the University of Georgia's Office of Animal Care and Use (Animal Use Protocol #A2012 09–015-Y1-A0).

The research was divided into 2 experiments. Experiment 1 was a feeding trial conducted from December to March during three consecutive years: 2010 to 2011 (YR1); 2011 to 2012 (YR2); and 2012 to 2013 (YR3). Experiment 2 was an in vitro digestion trial. The same treatments offered to animals in the feeding trial were incubated for up to 48 h for assessment of degradability, formation of gases (CO_2 and CH_4), VFA, and transformation of dietary energy.

Exp. 1

A 3-yr feeding trial using weaned stocker animals was conducted at the Georgia Mountain Research and Education Center, located in Blairsville, GA. Over 3 yr, a total of 276 animals were used: 93 in yr 1, 93 in yr 2, and 90 in yr 3. In each year, animals were fed for a period of 84 d.

Animal and Diet Management. Prior to the experimental period, animals were preconditioned for 55 d. They were delivered at the research station during the third week of October, when they were treated for parasites using transdermal ivermectin (Durvet, Inc., Blue Springs, MO). During this 55-d preconditioning period, animals were supplemented with ground ear corn at 4.5 g/kg of BW and grazed stockpiled tall fescue (*Festuca arundinacea* cv. Kentucky 31) and orchard grass (*Dactylis glomerata*).

After the backgrounding phase, animals were weighed (initial BW = 285 ± 9.7 kg), stratified by weight, and assigned to a pen. A total of 9 pens were used. Each one was approximately 4 ha and composed of dormant grasses, which had been previously mowed to ground level to ensure animals would not graze during the experimental period. Each pen was randomly assigned to 1 of 3 treatments. On a DM basis, the experimental treatments were formulated to contain: 1) 75% corn silage, 15% ground ear corn, and 10% soybean meal (SBM); 2) 75% corn silage, 10% ground ear corn, and 15% canola meal (CAN); 3) 75% corn silage, 10% ground ear corn, and 15% sunflower meal (SUN). Due to variation in the DM contents, the actual formulation that animals received was slightly different (Table 1). Each day, troughs were inspected at 0800 h to evaluate feed consumption from the previous day. Next, diets were weighed, mixed, and offered to provide approximately 110% of previous day's intake based on visual observation of the bunk. Feed was placed in fence-line concrete troughs that were covered to protect from precipitation and allow at least 41 cm of linear bunk space per animal. On Monday of each week, orts were collected, weighed, and dried for subsequent DMI estimation. Weekly DMI was estimated as the difference of sum of daily offering and the weekly orts. Animals had free access to water and a commercial mineral throughout the experiment (12% Ca, 9% P, 24% NaCl, 0.20% K, 0.30% Mg, 0.20% S, 50 mg/kg Co, 150 mg/kg Cu, 70 mg/kg I, 1,000 mg/kg Mn, 1,750 mg/kg Zn, 1,000 mg/kg Fe). Samples from the experimental diets were submitted for chemical analysis

Table 1. Composition and chemical analysis of the experimental treatments fed to stocker animals (DM basis)

	Treatment[1]		
Item	SBM	CAN	SUN
Ingredient, % of DM			
Corn silage	74.0	74.4	74.5
Ear corn	15.2	9.8	9.8
Soybean meal	10.8	–	–
Canola meal	–	15.8	–
Sunflower meal	–	–	15.7
Chemical analysis[2], % of DM			
Dry matter	46.4	46.9	46.9
Crude protein	13.5	12.9	12.3
Calcium	0.19	0.23	0.21
Phosphorus	0.27	0.36	0.34
TDN	73.3	71.0	70.4
ME[3], Mcal/kg of DM	2.64	2.56	2.54
Cost, $/t	80.63	75.34	71.76

[1]SBM: protein supplement was soybean meal; CAN: protein supplement was canola meal; SUN: protein supplement was sunflower meal.

[2]The University of Georgia Feed and Environmental Water Laboratory, Athens, GA.

