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Research Article

Replacing corn silage with fodder beet silage: Impacts on intake, digestibility, and milk production in lactating dairy cows

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ABSTRACT- Due to the negative effects of climate change on forage production, this research was conducted to assess the effects of replacing corn silage (CS) with fodder beet (FB) silage (a drought-tolerant forage crop harvested in autumn) on dry matter intake, nutrient digestibility, and milk production in dairy cattle. Ten multiparous dairy cows (Holstein × Simmental) were assigned to a completely randomized design (CRD) with a changeover system. The experimental diets were formulated to be isoenergetic and isonitrogenous, and animals had free access to water. Dietary inclusion of FB decreased dry matter intake as well as the consumption of other nutrients. The inclusion of FB in forage improved the digestibility of dry matter, organic matter, and crude protein. Although neutral detergent fiber digestibility was numerically lower, the difference was not significant. Substituting CS with FB silage increased milk yield, milk protein percentage, and lactose content. However, it decreased milk fat concentration. In conclusion, we showed that replacing 25% of CS with FB decreased feed intake, but the higher nutrient digestibility in the FB diet improved milk yield in dairy cows.

INTRODUCTION

Forages, such as corn silage (CS) and alfalfa (high-water required), play a crucial role in successful dairy herd production. In recent years, climate change, together with drought, has significantly reduced the yield of these water-intensive forage crops in most parts of the Islamic Republic of Iran (Abarghuei et al., 2010). In such a situation, purchasing fodder from other regions becomes necessary. But this strategy is associated with many challenges, including high transportation costs and environmental pollution. Moreover, the imported feed is nutritionally deficient oftentimes (Hao et al., 2017; Alqaisi et al., 2019). So, relying solely on purchased feed cannot be a practical and effective strategy. Research has shown that cultivating local and alternative forages with high nutritional value and low water demand can reduce expenses, while maintaining productivity. Surveys in the northern provinces of Iran, Mazandaran and Golestan, have demonstrated that most farmland lies fallow during winter and autumn. Cultivating autumn forages in these provinces is a viable opportunity to overcome forage shortages (Ghorbani and Majidian, 2020). Recently, fodder beet (FB) has gained attention because of its high yield potential, excellent palatability, various stress tolerance, and compatibility for making mixed silage with other forage (Karimi et al., 2021; Fazaeli et al., 2023). FB has suitable nutritional ingredients (i.e., 14% crude protein, 35% neutral detergent fiber, 19% acid detergent fiber, 0.02% crude fat, and 18% ash content), making it useful for livestock nutrition (Karimi et al., 2021). Numerous studies have investigated the beneficial inclusion effects of FB in livestock diets, including dairy cattle (Pacheco et al., 2020; Fleming et al., 2021), sheep (Hammond et al., 2022; Papi et al., 2022), and beef cattle (Gibbs et al., 2015; Johnston et al., 2016). Khodaverdi et al. (2024) reported that Afshari fattened lambs fed with FB-based diet exhibited better performance than those fed CS based diet. The elevated and positive effect of using FB in substitution with CS on dairy cow milk production was reported in the Dalley et al. (2020) investigation.

Incorporating FB into livestock feed systems could help address nutritional challenges. However, effective post-harvest management and storage remain critical constraints to its wider use. This is largely due to its high moisture content (exceeding 80%) and its harvest period, which coincides with rising mid-spring temperatures. The high soluble carbohydrate content of FB makes it a strong candidate for preservation through silage. However, studies on high-moisture forages indicate that ensiling FB alone can promote clostridium-dominated fermentation and excessive effluent production, leading to suboptimal preservation (Pacheco et al., 2020; Fazaeli

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et al., 2022). Incorporating absorbing additives such as wheat straw or bran can increase silage dry matter, thereby improving fermentation quality and reducing spoilage (Waghorn et al., 2018).

