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ORIGINAL PAPER

Sorghum silage and cover crop silage in diets for late-lactation cows: Effects on feed intake, digestibility, feeding behaviour, and milk yield

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ABSTRACT. Climate change poses new challenges in dairy cow nutrition. Sorghum has gained interest due to its higher water use efficiency and tolerance to drought conditions. In addition, the use of cover crops become increasingly popular for improving residual soil nitrogen and preventing erosion during fallow periods. The aim of the study was to assess feed intake, apparent total tract digestibility, feeding behaviour, performance, and milk quality in late-lactation dairy cows fed diets differing in silage type (Diet 1: sorghum silage; Diet 2: cover crop silage). The study used 8 Holstein-Friesian dairy cows in the last stage of lactation fed experimental diets in a cross over design trial. Diet 1 resulted in higher apparent digestibility of dietary protein ($P < 0.05$), lower rumination chews ($P < 0.05$), and a tendency towards lower eating chews ($P < 0.10$) than Diet 2. However, no differences were observed in dry matter intake, milk yield, or milk composition ($P > 0.05$). The results indicate that cover crop silage can be used as an alternative to sorghum silage in diets of late-lactation dairy cows.

Introduction

Climate change has significantly increased difficulties in sourcing raw materials for the livestock sector. To address this issue, farmers in many regions are adapting cultivation and ensiling processes by introducing alternative crops (McCary et al., 2020). In this context, sorghum has received attention, and many studies have been conducted to confirm its water use efficiency and high tolerance to drought conditions (Bhattarai et al., 2020; Safian et al., 2022). Sorghum silage is typically used for cattle requiring lower energy and higher fibre content in the diet. Considering milk production and quality, sorghum has proven suitable for late-lactation dairy cows when diets are appropriately supplemented with starch sources (Bhattarai et al., 2019).

Cover crops silage, consisting, e.g., of small grains and clovers, can be an alternative to sorghum silage. Its use in dairy cow rations has grown in popularity as a way of offsetting planting costs, increasing annual forage yield, preventing soil erosion in the absence of crops, providing residual nitrogen in soil, and controlling weeds and insects (Harper et al., 2017). Maxin et al. (2020) evaluated seven different cover crop species and demonstrated their suitability for ruminant feeding. Although their energy content is moderate, cover crops provide a substantial amount of utilisable protein at the ruminal level, which helps reduce methane and ammonia production.

This study investigated the impact of different silage types on late-lactation dairy cows. The hypothesis was based on the fact that cows in this phase have relatively low nutritional requirements that could be met by alternative crops. This approach has the potential to lower feed costs while addressing climate change challenges without compromising dairy cow productivity or welfare. Therefore, the objective of the study was to compare cover crop silage with sorghum silage in late-lactation cow nutrition, focusing on apparent digestibility, feeding behaviour, milk production, and quality.

Material and methods

Animals, housing, dietary treatments, and experimental design

The study was conducted in compliance with EU Directive 2010/63 and Italian legislation (DL n. 26, 4 March 2014), and adhered to the regulations of the University of Udine. All animal procedures were approved by the Ethics Committee of the University of Udine (Prot. No. 4/17).

Eight multiparous Holstein-Friesian dairy cows in the last stage of lactation (days in milk > 200) were included in the study. The cows were individually housed in a tie-stall barn at the A. Servadei experimental farm (Pagnacco, Udine, Italy) and were fed and milked twice daily.

The dietary treatments consisted of two diets differing in silage type. Diet 1 contained sorghum (*Sorghum bicolor* L. Moench) silage. Sorghum was harvested at the soft dough stage and chopped, and subsequently ensiled in a rectangular trench silo with a slight slope for moisture drainage. Diet 2 contained cover crop silage composed of a mixture of triticale *(Triticosecale* Wittmack), oats (*Avena sativa* L.), wheat (*Triticum aestivum* L.), and vetch (*Vicia sativa* L.). This mixed crop was ensiled in polyethylene film-wrapped round bales without the addition of inoculants.