[3]Calculated according to the NRC (2000).

at The University of Georgia Feed and Environmental Water Laboratory, located in Athens, GA (Table 1).

Animal Performance. Animals were weighed on d 0, 28, 56, and 84 of the trial. Both initial and final BW were measured on 2 consecutive days and averaged to minimize the effects of fill. Animals were weighed in the morning, before being fed. The cost to gain 1 kg of BW was calculated using actual prices for ingredients in each year, along with estimated DMI and ADG data.

Statistical Analysis. Analysis of variance for animal performance was performed using the software R (The R Foundation for Statistical Computing, Vienna, Austria) in a completely randomized design with 3 treatments (SBM, CAN, and SUN). Pen was considered as the experimental unit. Treatment, year, and pen were considered as fixed effects. Initial BW was used as a covariate for analyses of final BW and DMI. The model also included a treatment × year interaction. Orthogonal contrasts were tested using Tukey's honest significant difference test. Means were considered different at $\alpha = 0.05$.

Exp. 2

The diets used in experiment 1 were subjected to in vitro digestion to estimate degradability of DM and to measure concentration of fermentative byproducts. Samples from the experimental diets were collected each year, composited across year within diet, and used as substrate for the in vitro fermentations.

Substrate Preparation and Inoculation Process. Substrates were ground to pass a 2 mm screen using a Model 4 Wiley Mill (Thomas Scientific, Swedesboro, NJ) and were dried to constant weight for determination of DM. Next, 1.5 g of the substrate-diets were placed into 160-mL septum bottles along with 67 mL of McDougall's buffer. Thirty septum bottles were used for the incubations. An additional set of 10 bottles were included to account for blank contributions.

Ruminal fluid was collected from three lactating dairy cows prior to their morning feeding to represent a silage-based diet. Approximately 750 mL was collected from each animal, placed in a sealed thermos and transported to the laboratory. Ruminal fluid from each cow was strained through a 500-micrometer nylon mesh to remove feed particles and then combined into 1 mixture. The mixture was placed in a water bath at 39°C and flushed with CO_2. Next, all septum bottles were inoculated with 33 mL of the processed rumen fluid. Since each bottle had previously received 67 mL of McDougall's buffer, the achieved ratio of buffer to rumen fluid was 2:1. Bottles were gassed with CO_2, sealed with rubber stoppers, and placed in a water bath incubator at 39°C. Incubations times were: 0, 6, 12, 24, and 48 h post inoculation.

Collection and Analysis of Gases. Collection of fermentation gases were conducted at 3-hr intervals using a water displacement method. This method consisted of inserting 22-gauge needles into the incubation bottle and into a water-filled bottle connected to a three-way valve and a 60-mL syringe. During gas measurement, the valve was directed to allow gas to flow from the incubation bottle to the 60-mL syringe. Gas pressure moved the syringe plunger until pressure was equilibrated. The incubation bottle was swirled to allow gas to escape. Once the plunger stopped moving during swirling of the septum bottle, gas pressure was equilibrated and the syringe reading was recorded. The valve was then turned to direct the collected gas into the water-filled bottle. During this procedure, an extra 22-gauge needle was inserted into the water-filled bottle to allow displacement of water and capture of gas inside the bottle. The apparatus was then disconnected and the water displacement bottle was stored upside down until analysis of its gas content.

Compositional analyses were performed for CO_2 and CH_4 using a gas chromatograph (SRI Instruments, Torrance, CA) equipped with a thermal-conductivity detector, a flame ionization detector, and a gas sampling valve with a 0.5-mL sample loop. Separation was achieved using a 0.3 by 90 cm HayeSep D packed column. The carrier gas was helium and the oven temperature was maintained at 40°C. Gas samples were manually injected into the sample loop with a syringe.