Despite the documented advantages and challenges associated with FB, significant research gaps remain regarding its potential to replace CS and the optimization of its cultivation, harvesting, and ensiling practices. Most research on FB has been conducted at the pasture level. Considering the challenges related to forage harvesting and storage time, limited studies have investigated silage preparation, particularly in the northern regions of the country. Given these limitations, developing optimal methods for storing FB and preserving its nutritional value is essential, as well as comparing its effects on dairy cow performance with those of CS. We assumed that combining FB with moisture-absorbing materials such as wheat straw, wheat bran, and rice bran would produce high-quality silage suitable for dairy cows. Therefore, this study aimed to evaluate the qualitative features of FB-based silage as a partial replacement in mixed rations and to compare its effects with CS on dairy cow feed intake, digestibility, and milk production.

MATERIALS AND METHODS

Crops cultivation and preparation of silage

The field experiments for plant cultivation and the animal trial were conducted at the National Station for Research and Development of Dual-Purpose Cattle (Gavdasht) in Babol County, Mazandaran Province, from autumn 2023 to winter 2024. All laboratory analyses, including the evaluation of silages, diets, fecal samples, and milk composition, were carried out at the National Institute of Animal Sciences Research in Alborz Province. The Java variety of FB was cultivated in autumn 2023 on 2.5 hectares of arable land at the Gavdasht farm. At the appropriate growth stage, the crop was harvested in spring 2024. The FB was grown entirely under rainfed conditions, relying solely on the region's natural rainfall. In contrast, corn cultivation required supplemental irrigation; in addition to rainfall, 2,000 m^3 of water per hectare was applied. Five days before the main harvest for ensiling, FB samples were collected from various locations across the field and transported to a laboratory for analysis of chemical composition. The samples were oven-dried at 55 °C for 48 hours and analyzed for dry matter (DM), crude protein (CP; calculated as nitrogen × 6.25), ash, ether extract (EE), neutral detergent fiber (NDF), and acid detergent fiber (ADF) according to standard protocols (Van Soest et al., 1991; AOAC, 2012). After harvest, the FB was cleaned thoroughly to remove any soil and foreign materials and mechanically chopped into 1–2 cm pieces using a commercial beet shredder. The chopped material was ensiled with wheat bran, rice bran, corn bran, wheat straw, and urea according to the formulated ratios. After a 60-day fermentation period, representative silage samples were collected for chemical analysis using the same standard methods (Van Soest et al., 1991; AOAC, 2012) to define nutritional makeup. To ensure consistent quality, additional sampling was performed at 15-day intervals after opening the silos to assess pH and chemical composition using the same standard analytical procedures.

Animals and treatments

A completely randomized changeover design was used, consisting of two 30-day experimental periods and two dietary treatments (CS-based vs. FB-based silage). Ten lactating dairy cows (Holstein × Simmental) were selected for the study, with an average of 92 ± 9 days in milk, in their third lactation, an average body weight of 537 ± 24 kg, and an average milk production of 28.3 ± 0.9 L day^{-1}. The cows were housed in individual pens with free access to water throughout the experiment. The animals were fed total mixed rations (TMR) formulated to meet their nutritional requirements (Table 1; NRC, 2021). The TMR was offered three times daily at 06:00, 12:00, and 18:00 h, immediately after each milking to promote feeding regularity. Feed was provided ad libitum, and daily refusals were maintained at 3–5% of the offered feed to ensure consistent intake.

Intake and digestibility of nutrients

Each experimental period lasted 30 days and consisted of a 23-day dietary adaptation phase followed by a 7-day sampling phase. During the sampling phase (days 24–30), the daily feed offered and refusals (orts) were quantitatively recorded and sampled for each cow to determine dry matter intake and the intake of other nutrients. Nutrient digestibility was assessed using the acid-insoluble ash (AIA) method described by Van Keulen and Young (1977). Fecal samples were collected from each cow on consecutive days during the sampling period (days 24–30) and analyzed for DM, CP, ash, and NDF. Digestibility coefficients were then calculated based on the AIA concentrations in both the feed and fecal samples.