The trial was conducted using a crossover experimental design. After a 14-day adaptation period in the barn, four cows were fed Diet 1 for 20 days, followed by a 31-day washout period before being fed Diet 2 for an additional 20 days. The second dietary group of four cows received the same treatments, but in reverse order. During the adaptation and washout periods, the cows were offered hay *ad libitum* to meet or exceed the fibre requirements recommended by the NRC (2001), along with 9.2 kg dry matter (DM) of compound feed. It was composed of maize (426 g/kg), soybean meal (215 g/kg), wheat bran (157 g/kg), sunflower meal (81 g/kg), wheat middlings (78 g/kg), minerals and vitamins (44 g/kg). Diet 1 offered during the experimental period consisted of 6 kg sorghum silage DM, grass hay *ad libitum*, and 9.2 kg compound feed DM. Diet 2 consisted of 6 kg cover crop silage DM, grass hay *ad libitum* and 9.2 kg DM of the same compound feed. The ingredients and chemical composition of the feeds are summarised in Table 1. The silages differed in physical characteristics (particle size and DM %), but had similar chemical composition in terms of fibre and protein content. The pH of the silages was 4.5 for cover crop silage and 4.0 for sorghum silage. The absence of mycotoxins was confirmed for both silages, and their organoleptic quality parameters (smell, texture, colour) were within the desired range for these crops.

Table 1. Chemical and physical characteristics of feed offered to dairy cows

Item	Hay	Sorghum silage	Cover cropsilage	Compound feed
Dry matter (DM), %	90.4	27.9	67.1	89.7
Chemical composition, % DM				
crude protein	6.7	6.5	6.9	24.5
ether extract	1.6	2.3	1.8	6.5
starch		16.7	1.6	24.7
crude fibre	39.2	37.7	38.6	10.0
neutral detergent fibre	70.3	58.4	63.0	24.6
acid detergent fibre	41.4	36.5	36.7	12.9
acid detergent lignin	9.4	7.0	6.7	3.0
ash	8.8	6.4	5.8	7.5
non-fibre carbohydrates	12.6	26.4	22.5	36.9
Net energy for lactation, Mcal/kg DM	0.95	1.24	1.21	1.87
Particle size fraction (% retained as-fed basis)				
>19 mm	95.8	2.7	87.8	
>8.0 mm	2.5	64.6	9.1	
>1.18 mm	1.4	31.3	2.8	
bottom pan	0.2	1.3	0.2	

At the beginning of the first experimental period, dairy cows were assigned to two balanced dietary groups based on milk yields (16.6 ± 1.30 kg/day [means ± SD]; $P > 0.05$), days in milk (247 ± 35 days; $P > 0.05$), and body weight (650 ± 60.3 kg; $P > 0.05$). The animals involved in the trial were not pregnant, their mean age was 5.8 ± 2.05 years, and somatic cell count was less than 200 000 cells/ml.

Samples and data collection

Ingredients were sampled weekly and analysed for chemical composition. Daily individual dry matter intake (DMI) of hay, silages, and compound feed was measured before morning milking by weighing the feed offered and refused; the chemical composition was also assessed.

During the last six days of each experimental period, the apparent total tract digestibility (ATTD) was assessed following the method described by Ponce et al. (2013). Briefly, ingredient samples were collected daily, and DMI of each ingredient was determined as previously described. Faecal samples were collected twice daily from the floor directly after defecation for each cow separately at 08:00 and 16:00 and homogenised. At the end of the collection period, faecal and dietary samples were analysed for chemical composition. Diet composition per animal was calculated based on the chemical composition and DMI of ingredients.

Individual daily milk yield was recorded for the last three days of each experimental period, with milk samples collected from each cow during morning milking. Milk yield was standardised to fat-corrected milk (FCM) at 4% fat, calculated according to the method of Tyrrell and Reid (1965).

During both experimental periods, dairy cows were fitted with a noseband pressure sensor (RumiWatch system, ITIN+HOCH GmbH, Liestal, Switzerland), validated for assessing feeding behaviour, as described by Ruuska et al. (2016). The collected raw data were processed according to the procedure outlined by Romanzin et al. (2018). The following feeding behaviour variables were included in the analysis: rumination and eating time (min/day), number of rumination and eating chews (n/day), number of rumination boluses (n/day), and rumination intensity (n bites/bolus). Data from the final three days of each experimental period were averaged per animal and used for statistical analysis.

Chemical analysis

Feed, feed residue, and faecal samples were pre-dried at 60 °C for 48 h. Feed and faecal samples were subsequently ground and sieved through a 1-mm screen (Pulverisette; Fritsch, Idar-Oberstein, Germany). Residual DM was determined by heating the samples at 105 °C for 3 h (AOAC, 2016). Ash content was measured by incineration in a muffle furnace at 550 °C for 2 h (AOAC, 2016). Acid insoluble ash (AIA) content was measured according to the method of Van Keulen and Young (1977).

