Effect of Live Yeast and Mannan-oligosaccharides on Performance of Early-lactation Holstein Dairy Cows

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ABSTRACT: This study evaluated the effects of live yeast and yeast cell-wall mannan-oligosaccharide supplementation on performance and nutrient digestibility during early lactation in cows fed a diet based on a mixture of corn silage and alfalfa hay as forage sources. Eight multiparous Holstein dairy cows (average days in milk, 27±6) were used in a replicated 4×4 Latin square design. Diets contained 45% forage and 55% concentrate on a dry matter (DM) basis and treatments were: i) basal diet without additive (Control), ii) basal diet with 32 g/d of mannan-oligosaccharides (MOS), iii) basal diet with 1.2×10^{10} colony forming units per day (cfu/d) of live yeast (*Saccharomyces cerevisiae* CNCM 1-1077; SC), and iv) basal diet with a mixture of MOS (32 g/d) and SC (1.2×10^{10} cfu/d; MOS+SC). Treatments had no effect (p>0.05) on DM intake and yields of milk, 3.5% fat-(FCM) and energy-corrected milk (ECM), and on milk fat percentage, body condition score and blood metabolites. Compared with the Control, only supplementation of SC resulted in numerically higher yields of FCM (41.9 vs. 40.1 kg/d) and ECM (41.8 vs. 40.3 kg/d), and milk fat percentage (3.64 vs. 3.43%). While the MOS diet had no effects on performance compared to the Control, the combination treatment MOS+SC increased milk protein percentage (p<0.05). Also, the MOS supplementation, both alone or in combination with SC, numerically increased milk fat percentage. The SC supplementation increased apparent digestibility of DM and crude protein while the MOS supplementation did not affect digestibility. Concentrations of total volatile fatty acids (VFA) and ruminal pH were similar across treatments. Overall results indicated that supplementation of MOS produced variable and inconsistent effects on rumen metabolism and performance, whereas SC supplementation improved nutrient digestibility and numerically increased FCM and ECM yields, which could not be enhanced by the combined supplementation of MOS+SC. According to our experimental condition, there was no effect of MOS alone or in combination with SC on dairy cow performance. (**Key Words** : Feed Additive, Yeast, Mannan-oligosaccharides, Dairy Cow, Performance)

INTRODUCTION

During early lactation, cows experience huge negative energy balance and insufficient dry matter intake (DMI) that may increase the incidence of energy-related metabolic disorders. As achieving maximum potential intake is difficult during this critical stage, a promising approach is to use additives that increase the digestibility of the diet, especially fiber fractions, and consequently increase energy and nutrient supply. Live yeasts are among those additives that have been shown to increase digestibility of fiber and CP (Erasmus et al., 1992; Wohlt et al., 1998) in some but not all (Arambel and Kent, 1990; Wohlt et al., 1991) studies. As an alternative, some forms of complex oligosaccharides

including mannan-, galacto-, and fructo-oligosaccharides, which recently have been used as prebiotics in monogastric feeding regimens (Shafey et al., 2001; Yang et al., 2007), may also be examined in ruminant diets to test whether or not these compounds act as agents that selectively attach to bacteria and may thus ultimately modify ruminal metabolism. At the intestinal level, irreversible attachment of fructo- and mannan-oligosaccharides to pathogens, which thereby reduce the chance of pathogen attachment to intestinal mucosa, has been documented (Sohn et al., 2000). In sheep and cattle, galacto-oligosaccharides (GOS) have been used with the objective of reducing methanogenesis or improving nitrogen utilization efficiency through decreased urinary N excretion (Mwenya et al., 2004; Sar et al., 2004b; Mwenya et al., 2005b). Very limited data is available about the ruminal effects of oligosaccharides when they are supplemented to diets of dairy cows. Mwenya et al. (2005a) observed that GOS lowered ruminal pH, increased VFA concentrations and had minor effects on ruminal DM

degradation profile and microbial nitrogen supply. However, information regarding the consequences of using selected oligosaccharides on performance is scarce. In terms of microbe-attaching properties and also as a nutrient source for some selected microorganisms, it seems limited studies have been conducted on ruminal effects of mannan-oligosaccharides (MOS). We hypothesized that MOS may also modify ruminal fermentation by selective inhibition or stimulation of microbial activity, thus they may also have an influence on milk production or composition. Examining the feeding of a mixture of yeast and MOS in diets of lactating cows would be of interest because the stimulatory impact of SC (Chaucheyras-Durand et al., 2008) may interact with possible inhibitory effects of MOS, at least on certain ruminal populations, and would alter the net products of rumen metabolism.