Ammonia Nitrogen, VFA, and Digestibility Analyses. After the final gas collection at the end of the incubation periods, incubation bottles were opened. The contents from each bottle were transferred to Nalgene bottles and frozen at –20°C to stop fermentation and be stored until further analysis. Three days later, the frozen bottles were thawed and the contents were separated into liquid and particulate fractions by centrifuging at 1,400 × *g* for 10 min using a C-6000 centrifuge (International Equipment Company, Needham Heights, MA). The liquid fraction was further prepared for analysis of VFA and NH_3–N. Preparation included freezing the liquid at –20°C for 3 d, thawing, and centrifuging it at 1,400 × *g* for 15 min. Then, 5 mL of the supernatant was pipetted into 15-mL tubes. A 25% metaphosphoric acid solution was prepared and 1 mL was added to the tubes. Tubes were sealed, vortexed, and frozen at –20°C. Twenty-4 h later, samples were thawed, centrifuged at 1,400 × *g* for 20 min, and 1.5 mL of the supernatant was transferred into vials for analysis of VFA by gas chromatography (Varian, Inc., Santa Clara, CA) using a flame ionization detector and a capillary column (CP-WAX 58 FFAP 25 m 0.53 mm, Varian CP7767). The oven temperature was set at 100°C and was held for 1 min. Temperature was then increased to 120°C and was held for 7 min.

Injector and detector temperatures were set at 170 and 175°C, respectively. Sample injection volume was 1.0 μL. Nitrogen was the carrier gas set at a flow rate of 20 mL/min. Analysis of NH_3–N was performed according to the procedure described by Broderick and Kang (1980) using a Beckman DU-600 spectrophotometer at 620 nm (Beckman Coulter, Inc., Brea, CA).

The particulate fraction, composed mainly of undigested substrate and microbial organic matter, was dried in a forced-air oven at 55°C until constant weight for determination of DM (Blue M Electric Company, Blue Island, IL). The dried residues were weighed and recorded to estimate DM disappearance. The energy content of the solid fraction was also evaluated. The dried residues were subjected to GE analysis in a Parr 1261 bomb calorimeter (Parr Instrument Company, Moline, IL). This procedure was also performed on the original diets. Through the use of standard caloric coefficients, the quantities of VFA and CH_4 produced in vitro were converted to their equivalents in calories. This information allowed estimation of the extent that both VFA and CH_4 contributed to apparent in vitro DE.

Statistical Analysis. In vitro DM disappearance rates were calculated using the exponential equation of Ørskov and McDonald (1979): $Y = a + b(1 - e^{-ct})$, where Y was DM disappearance in time, and a, b, and c were constants of the exponential equation, as follows: a = the DM disappearance at time 0, b = the proportion of DM disappearance during time (t), and c = the rate of DM disappearance of the degradable fraction.

Analysis of variance was performed to verify the effects of treatment, incubation length, and their interactions on the fermentation traits. Contrasts were compared using Tukey's honest significant difference test. Differences were considered significant at $\alpha < 0.05$. Additionally, a regression analysis was performed to evaluate the trends that fermentation traits followed over time. Traits were tested for both linear and quadratic effects. Analyses were performed using the software R (The R Foundation for Statistical Computing, Vienna, Austria).

RESULTS AND DISCUSSION

Exp. 1

Animal performance data showed that there was no effect of the experimental treatments on DMI expressed as kg/d or as a percentage of the BW ($P \geq 0.087$; Table 2). Regarding development and growth, data revealed that initial BW was similar for all treatments ($P = 0.56$); whereas, final BW was greater ($P = 0.009$) in the SBM and CAN groups compared to cattle fed SUN. Average daily gain was also greater ($P = 0.007$) for both SBM and CAN treatments compared to SUN. Similar ADG in ruminants fed soybean meal or canola meal as protein supplements have been reported by Rule et al. (1994) and Ponnampalam et al. (2005). However, the decreased ADG observed when sunflower meal was fed differs from the findings reported by Stake et al. (1973). These authors observed similar ADG for weaned calves supplemented with either sunflower meal or soybean meal. Nevertheless, one important observation is that those authors used sunflower meal containing 37% CP, whereas, the one used in our study had 32.5% CP. Feed efficiency, expressed as gain:feed ratio, was greatest in SBM ($P = 0.02$), lowest in SUN, with CAN being intermediate (Table 2). Rule et al. (1994) conducted 2 feeding trials using corn silage as roughage and canola meal or soybean meal as the protein sources. They found similar gain:feed ratio in cattle fed either soybean meal or canola meal. A study by Stake et al. (1973) reported similar feed efficiency for weaned calves fed sunflower or soybean meals, which differs from our results.