Nitrogen (N) content was determined using the Kjeldahl method (AOAC, 2016), and crude protein (CP) content was calculated as N × 6.25. Neutral detergent fibre (NDF) content was determined using a fibre Ankom II Fibre Analyser (Ankom Technology, Macedon, NY, USA) following the procedure of Van Soest et al. (1991), without correction for residual ash, and with α-amylase pre-treatment of the samples. For feed samples only, ether extract (EE) was determined using the Soxhlet method (AOAC, 2016). Feed energy value, expressed as net energy for lactation (NE_L), was estimated according to the INRA standard (INRA, 2010).

$$100 - \left(100 \times \left(\frac{\%\ \text{AIA in feed}}{\%\ \text{AIA in feces}}\right) \times \left(\frac{\%\ \text{OM in feces}}{\%\ \text{OM in feed}}\right)\right)$$

Organic matter (OM) ATTD was calculated as follows:

The same calculation was applied for CP and NDF.

Milk samples were analysed for chemical composition, including fat, protein, and lactose content according to ISO 9622:2013 using a MilkoScan FT6000 (FOSS Electric, Hilleroed, Denmark).

Statistical analysis

Data were analysed using R software, ver. 4.1.2 (R Core Team, 2020). The total sample size was determined using the PowerTOST package (Labes et al., 2024), ensuring a statistical power of at least 80%. Data normality was assessed using the Shapiro-Wilk test, and Tukey transformations were applied for parametric testing when appropriate. The effect of dietary treatment (Diet 1 vs. Diet 2) on variables was assessed as a cross-over design. Specifically, dietary treatment, period (P1 vs. P2), and the sequence in which animals received the experimental diets were considered as fixed factors, while dairy cow was treated as a random factor. Differences between dietary treatments at $P < 0.05$ were considered statistically significant, while differences at $P < 0.10$ were considered as a tendency towards statistical significance.

Results

The effects of silage type on feed and nutrient intake, as well as ATTD are summarised in Table 2. DMI did not differ significantly between the dietary treatments ($P = 0.83$), nor did the intakes of Diet 1 and Diet 2 silages ($P = 0.30$). Similarly, hay consumption was comparable between the two groups. Overall, the Diet 2 group ingested 0.7 kg DM more forage than the Diet 1 group, but the difference was not significant ($P = 0.13$). On the other hand, a significant difference was observed in compound feed intake, with cows on Diet 1 consuming 0.7 kg more ($P < 0.01$). This difference was partly reflected in higher CP and starch intake in Diet 1 than in Diet 2, with increases of 1 and 4 percentage points,

Table 2. Effects of silage type on feed intake, nutrient assimilation and digestibility in dairy cows

Item	Dietary group		RSD	*P*-value
	Diet 1	Diet 2		
Intake				
compound feed, kg DM	8.9	8.2	0.45	<0.01
forage, kg DM	6.8	7.5	0.85	0.13
silage, kg DM	3.7	4.1	0.71	0.30
hay, kg DM	3.1	3.4	0.42	0.19
total, kg DM	15.8	15.7	0.87	0.83
crude protein, %	16.9	15.9	0.66	<0.01
starch, %	17.5	13.5	0.53	<0.01
neutral detergent fibre, %	41.8	44.6	1.37	<0.01
Apparent total tract digestibility, %				
organic matter	68.3	67.7	3.15	0.74
crude protein	70.8	66.7	3.57	0.02
neutral detergent fibre	49.2	51.6	4.02	0.24

Diet 1 – sorghum silage diet, Diet 2 – cover crop silage diet; RSD – residual standard deviation, DM – dry matter; $P < 0.05$ indicate that data are significantly different

respectively ($P < 0.01$). Conversely, cows on Diet 2 consumed more NDF ($P < 0.01$). The ATTD of OM and NDF did not differ between the dietary groups ($P > 0.05$). However, cows fed Diet 1 exhibited a significantly higher ATTD for CP, with an increase of 4.1 percentage points compared to Diet 2 ($P = 0.02$).

Average milk production was approximately 12.0 kg/day and was nearly identical between the two diets when adjusted for energy (12.4 kg/day; $P > 0.05$; Table 3). The use of late-lactation cows, which produce less milk, also contributed to the higher fat and protein content in milk. However, no significant differences were found between the two dietary treatments in terms of milk composition (protein, fat, and lactose) or somatic cell count ($P > 0.05$).