MATERIALS AND METHODS

Animals and treatments

Eight multiparous cows in early lactation and averaging 27±6 days in milk were used in a replicated 4×4 Latin square experiment. Cows were housed in individual pens (2.0×2.2 m) and fed the experimental diets as a total mixed ration (TMR) in equal allocations at 09:00 and 16:00 h. The basal diet consisted of (% DM): 29.96 alfalfa hay, 14.98 corn silage, 28.70 barley grain, 3.88 corn grain, 1.68 fat supplement, 10.86 soybean meal, 5.22 canola meal, 2.38 cotton seed meal, 0.63 calcium carbonate, 1.32 micro mineral-vitamin premix, and 0.42 salt. Energy and nutrient concentrations (DM basis) were; 6.82 MJ/kg NE_L, 17.1% CP, 31.6% NDF (22.4% forage-NDF), 21.9% ADF, 3.6% ether extract, 0.8% calcium, and 0.4% phosphorus. Values for NE_L, calcium and phosphorus were taken from NRC (2001) tables. The TMR was offered for *ad libitum* intake and feed consumption was monitored daily to ensure 5 to 10% refusals. Fresh water was continuously available and cows were milked at 05:00, 12:00, and 21:00 h. Each experimental period was 21 d in length, allowing 14 d for adaptation and 7 d for sampling and data collection. Treatments were Control, basal diet without additive; MOS, basal diet with 32 g/d of MOS (Agrimos®, Lallemand, Blagnace, France); SC, basal diet with $1.2×10^{10}$ colony forming units per day (cfu/d) of *Saccharomyces cerevisiae* CNCM 1-1077 (Levucell® SC, Lallemand, Blagnace, France); and MOS+SC, basal diet with a mixture of MOS (32 g/d) and SC ($1.2×10^{10}$ cfu/d). The study was conducted at the Dairy Facilities of the Lavark Research Station (Isfahan University of Technology, Isfahan, Iran) from October to December, 2007. Animals were cared for according to the guidelines of the Iranian Council of Animal Care (1995).

Sample collection

Samples of TMR and orts, for individual cows, were collected from d 15 to 20 of each period. Fecal samples were collected after the a.m and p.m feeding from the rectum of each cow for three consecutive days and frozen at -13°C. Milk yield was recorded for three consecutive days from day 15 to 17 of each period and was sampled at all milkings for compositional analysis. On d 21, rumen fluid was obtained via a stomach tube 3 h after morning feeding, and pH of the squeezed fluid was immediately determined with a portable pH meter (HI8314, Hanna Instruments, Cluj-Napoca, Romania); 10 ml of fluid was preserved with 1 ml of 5% sulfuric acid for later analysis of volatile fatty acids (VFA) and ammonia nitrogen. Blood was sampled from the tail vein 2.5 h post-feeding at day 21, centrifuged at $1,000×g$ for 20 min and serum was stored at -13°C. Cows were weighed at the start and end of each period after the 12:00 h milking and scored for body condition using a scale of 1 to 5 according to Ferguson et al. (1994). Also, a fecal scoring system was used on 3 consecutive days based on the scores; 1 for watery or extremely loose and 5 for extremely hard feces. We aimed to visually monitor manure consistency and color to see whether inclusion of ground barley induced sub-acute ruminal acidosis and whether additives prevented manure inconsistency and deformity.

Chemical analysis

After thawing at room temperature, samples were composited by treatment (TMR) and cow by period (orts and feces) and DM contents were determined by oven drying at 55°C for 48 h. Dried samples were ground through a 1 mm screen. The NDF and ADF were determined on entire diets and fecal samples according to Van Soest et al. (1991). A heat stable alpha-amylase (A3306, Sigma-Aldrich, Steinheim, Germany) was used for feed NDF analysis but sodium sulfite was omitted. The NDF and ADF were not corrected for ash contents. Crude protein (976.05), ether extract (954.02), and ash (942.05) concentrations of TMR were determined according to AOAC (2002). Acid-insoluble ash of TMR and feces were determined according to method 942.05 of AOAC (2002), and was used as an internal marker for the estimation of apparent nutrient digestibility. Milk composition was determined by an automated near infra-red reflectance spectroscopy analyzer (Foss 605B Milko-Scan; Foss Electric, Hillerød, Denmark).