Table 2. Performance of stocker animals receiving the experimental treatments

	Treatment[1]				
Item	SBM	CAN	SUN	SE	*P*-value
Number of animals[2]	89	89	98		
Initial BW, kg	285.8	286.1	283.8	1.60	0.56
Final BW, kg	394.3[a]	393.6[a]	384.3[b]	1.58	0.009
ADG, kg	1.29[a]	1.28[a]	1.20[b]	0.018	0.007
DMI, kg/d	6.67	6.82	6.73	0.05	0.167
DMI, g/kg BW	1.96	2.01	2.01	0.02	0.087
G:F, kg	0.195[a]	0.188[ab]	0.178[b]	0.003	0.02
Cost of gain, $/kg of BW gain	1.13	1.09	1.10	0.02	0.31
Daily feed cost, $[3]	1.44[a]	1.38[b]	1.30[c]	0.01	< 0.001

[a–c]Means within a row lacking a common superscript differ ($P < 0.05$).

[1]SBM: protein supplement was soybean meal; CAN: protein supplement was canola meal; SUN: protein supplement was sunflower meal.

[2]Number of animals used in the 3 yr of the experiment.

[3]Daily Feed Cost: Average daily cost per animal considering prices across the 3 yr.

The cost to gain 1 kg of BW was similar ($P = 0.31$) across all treatments. Nevertheless, the alternative diets CAN and SUN yielded lower ($P < 0.001$) cost per head per day when compared to SBM. Considering SBM as reference, the daily feeding cost per animal was reduced up to 9.7% with the use of the alternative diets.

Exp. 2

Regression analysis revealed a quadratic ($P < 0.001$) effect for total gas production over the incubation period. Moreover, gas production was highest for SBM and CAN, and lowest for SUN ($P = 0.002$; Table 3). No dif-

Table 3. Proportions of VFA (mol/100 mol), total VFA concentration (m*M*), IVDMD, NH_3–N, total gas production, and production of CH_4 and CO_2 for the different treatments incubated for up to 48 h

	Treatment[1]				
Item	SBM	CAN	SUN	SE[2]	*P*-value
Acetate	57.5[b]	58.1[a]	58.3[a]	0.14	0.002
Propionate	27.72[a]	27.24[ab]	27.16[b]	0.13	0.02
Isobutyrate	0.75	0.73	0.74	0.006	0.10
Butyrate	10.96	11.01	10.87	0.066	0.35
Isovalerate	1.66[a]	1.53[b]	1.53[b]	0.01	< 0.001
Valerate	1.42[a]	1.39[ab]	1.37[b]	0.01	0.03
Total VFA, m*M*	81.4	80.2	79.4	0.73	0.185
A:P ratio[3]	2.09[b]	2.14[a]	2.16[a]	0.014	0.006
IVDMD, %	49.91[a]	47.47[b]	45.95[b]	0.6	< 0.001
NH_3–N, m*M*	4.03	4.10	3.67	0.20	0.308
Total gas production, ml	181.7[a]	179.8[a]	171.6[b]	1.7	0.002
CH_4, µmoles/ml of gas	6.2	6.7	6.2	0.2	0.31
CO_2, µmoles/ml of gas	21.5	23.3	21.7	0.9	0.43

[a,b]Means within a row lacking a common superscript differ ($P < 0.05$).