Table 3. Effect of silage type on milk yield and milk composition of dairy cows

	Dietary group		RSD	*P*-value
	Diet 1	Diet 2		
Milk yield, kg/day	11.8	12.2	2.24	0.71
Fat-corrected milk, kg/day	12.4	12.4	1.89	0.99
Milk composition, %				
protein	3.48	3.43	0.300	0.75
fat	4.33	4.19	0.542	0.60
lactose	4.37	4.48	0.146	0.17
Somatic cell count, cells/ml	229474	199992	47724	0.22

Diet 1 – sorghum silage diet, Diet 2 – cover crop silage diet; RSD – residual standard deviation; $P > 0.05$

Table 4. Effect of silage type on feeding behaviour of dairy cows

	Dietary group		RSD	*P*-value
	Diet 1	Diet 2		
Rumination time, min/day	462	521	75.3	0.12
Eating time, min/day	235	258	50.9	0.37
Rumination chews, n/day	24299	29141	3875	0.01
Eating chews, n/day	11993	14362	3671	0.10
Boluses, n/day	481	545	78.5	0.10
Rumination intensity, n chews/bolus	48.3	49.8	2.92	0.32

Diet 1 – sorghum silage diet, Diet 2 – cover crop silage diet; RSD – residual standard deviation; $P < 0.05$ indicate that data are significantly different

The feeding behaviour of dairy cows is presented in Table 4. The Diet 2 treatment consistently reached numerically higher values in both eating (eating time and eating chews) and rumination (rumination time, rumination chews, number of boluses, and rumination intensity) variables. However, these differences were statistically significant only for the number of rumination chews (+4842 chews/day, $P = 0.01$), while a tendency towards significance was recorded for the number of eating chews (+2369 chews/day, $P < 0.10$). Although a variation of approximately 1 hour per day in rumination times was recorded, the differences between the dietary groups were not significant ($P = 0.12$).

Discussion

The results in Table 2 show that dietary treatment did not affect total DMI. In fact, the difference in compound feed consumption was compensated, although not statistically significantly, by differences in forage consumption levels. It should be noted that the two groups of cows consumed different amounts of compound feed, likely affecting animal performance indicators.

The CP content of the two silages was comparable, while there was a difference in starch content 16.7 vs. 1.6% for sorghum silage and cover crop silage, respectively (Table 1). This disparity contributed to variations in DMI composition (CP, NDF, and starch). Therefore, it can be assumed that the variable consumption of compound feed was the only cause of the difference in CP intake (+1 percentage point). On the other hand, the more pronounced difference in starch intake (+4 percentage points) can be attributed not only to compound feed consumption but also to the distinct starch content of the silages. Thus, interestingly, cows consuming the low-starch silage (Diet 2) were also those that consumed the least compound feed.

Differences in NDF intake may be related to the higher forage intake in Diet 2 compared to Diet 1, although this difference was not statistically significant ($P = 0.13$), as well as to varying NDF content of the silages. The different composition of DMI, in addition to variation in particle size between the two silages, were probably the main factors that led to differences in CP digestibility. Despite this, the differences in ingesta composition did not translate into changes in overall digestibility. In contrast, a study comparing three diets based on maize silage, whole plant grain sorghum silage, and forage sorghum silage, supplemented with increasing levels of maize meal, demonstrated a higher total-tract digestibility of OM and NDF in animals fed the forage sorghum diet compared to diets based on maize silage or whole plant grain sorghum silage, with no differences observed in CP digestibility (Colombini et al., 2012). Sorghum seeds are covered by a protective coating that reduces starch degradability. Herrera-Saldana et al. (1990) reported that starch degradability of sorghum was lower than in oats, wheat, barley, and maize. In the present study, as previously mentioned, cows fed Diet 1 ingested higher amounts of starch, but their main source of this carbohydrate was compound feed (approx. 2.2 kg compared to 0.6 kg from sorghum). This may have reduced the effect of lower sorghum's starch degradability, which could partly explain the lack of significant differences in milk yield between the two treatments.