Milking and milk analysis

Milk yield was recorded daily throughout the 7-day sampling period (day 24–30). To carry out compositional analysis, milk samples were collected from each milking session (morning, noon, and evening), pooled for each cow, preserved with potassium dichromate, refrigerated immediately, and then transported to the laboratory for analysis. Milk composition, including fat, protein, and lactose contents, was determined using a MilkoScan infrared analyzer (Foss Electric, Hillerød, Denmark), following standardized procedures in routine calibration against reference methods.

Table 1. Diet components and chemical compositions of feed

Item	Corn silage (control)	Fodder beet silage
Components (g/100 g)		
Corn silage	26.70	0.00
Fodder beet	0.00	24.80
Wheat straw	11.91	13.70
Wheat bran	8.33	8.33
Rice bran	6.38	6.82
Corn bran	3.28	3.28
Barley	17.41	17.38
Corn	12.32	12.32
Soybean meal	9.52	8.90
Urea	0.96	0.96
Calcium carbonate	0.69	0.95
di-Calcium phosphate	0.21	0.27
Magnesium oxide	0.35	0.35
Sodium bicarbonate	0.35	0.35
Ammonium sulfate	0.28	0.28
Salt	0.26	0.26
Mineral-vitamin supplement	0.24	0.24
Bentonite	0.81	0.81
Chemical composition		
Dry matter (DM, %)	50.90	46.23
Organic matter (OM, %)	93.11	93.30
Crude protein (CP, %)	15.03	15.06
Neutral detergent fiber (NDF, %)	38.60	35.70
Acid detergent fiber (ADF, %)	19.81	18.68
Ether extract (EE, %)	2.80	2.61
Non-fiber carbohydrate[1] (NFC, %)	36.68	37.93
NFC to NDF ratio	0.95	1.06
Calcium (%)	0.67	0.67
Phosphorous (%)	0.38	0.38
NEl[2] (Mcal/kg DM)	1.53	1.54

[1]Non-fiber carbohydrates = 100 – (CP% + Ash% + EE% + NDF%); [2]NEl = net energy of lactation (Predicted values from NRC (2001) model).

Statistical analysis

Data for intake, digestibility, and milk production were gathered and analyzed in a changeover of a completely randomized design (CRD), using the MIXED procedure of SAS (version 9.1). This included treatment as a fixed effect and period as a random effect.

Yijk = μ + Ti + Etik + Rj + TRij + Erijk

The statistical model used in the analysis defines Y_{ijk} as the observed value, μ as the overall mean of the traits, T_i as the treatment effect, E_{tik} as the primary error, R_j as the effect of period, TR_{ij} as the treatment × sampling time (period) interaction, and E_{rijk} as the residual error. Differences between treatments were considered significant at $P < 0.05$ using the Least Significant Difference (LSD) correction for multiple comparisons. Due to the design limitations and a low number of replications, statistical test power was assessed using the Cumulative Distribution Function (CDF) ('F', Fcrit, df1, df2, λ) function in SAS. In this function, the non-centrality parameter (λ) was calculated by dividing the treatment sum of squares by the mean square error. The F critical value (Fcrit) was calculated using the FINV function with 1-alpha (alpha = 0.05), the treatment degrees of freedom, and the error degrees of freedom as inputs. In accordance with Cohen's conventions and the experimental conditions of the present design, effect sizes ≥ 0.5 were considered to represent statistically powerful effects, corresponding to medium (d = 0.5) to large (d ≥ 0.8) magnitudes.