[1]SBM: protein supplement was soybean meal; CAN: protein supplement was canola meal; SUN: protein supplement was sunflower meal. Substrates were incubated for 0, 6, 12, 24, and 48 h. Values are the means for all incubation times.

[2]Standard error of the main-effect means.

[3]A:P ratio = acetate:propionate ratio.

ferences ($P \geq 0.31$) were observed across treatments for concentrations of CH_4 and CO_2 per mL of gas, however, across incubation times, a linear ($P = 0.01$) effect was observed for concentration of CH_4, and a quadratic ($P = 0.004$) effect was observed for concentration of CO_2. Production of NH_3–N was not influenced by treatments ($P = 0.308$), but there was a quadratic ($P < 0.001$) effect for incubation time (Table 4). Across treatments, NH_3–N was greatest ($P < 0.001$) when the incubations lasted 48 h, followed by the 24 h time period, and it was least for either the 12, 6, or 0 h time periods (data not shown).

No differences ($P = 0.185$) were found across treatments regarding total VFA production, however, this trait increased in a quadratic manner ($P < 0.001$) over the 48-h incubation period. For the 24-h of incubation length, total concentration of VFA was 102.7 m*M*. This value is lower than the ones reported by Quinn et al. (2009), May et al. (2010), and Smith et al. (2010) for in vitro incubations lasting 24 h. These authors reported concentrations ranging from 124.6 to 166.8 m*M*, however, the substrate-diets used in their studies were substantially different from the ones used in this experiment. In the current research, the diets contained approximately 75% roughage as corn silage, whereas, in the mentioned studies, the inclusion of roughage varied from 0 to 9%, closely resembling diets offered in feedlots and not in stocker operations.

Regarding the molar proportions of VFA, a treatment effect ($P \leq 0.03$) was observed on production of acetate, propionate, isovalerate, and valerate (Table 3) with SUN yielding the highest proportion of acetate, and the lowest proportion of all the other mentioned VFA. The SBM treatment yielded the lowest ($P = 0.002$) proportion of acetate and the highest ($P = 0.02$) molar proportion of propionate. Furthermore, SBM

Table 4. Effect of incubation time on proportions of VFA (mol/100 mol), total VFA concentration (m*M*), IVDMD, NH_3–N, total gas production, and production of CH_4 and CO_2 for the different treatments incubated for up to 48 h

	Incubation Period, hours[1]						*P*-value[2]	
Item	0	6	12	24	48	SE[3]	L	*Q*
Acetate	61.7	56.9	56.6	57.0	57.6	0.17	0.006	< 0.001
Propionate	24.7	29.0	29.2	27.7	26.4	0.17	0.62	< 0.001
Isobutyrate	0.66	0.61	0.63	0.79	1.01	0.008	< 0.001	0.001
Butyrate	10.5	10.8	10.8	11.4	11.1	0.086	< 0.001	< 0.001
Isovalerate	1.26	1.27	1.34	1.70	2.29	0.01	< 0.001	0.02
Valerate	1.12	1.40	1.39	1.49	1.58	0.015	< 0.001	< 0.001
Total VFA, m*M*	28.3	65.1	79.6	102.7	125.8	0.94	< 0.001	< 0.001
A:P ratio[4]	2.49	1.97	1.94	2.06	2.19	0.018	0.39	< 0.001
IVDMD, %	23.2	39.0	46.0	60.3	70.3	0.7	< 0.001	< 0.001
NH_3–N, m*M*	1.95	0.96	1.11	4.23	11.42	0.26	< 0.001	< 0.001
Total gas production, ml	–	105.5	169.5	270.5	343.0	2.2	< 0.001	< 0.001
CH_4, mmoles/ml of gas	–	6.1	5.7	6.8	6.8	0.3	0.01	0.43
CO_2, mmoles/ml of gas	–	19.8	22.0	24.9	21.9	1.2	0.26	0.004

[1]Experimental diets composed of 75% corn silage plus supplements were incubated for 5 different lengths ranging from 0 to 48 h. Values are the means of all treatments.