Ammonia nitrogen was determined by the colorimetric phenol-hypochlorite method of Broderick and Kang (1980). The VFA were determined by gas chromatography (Chrompack, Model CP-9002, Chrompack, Middelburg, Netherlands) with a 50-m (0.32 mm ID) silica-fused column

Table 1. Least squares means of dry matter (DM) intake, milk yield, milk composition, fat- (FCM) and energy-corrected milk (ECM), and feed efficiency for cows fed a diet containing no additive (Control), mannan-oligosaccharide (MOS), yeast (SC),or mannan-oligosaccharide plus yeast (MOS+SC)

Item	Treatments				SEM	p<
	Control	MOS	SC	MOS+SC		
DM intake						
kg/d	24.7	24.2	25.0	24.7	0.89	0.29
% of body weight	3.79	3.79	3.79	3.80	0.121	0.96
Yield (kg/d)						
Milk	40.5	40.2	40.8	39.6	1.97	0.57
3.5% FCM	40.1	40.6	41.9	39.7	2.02	0.31
ECM	40.3	40.4	41.8	39.9	1.96	0.36
Fat	1.37	1.43	1.55	1.40	0.064	0.21
Protein	1.25	1.21	1.24	1.24	0.040	0.86
Composition (%)						
Fat	3.43	3.57	3.64	3.53	0.114	0.20
Protein	3.10[a]	3.04[a]	3.09[a]	3.16[b]	0.076	0.003
Feed efficiency (kg/kg)						
FCM/DMI	1.62	1.68	1.68	1.62	0.058	0.74
ECM/DMI	1.63	1.67	1.67	1.63	0.053	0.81

[a,b] Means within a row with different superscripts differ (p<0.05).

3.5% FCM yield calculated as (milk (kg)×(0.4255+(16.425×milk fat/100)).

ECM yield calculated as (kg of milk×0.3246)+(kg of milk fat×12.96)+(kg of milk protein×7.04); Jenkins et al. (1998).

(CP-Wax Chrompack Capillary Column, Varian, Palo Alto, CA, USA). Helium was used as carrier gas and oven initial and final temperature was 55 and 195°C, respectively, and detector and injector temperature was set at 250°C. Crotonic acid (1:7, v/v) was used as internal standard. Blood serum glucose was determined by an enzymatic procedure with a commercial kit (Pars Azmon, Tehran, Iran). Serum urea nitrogen was determined colorimetrically (Technicon Auto Analyzer II; Technicon, Tarrytown, NY, USA).

Statistical analysis

Data were analyzed using the MIXED procedure of SAS (SAS Institute, 1999) according to the following model;

$$Y_{ijk} = \mu + P_i + S_j + T_k + C_l(S_j) + e_{ijkl}$$

Where P_i (i = 1 to 4), S_j (j = 1 to 2), T_k (k = 1 to 4) were fixed effects of period, square, and treatment respectively, $C_l(S_j)$ was random effect of cow (l = 1 to 4) within square and e_{ijkl} was pooled experimental error. Data of feed intake, milk production and composition, and fecal scores that were

repeated over time were analyzed using the REPEATED statement with time of sampling as a repeated measure. The compound symmetric (CS) covariance structure was tested and selected based on the nearest AIC and BIC to zero. Normality of distribution of response variables was tested using PROC UNIVARIATE of SAS (SAS Institute, 1996). Treatment least squares means were compared when the treatment effect in the statistical model approached significance (p<0.05) and trends were noted at p<0.10.

RESULTS

Animal performance and feed intake

Dry matter intake was not affected by supplementation of additives (p>0.05, Table 1), yet compared to the control diet, MOS supplementation slightly reduced (24.2 vs. 24.7 kg/d) and SC supplementation slightly increased (25.0 vs. 24.7 kg/d) the DMI (p = 0.29). Expressed as percent of body weight (BW), DMI was the same for all four diets (p>0.05).