RESULTS AND DISCUSSION

Average yield and chemical composition of the dietary forage portion

Table 2 presents the average yield and chemical composition of the forage components. The dry matter yield of FB in this study (6.33 t ha^{-1}) was lower than previously reported values, which ranged from 10.51 to 18.85 t ha^{-1} (Saberi and Hosseini, 2024). The nutritional composition of the FB used here was generally consistent with the findings of Shakeri et al. (2022). However, crude protein (9.80%) and ash (8.28%) levels were notably lower than those reported by Karimi et al. (2021), who documented values of 14% and 18%, respectively. As highlighted by Dhital et al. (2025), such compositional differences can arise due to several factors, including (1) cultivation practices, (2) environmental conditions, (3) genetic characteristics of cultivars, and (4) fertilizer-use regimes. For example, a study conducted in Golestan Province demonstrated substantial differences in dry matter yield between two FB cultivars: Timbale (18.85 t ha^{-1}) produced nearly 80% more than Kara (10.51 t ha^{-1}) (Saberi and Hosseini, 2024). The nutritional composition of CS used in this study (DM: 23.20%, CP: 8.69%, NDF: 49.82%, and ADF: 29.63%) closely matched the values reported by Shadi et al. (2020) (DM: 22.5%, CP: 8.0%, NDF: 51.5%, and ADF: 31.8%). Nevertheless, these potential sources of variation highlight the importance of conducting local forage nutritional analyses, even for widely used forage crops such as CS, to ensure accurate ration formulation and support optimal animal performance.

Daily nutrient intake

Replacing CS with FB silage in the forage portion of the diet decreased the daily intake of dry matter, organic matter, protein, and neutral detergent fiber (P < 0.0001; Table 3). Research into using FB in dairy cattle diets indicated that the best performance in livestock was achieved when FB constituted a maximum of 30% of dry matter, which confirmed the results of the present study (Waghorn et al., 2018; Dalley et al., 2020). The reduced intake associated with FB inclusion may be partially attributed to a decline in diet palatability. Studies have indicated a lower dry matter intake due to the reduced diet palatability observed when incorporating FB into dairy cow diets (Abd El Tawab et al., 2017). Similarly, Roshanzamir et al. (2024) found that a complete replacement of CS with the FB aerial part silage reduced the consumption of dry matter, protein, non-fibrous carbohydrates, and organic matter. Furthermore, a higher proportion of straw in the FB-based ration compared to the CS ration may further depress voluntary intake (Table 1, Fazaeli et al., 2023). In contrast to the present findings, Fleming et al. (2018) reported an increase in feed intake when the FB bulb was added to diets of grazing cows. These discrepancies are likely attributed to variations in feeding methods, animal type, management practices, and dietary formulation.

Nutrient digestibility

Table 4 presents the effects of substituting FB for CS on nutrient digestibility. Replacing CS with FB significantly increased (P < 0.0001) the digestibility of dry matter, organic matter, and crude protein, whereas neutral detergent fiber digestibility was not affected (P = 0.4270). The improved digestibility observed with the FB diet is consistent with the principle that reduced dry matter intake (Table 3) can extend ruminal retention time. A slower passage rate allows more extensive microbial fermentation, thereby enhancing nutrient digestibility (Van Soest, 1994). In addition, the superior digestibility of the FB diet may be attributed to its distinct chemical composition (Table 2), particularly its higher concentration of readily fermentable non-fibrous carbohydrates (NFC) and lower NDF content compared with CS (Ferraretto et al., 2013; Shakeri et al., 2022). In contrast, Roshanzamir et al. (2024) reported that substituting CS with FB aerial-part silage in dairy cow diets reduced nutrient digestibility, which they attributed to the higher NFC content in the control ration. The greater digestibility observed in the present study, compared with those findings, may be related to the use of the entire FB plant (including both leaves and bulb) rather than only the aerial portion. The FB bulb contains high concentrations of water-soluble carbohydrates and NFC, which are highly fermentable and can enhance ruminal digestibility in livestock diets (Waghorn et al., 2018; Fleming et al., 2020).

Consistent with these findings, pasture-based research has shown that incorporating whole FB at inclusion levels below 23% of dietary dry matter can improve nutrient digestibility in dairy cows (Waghorn et al., 2018). However, the lower NDF digestibility observed with the FB diet may reflect an imbalance in the carbohydrate profile, particularly a higher NFC-to-NDF ratio. Elevated dietary NFC:NDF ratios can suppress fiber digestion, mainly due to the reduction in ruminal pH associated with increased NFC fermentation (Ma et al., 2015).