[2]Significance of regression coefficients for traits on incubation time. Linear (L) and quadratic (Q) effects.

[3]Standard error of the main-effect means.

[4]A:P ratio = acetate:propionate ratio.

yielded the lowest ($P = 0.006$) acetate:propionate ratio, while both CAN and SUN yielded higher ratios. Data from regression analysis show that the proportions of all measured VFA and the acetate:propionate ratio followed a quadratic trend ($P \leq 0.02$) for incubation time.

As observed for several other traits, IVDMD increased in a quadratic ($P < 0.001$) manner as incubation time was extended (Table 4 and Fig. 1). A treatment effect was also observed, with SBM averaging the highest ($P < 0.001$) IVDMD, followed by CAN and SUN (Table 3). Dry matter degradation rate was different ($P < 0.01$) across treatments, with SBM having the highest percentage per h, followed by CAN, and SUN (Table 5). However, when comparisons were performed by fraction, no differences were found ($P = 0.10$) for the fraction A (immediately degradable), but distinct degradation rates ($P < 0.01$) were observed in fraction B (degradable at a measurable rate), and C (which is the fraction unavailable to ruminal degradation). In alignment with our other findings, SUN had the greatest fraction C among all treatments (Table 5).

The assessment of caloric values of the original diets, the digested residues, and the blank samples allowed estimation of in vitro DE. The produced amounts of VFA and CH_4 were also expressed as energy (calories) through the use of standard coefficients and were converted to a percentage of the in vitro DE.

Table 5. In vitro DM degradation of the experimental treatments after incubation for 48h

	Treatment[1]				
Item	SBM	CAN	SUN	SE[2]	*P*-value
Rate of degradation, %/h	1.55[a]	1.43[b]	1.40[c]	0.005	< 0.01
Degradation fraction,[3] % of DM					
A	22.03	25.21	22.45	0.85	0.10
B	52.54[a]	43.54[c]	45.04[b]	0.26	< 0.01
C	25.42[c]	31.25[b]	32.50[a]	0.25	< 0.01

[a–c]Means within a row lacking a common superscript differ ($P < 0.05$).

[1]SBM: Protein supplement was soybean meal; CAN: Protein supplement was canola meal; SUN: Protein supplement was sunflower meal.

[2]Standard error of the main-effect means.

[3]A = fraction immediately degradable; B = fraction degradable at a measurable rate; C = fraction unavailable to ruminal degradation.

No effect ($P \geq 0.17$) of treatment was observed on the efficiencies of transformation of energy (data not shown), but the effect of changing the length of incubation was very evident in all the evaluated traits ($P < 0.001$; Table 6). The present study found that 11.14% of DE was converted into CH_4 for incubations lasting 24h (Table 6). This finding is in alignment with the results reported by McGinn et al. (2004). These authors conducted two experiments where steers were fed a high-forage diet (75% barley silage, DM basis) and placed in chambers to measure gas emissions. In