Treatments had no effect on milk production (p>0.05), although cows on the SC diet had numerically greater milk production. Cows fed MOS+SC produced milk with a

Table 2. Least squares means apparent total-tract digestibility (%) of dry matter, neutral detergent fiber and crude protein for cows fed a diet containing no additive (Control), mannan-oligosaccharide (MOS), yeast (SC),or mannan-oligosaccharide plus yeast (MOS+SC)

Item	Treatments				SEM	p<
	Control	MOS	SC	MOS+SC		
Dry matter	69.1[a]	71.2[ab]	74.1[b]	73.0[b]	1.20	0.02
Neutral detergent fiber	54.8[ab]	53.8[a]	59.0[b]	58.8[b]	1.79	0.04
Crude protein	70.4[a]	72.7[ab]	75.8[b]	75.3[b]	1.40	0.04

[a,b] Means within a row with different superscript differ (p<0.05).

Table 3. Least squares means of ruminal pH, ammonia nitrogen, and volatile fatty acid (VFA) profile for cows fed a diet containing no additive (Control), mannan-oligosaccharide (MOS), yeast (SC),or mannan-oligosaccharide plus yeast (MOS+SC)

Item	Treatments				SEM	p<
	Control	MOS	SC	MOS+SC		
Ruminal pH	6.32	6.37	6.41	6.25	0.111	0.66
Ammonia nitrogen (mmol/L)	6.8	6.3	6.2	7.3	0.50	0.39
Total VFA (mmol/L)	76.5	89.9	74.6	94.0	8.90	0.29
Acetate (A) (mol/100 mol)	69.7	69.0	69.5	69.6	0.98	0.96
Propionate (P) (mol/100 mol)	18.8	19.5	18.9	18.2	0.97	0.81
Butyrate (mol/100 mol)	9.3	9.4	9.3	9.7	0.34	0.80
Isobutyrate (mol/100 mol)	0.23	0.41	0.34	0.40	0.062	0.31
Valerate (mol/100 mol)	1.24	1.41	1.30	1.27	0.074	0.19
Isovalerate (mol/100 mol)	0.60[a]	0.57[a]	0.67[ab]	0.77[b]	0.047	0.03
A:P ratio (mol/mol)	3.83	3.74	3.77	3.87	0.261	0.91

[a, b] Means within a row with different superscript differ (p<0.05).

higher protein percentage than other cows (p<0.05, Table 1). Feed efficiency, either expressed as FCM or ECM (kg) per unit of DMI, was not affected by treatments (p>0.05, Table 1).

Nutrient digestibility

Digestibilities of DM, NDF, and CP are shown in Table 2. Supplementation of SC and MOS+SC significantly increased the digestibility of DM and CP of the diets relative to the Control (p<0.05). Cows fed MOS had lower NDF digestibility than cows supplemented with SC and MOS+SC (p<0.05).

Ruminal fermentation and pH

Ruminal fermentation variables of cows fed the four diets are shown in Table 3. Treatments did not affect rumen pH, which only ranged from 6.25 (MOS+SC) to 6.41 (SC). The molar proportion of propionate was slightly higher for the MOS diet. Although isovalerate accounted for less than 1% of total VFA, the MOS+SC supplemented cows had the highest proportion of isovalerate (p<0.05). No treatment differences were observed for ammonia concentration.

The BW, body condition score, and blood metabolites

In Table 4, treatment effects on BW, BW change, body condition score, fecal score, and serum glucose and urea nitrogen are shown. None of the variables was affected by

treatments (p>0.05). Although fecal scores were not affected, MOS cows had low fecal scores. Serum glucose and urea nitrogen did not differ between treatments (p>0.05).

DISCUSSION

Intake and performance

Intake responses of dairy cows to yeast supplementation have been quite variable ranging from substantial increase (Erasmus et al., 1992; Piva et al., 1993; Dan et al., 2000) to no change (Swartz et al., 1994; Robinson, 1997) or even a numerical decrease (Wohlt et al., 1991; Adams et al., 1995). When supplemental yeast culture was offered from 14 d pre-partum to 14 d post-partum, Robinson (1997) reported only a slight increase in DMI (0.3 kg/d) in fresh cows, which was very similar to the results of the current trial. Wang et al. (2001) showed that the potential of live yeast products to increase intake of fresh cows was more affected by total NDF concentration of the diet than by forage NDF intake. In all the above studies, total NDF concentration of the ration was close to that of our study. Although one reason for selecting early lactating cows was to test the ability of SC to increase the DMI of cows in the period when they are prone to physical or physiological constraints of intake, only a slight DMI increase was observed for SC cows. Average DMI of cows (3.80% of BW) was typical for