Milk production and composition

As shown in Table 5, cows fed FB silage produced significantly higher milk yield (P = 0.0015), more 4% fat-corrected milk (P = 0.0124), and higher milk protein (P = 0.0131) and lactose concentrations (P = 0.0241) compared to cows fed with CS. The milk-yield-to-dry matter intake ratio was significantly improved (P = 0.007) in cows receiving the FB diet. Although milk fat concentration was significantly higher (P = 0.0226) in cows fed with CS, daily fat yield did not differ between the two dietary treatments (P = 0.0776).

Table 2. Average yield and chemical composition of forage portions (Mean ± SD)

Item	Corn silage	Fodder beet
Yield (dry matter/ha)	8.04 ± 0.23	6.33 ± 0.10
Dry matter (%)	23.20 ± 0.58	17.60 ± 0.51
Crude protein (CP, %)	8.69 ± 0.61	9.80 ± 0.20
Organic matter (OM, %)	93.21 ± 0.76	91.72 ± 0.63
Neutral detergent fiber (NDF, %)	49.82 ± 1.30	40.85 ± 1.14
Acid detergent fiber (ADF, %)	29.63 ± 1.04	19.06 ± 0.88
Ether extract (EE, %)	2.86 ± 0.27	0.81 ± 0.10
Non-fiber carbohydrate[1] (NFC, %)	31.84 ± 1.38	40.26 ± 1.02
NFC to NDF ratio	0.64 ± 0.10	0.99 ± 0.13

[1]Non-fiber carbohydrates = 100 – (CP% + Ash% + EE % + NDF%)

Table 3. The results of experimental treatments on daily nutrients intake (*n* = 10)

Item	Diet including silage		SEM[1]	P-value			Power test[2]
	Corn	Fodder beet		Treatment (T)	Period (P)	T × P	
Dry matter intake (kg/day)	23.78	21.11	0.391	< 0.0001	0.1162	0.2779	0.873
Organic matter intake (kg/day)	21.94	18.97	0.366	< 0.0001	0.0396	0.0980	0.890
Crude protein intake (kg/day)	3.58	3.16	0.062	< 0.0001	0.0189	0.1645	0.927
Neutral detergent fiber intake (kg/day)	8.59	7.42	0.193	< 0.0001	0.1880	0.3083	0.805

[1]SEM = standard error of mean; [2]The power of the test was calculated assuming a significance level of α = 0.05.

Table 4. The results of experimental treatments on nutrients digestibility (*n* = 10)

Item	Diet including silage		SEM[1]	P-value			Power test[2]
	Corn	Fodder beet		Treatment (T)	Period (P)	T × P	
Dry matter digestibility (%)	65.11	68.39	0.652	< 0.0001	0.3721	0.4956	0.749
Organic matter digestibility (%)	66.49	69.53	0.772	< 0.0001	0.1912	0.5455	0.926
Crude protein digestibility (%)	66.96	71.05	0.719	< 0.0001	0.2231	0.3751	0.887
Neutral detergent fiber digestibility (%)	40.98	40.11	1.366	0.4270	0.5271	0.6709	0.232

[1]SEM = standard error of mean; [2]The power of the test was calculated assuming a significance level of α = 0.05.