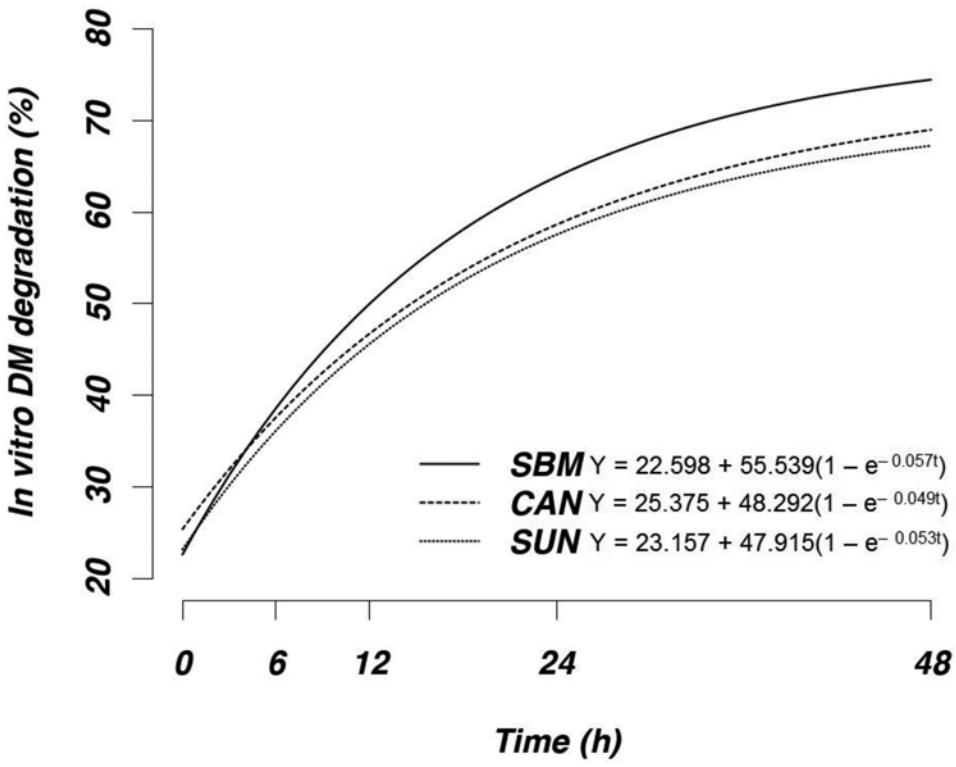

Figure 1. Calculated IVDMD for the treatments soybean meal (SBM), canola meal (CAN), and sunflower meal (SUN). Dry matter degradation rates were not different ($P > 0.05$) across treatments. Degradation rates were calculated using the exponential equation of Ørskov and McDonald (1979): $Y = a + b(1 - e^{-ct})$, where Y = DM disappearance in time (t); a = DM disappearance at time 0; b = the proportion of DM disappearance during time, and c = the rate of DM disappearance of the degradable fraction.

Table 6. Effect of incubation time on percentage of DE converted into VFA, CH_4 and microorganism cells

	Incubation period, hours[1]						
Item	0	6	12	24	48	SE[2]	*P*-value
% of DE converted into VFA	8.94[c]	49.37[b]	56.68[ab]	59.91[a]	65.61[a]	2.07	< 0.001
% of DE converted into CH_4	–	5.57[b]	7.41[b]	11.14[a]	11.94[a]	0.47	< 0.001
% of DE retained as microorganisms	74.95[a]	46.47[b]	34.70[c]	29.13[cd]	23.34[d]	1.48	< 0.001
Percentage of DE accounted in vitro[3]	83.89	101.41	98.79	100.18	100.89		

[a–d]Means within a row lacking a common superscript differ ($P < 0.05$).

[1]Experimental diets composed of 75% corn silage plus supplements were incubated for 5 different lengths ranging from 0 to 48 h. Values are the means of all treatments.

[2]Standard error of the main-effect means.

[3]Percentage of DE accounted in vitro = percentage converted into VFA + percentage converted into CH_4 + percentage retained as microorganism cells.

the first experiment 10.51% of the DE consumed was lost in the form of CH_4, and in the second experiment 11.36% of DE was lost in the form of CH_4.

Overall, although in vitro systems have some limitations in simulating in vivo conditions, the technique used in the present study yielded results that are consistent with the ones observed in live animals. Furthermore, according to the law of conservation of energy, energy can neither be created nor destroyed. Accordingly, the in vitro technique used in this study was able to account for virtually all the transformations of DE into other compounds such as VFA and CH_4.

Regarding the experimental diets, although SUN costed less per metric ton, animals on this diet had a poorer performance. However, animals receiving either CAN or SBM had similar performance, since no differences were observed in important traits such as final BW, ADG, and G:F. In addition, compared to SBM, CAN decreased the daily feeding cost per animal. Therefore, taken together, these results demonstrate that CAN is a viable alternative to SBM in stocker operations.

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