Table 4. Least squares means of body weight (BW), BW change, body condition score, fecal score, blood urea nitrogen (BUN), and blood serum glucose for cows fed a diet containing no additive (Control), mannan-oligosaccharide (MOS), yeast (SC), or mannan-oligosaccharide plus yeast (MOS+SC)

Item	Treatments				SEM	p<
	Control	MOS	SC	MOS+SC		
BW (kg)	659	674	666	672	28.6	0.11
BW change (kg/d)	0.10	0.39	0.15	0.98	0.285	0.15
Body condition score	3.37	3.53	3.59	3.43	0.191	0.21
Fecal score	3.0	2.8	3.0	2.9	0.13	0.82
BUN (mmol/L)	14.64	14.85	15.53	14.11	0.081	0.34
Serum glucose (mmol/L)	3.75	3.86	3.82	3.86	0.135	0.99

high producing dairy cows. Therefore, intake might have not been limited by physical constraints caused by fiber form or content in our study.

Due to numerically higher milk fat percentage, SC cows produced 1.8 kg more FCM per day. Similarly, Putnam et al. (1997) showed that 4% FCM of cows in early lactation tended to increase (28.4 vs. 26.5 kg) when diets were supplemented with 10 g/d of a yeast culture. Also in the study of Wang et al. (2001), amounts of milk and FCM during the first 30 days in milk were 2.5 kg higher in cows receiving a yeast culture supplement in diets containing 21% forage NDF. Numerical increases in milk fat percentage have been observed after yeast supplementation in some trials with dairy cows (Piva et al., 1993; Robinson, 1997; Erasmus et al., 2005). Increased digestibility of NDF in the SC treatment explains the 0.2 percentage unit increase in milk fat percentage observed in this trial.

The MOS supplementation decreased whereas MOS+SC increased milk protein percentage. Information regarding the effect of MOS or similar compounds on milk protein is scare. Nocek et al. (2007) reported a significant increase in milk protein percentage when they compared cows fed an enzymatically hydrolyzed yeast product (a non-live product that may be comparable to MOS) to those fed yeast culture or no additive. On the other hand, data confirming the result of the current work regarding the inefficiency of yeast products to increase milk protein percentage are abundant (Piva et al., 1993; Robinson, 1997). Given increased crude protein digestibility in SC-fed cows, no change in milk protein in this treatment is unexpected and the reason remains unclear.

Nutrient digestibility

The short duration of periods usually puts some limitations on Latin squares that may require the results to be interpreted with caution. Nevertheless, short terms of yeast supplementation may practically be applied in tight price situations or during early post-calving periods, therefore, it was hoped that results of this trial would aid in demonstrating the potential of SC and/or MOS to favorably alter the performance or metabolism of cows within a short time frame. We observed that digestibility of all of the measured nutrients were affected by one or more of the additives. In agreement with these results, Nocek and Kautz (2006) found that potentially degradable DM of forage was significantly higher for corn silage and mixed haylage when cows received direct-fed microbials containing 1×10^{10} cfu/d of live yeast. Also in supplemented cows, *in situ* undegraded forage DM was consistently lower from 12 to 72 h ruminal incubation, than in un-supplemented cows. Significant increases in digestibility of CP (Erasmus et al., 1992; Wohlt et al., 1998) and cell wall constituents (Wohlt et al., 1998) have also been observed with yeast

supplementation. In this trial, digestibility of nutrients was higher for SC and MOS+SC supplemented cows than for other cows and the higher DM digestibility probably was the result of higher digestibility of CP and NDF. Since the digestibility of MOS+SC cows did not exceed the digestibility of SC cows, it could be inferred that SC was responsible for the increased digestion in both treatments. This conclusion is confirmed by unchanged, or only slightly changed, digestibility of nutrients in MOS relative to the control. As a consequence of improved NDF digestion, it was expected that lipogenic precursors would be more available for SC-fed cows. We observed that a numerical, but biologically meaningful, increase occurred in BW, FCM and milk fat percentage suggesting that lipogenicity was stimulated. However, small number of cows and short experimental period probably did not allow for completion of SC effect on performance.