Numerous studies compared yield and milk composition of animals fed traditional forages with sorghum or cover crop silage. For instance, Amer et al. (2012) substituted alfalfa with sorghum silage in diets of early- to mid-lactation dairy cows and observed a reduction in milk yield and an increase in milk fat content, resulting in a comparable FCM yield. The authors attributed these findings to differences in NDF and CP intake by animals, which were higher and lower, respectively, for sorghum silage compared to the alfalfa-based diet. In general, increased dietary fibre intake is accompanied by a decrease in available energy. In a study involving partial replacement of maize silage with wheat or triticale silages, Harper et al. (2017) reported no differences in milk yield and composition in animals fed these alternative silages. Interestingly, the two experimental groups showed similar intakes of DM, CP, and NDF. Similarly, Li et al. (2020), substituting maize silage with four different inclusion levels of sweet sorghum silage, reported milk yields ranging from 11.4 to 12.6 kg/day, which was consistent with the findings of the present study. The absence of differences in milk production and composition in both cases may be due to the low nutritional requirements of late-lactation cows. In the current study, despite differences in forage-to-concentrate ratios, no significant changes in milk fat content were observed. This suggests that the variations in CP, starch, and NDF intake between the dietary groups were not sufficient to significantly affect milk composition and yield. Schalla et al. (2012) observed a negative relationship between apparent CP digestibility and milk protein content, suggesting that microbial CP production influences milk CP percentage and may reduce apparent CP digestibility. In our study, although CP digestibility was higher in Diet 1, no differences were observed between the dietary groups in milk CP content. This could be explained by the absence of differences in total DMI and the ATTD of OM both of which remained consistent between treatments and, as noted by Schalla et al. (2012), are factors that could impact milk production and composition.

In this study, feeding behaviour was evaluated using a noseband pressure sensor capable of recording and interpreting chewing movements, distinguishing between eating and rumination activities. The findings are generally consistent with previous studies employing the same device under similar conditions (Leiber et al., 2016). However, as expected, they diverge from results observed in grazing cows, especially in feeding time (Romanzin et al., 2018). Diet 2 yielded numerically higher values in both eating and rumination parameters than Diet 1. The silage types significantly influenced the number of rumination chews, and a tendency was found in the number of eating chews. Feeding behaviour can be influenced by the physical and chemical properties of the diet, which include particle size, fragility, and DM, NDF, and lignin contents. In a recent study, Florit et al. (2023) found that lignin and particle size are key factors increasing eating time on commercial dairy farms. Considering physical properties, particularly particle size, it is known that too long particles require more chewing to form to a feed bolus that can be swallowed (Grant and Ferraretto, 2018). In the present study, cows fed Diet 1 received sorghum silage composed of relatively short particles and consumed more compound feed, while Diet 2 included cover crop silage, which consisted of 87.8% long particles (>19 mm; Table 1). Diets with finely processed feed or a high proportion of short particles generally require shorter eating and rumination times (Beauchemin, 1991). Considering chemical properties, an increase in NDF and lignin intake in silages is associated with a higher number of rumination and eating chews. Beauchemin (1991) found a strong correlation between NDF intake and rumination activity (r = 0.94). Similarly, Rinne et al. (2002) compared four different maturity stages of grass silage, and reported higher NDF intake resulting in increased mastication time, a trend consistent with our findings. These authors also observed the same trend for CP digestibility, which decreased with increasing chewing period. These observations were partially confirmed by Tafaj et al. (2005), who suggested that fibrous diets require more chewing to compensate for limited microbial fibre breakdown, thus providing more surface area for microbial activity. In fact, chewing was shown to contribute approximately 70–80% to particle reduction, with microbial degradation accounting for 15–25% (McLeod and Minson, 1988). It is likely that the increase in chewing activity observed in fibrous and/or long fibre diets (Diet 2) may not have been sufficient to maintain protein digestibility levels similar to that recorded in the Diet 1 group.

Conclusions

The inclusion of cover crop silage can provide an alternative dietary source for cows in the late stage of lactation, a period characterised by lower energy requirements and milk yields. Diets based on cover crop silage were associated with lower apparent digestibility of dietary protein and a higher number of feeding chews without altering milk performance, milk quality, or feed intake of animals. However, the actual relevance of these findings may be confounded by the high compound feed consumption (about 50% of the diet), which could have masked the effect of the different silage types offered to both groups of cows. To better understand the potential role of alternative silages, future studies should consider diets with lower compound feed levels to more effectively assess the effects of silage composition on lactating dairy cows.

Conflict of interest

The Authors declare that there is no conflict of interest.

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