Ruminal fermentation

Yeast products are often claimed to smooth rumen pH fluctuations and increase pH nadir of the rumen (Chaucheyras-Durand et al., 2008). While some studies reported a positive effect (Mwenya et al., 2004), others reported no effect (Erasmus et al., 1992; Putnam et al., 1997; Robinson and Garret, 1999) of yeast or yeast cultures on rumen pH. In our study, samples of rumen fluid were taken 3 h post-feeding that was expected to represent the period of peak fermentation and consequently the lowest pH values. However, pH values were high on average and did not indicate a severe acidic condition. This may be due to incorporation of 45% forage DM in the diet of which two-thirds were alfalfa hay (30% DM) having a high intrinsic buffering capacity to neutralize fermentation acids (McBurney et al., 1983). Stabilized ruminal conditions led to a balanced metabolism in the rumen, thereby no change in fecal scores, including color and consistency, was observed.

Concentrations of total VFA were similar with slightly higher values for cows fed MOS and MOS+SC compared to the control. In sheep and cattle, feeding GOS did not alter VFA production (Mwenya et al., 2004; 2005b); however, GOS plus nitrate increased total VFA in sheep relative to the control diet (Sar et al., 2004a). In dairy cows, a combination of GOS and yeast decreased while GOS alone increased total VFA concentrations (Mwenya et al., 2005a). Similar to total VFA, molar proportions of individual VFA have also been variable, ranging from significant change (Mwenya et al., 2005a) to no change (Mwenya et al., 2005b), in studies with GOS on cattle and sheep, respectively. Molar proportion of isovalerate, a product of the fermentation of branched-chain amino acids in the rumen, was significantly increased after MOS+SC supplementation. The SC and MOS might have provided

factors stimulatory to proteolytic bacteria as suggested by Mwenya et al. (2004). In addition, greater NDF digestibility, which in turn causes more protein from the intracellular spaces of the forage cell-wall to be released and exposed to microbial attack (Bach et al., 2005), might have also been involved in elevated proportion of isoacids on diets containing additives.

Very often, yeast or yeast cultures did not cause any change in ruminal ammonia nitrogen (Erasmus et al., 1992; Piva et al., 1993; Mwenya et al., 2004) but in some cases lowered ammonia nitrogen was observed (Enjalbert et al., 1999). In addition, limited data on feeding GOS to sheep and steers have demonstrated a suppressing effect of GOS on rumen ammonia concentration (Mwenya et al., 2004, 2005b). In our trial, treatments had similar ruminal ammonia concentrations with only slightly higher values for MOS+SC. As time of blood sampling preceded rumen sampling on the same day, the difference between rumen ammonia and blood urea nitrogen was relatively high. In other words, blood samples were likely taken at the time when urea was at its highest concentration but rumen samples were taken when ammonia concentration had already passed its peak.

The BW, body condition score and blood metabolites

In some studies, yeast supplementation did not alter BW (Robinson, 1997) or BW change (Robinson and Garret, 1999), while in another study yeast supplementation decreased BW loss in early lactation (Dann et al., 2000). In the current experiment, cows consistently gained BW in the course of the trial indicating a positive energy balance that most likely arose from adequate DMI. As discussed earlier, BW gain was higher in supplemented than control cows suggesting a higher provision of energy for gain with additive supplementation.

Blood glucose was similar in feedlot cattle fed high grain diets without or with probiotic including *Enterococcus* plus live yeast (Beauchemin et al., 2003). Opposed to that, Nocek et al. (2003) and Nocek and Kautz (2006) observed a significant increase in blood glucose of lactating cows 7 d post-partum. The GOS fed to steers did not cause any change in blood glucose (Mwenya et al., 2005b). Similar propionate production among treatments in the current work can explain no change in blood glucose.

IMPLICATIONS

Post-partum supplementation with MOS, live yeast, and the mixture of the two additives resulted in no changes in cow performance and ruminal metabolism under the conditions of this experiment. Significant improvement in digestibility of nutrients in cows fed live yeast suggested that these products may have the ability to exert their

positive effects on digestion processes, but not necessarily on milk production, in a short duration. The MOS+SC only significantly increased milk protein percentage, but not milk protein yield. Using the combination of yeast and MOS did not show any advantage in ruminal metabolism over using yeast or MOS alone.

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