The enhanced milk production observed with the FB diet compared with the CS diet likely reflects three primary nutritional advantages: (1) improved overall nutrient digestibility (Table 4), (2) higher NFC content (Table 1; 39.93% vs. 36.68%), and (3) a more favorable NFC:NDF ratio (Table 1; 1.06 vs. 0.95). These results are consistent with Dalley et al. (2020), who also reported increased milk yield when CS was replaced with FB. In contrast, studies using FB leaf-only silage have shown reductions in milk production when substituted for CS. Roshanzamir et al. (2024) attributed this decline to the lower NFC content and decreased organic matter digestibility of the CS-based diet relative to leaf-only FB silage. Higher milk-fats observed in cows fed with CS may be explained by a greater neutral detergent fiber content (38.60% vs. 35.70%) and lower NFC level compared with the FB diet. The nutritional profile of whole-plant FB, characterized by low fiber content and high amounts of rapidly fermentable carbohydrates, supports a rumen fermentation pattern that increases propionate production at the expense of acetate (Jonker et al., 2017; Pacheco et al., 2020). This shift in volatile fatty acid production likely accounts for the reduced milk fat content in FB-fed cows, as acetate is the primary precursor for de novo milk fat synthesis. However, findings across the literature are not uniform. Fleming et al. (2018) reported that while FB inclusion increased milk yield, it had no significant effect on milk composition (fat, protein, or lactose). Dalley et al. (2020) similarly found that substituting 25% of CS with FB increased milk fat percentage. Such inconsistencies likely reflect differences in dietary formulation, animal genetics, physiological state, and feeding management practices (Ponnampalam et al., 2024).

STUDY LIMITATIONS

This study has several limitations that should be acknowledged. First, the research was conducted at a single site (Gavdasht Station), which may limit the generalizability of the findings to regions with different soil types, management systems, and climatic conditions. Multi-location studies are recommended to confirm the applicability of these results across broader production environments. Second, due to the constraints in accessing a larger population of animals with comparable production characteristics, the study was limited to 10 replicates per treatment. As indicated in the results, statistical power analysis showed suboptimal power for certain variables, including milk production and composition. Future studies should incorporate larger sample sizes to improve the robustness and statistical precision of the findings. Finally, the experiment was conducted on medium-producing dairy cows. Evaluating the effects of these dietary strategies in high-producing animals is an important avenue for future research.

Table 5. The results of experimental treatments on milk production and components (*n* = 10)

Item	Diet including silage		SEM[1]	P-value			Power test[2]
	Corn	Fodder beet		Treatment (T)	Period (P)	T × P	
Milk yield (kg/day)	25.13	26.57	0.354	0.0015	0.4639	0.7562	0.822
Fat corrected milk[3] (4%, kg/day)	22.31	23.36	0.329	0.0124	0.2624	0.3463	0.523
Fat (g/kg)	32.58	31.95	0.242	0.0226	0.2087	0.4868	0.511
Fat (kg/day)	0.82	0.85	0.014	0.0776	0.3945	0.3359	0.354
Protein (g/kg)	31.03	31.67	0.217	0.0131	0.3072	0.4997	0.331
Protein (kg/day)	0.78	0.84	0.016	0.0217	0.2442	0.6127	0.572
Fat to protein ratio	1.05	1.01	0.025	0.1125	0.2844	0.5157	0.382
Lactose (g/kg)	43.92	45.63	0.737	0.0241	0.4382	0.6108	0.634
Lactose (kg/day)	1.11	1.21	0.030	< 0.0001	*0.2886*	0.4886	0.499
Milk yield/DMI[4]	1.05	1.26	0.033	0.0007	0.0795	0.7182	0.918

[1]SEM = standard error of mean; [2]The power of the test was calculated assuming a significance level of α = 0.05; [3]Fat corrected milk (4%) = 0.4 Milk yield (kg/d) + 15 Fat (kg/d) (NRC, 2001); [4]DMI= Dry matter intake (kg/day).

CONCLUSION

The results of the present study indicated that dietary inclusion of fodder beet reduced feed intake in dairy cows. However, this reduction did not negatively affect animal performance. Instead, the improved nutrient digestibility associated with replacing corn silage with FB led to increased milk production. Considering the favorable climatic conditions for cultivating autumn crops such as FB in northern regions, together with the positive animal responses observed in this study, fodder beet appears to be a suitable alternative that can replace up to 25% of conventional forages in dairy cow diets. Nevertheless, it should be noted that this study was conducted using mid-lactation cows with moderate milk production and a limited number of experimental replicates. Statistical power analysis for milk production traits indicated that a larger number of replicates would be required to obtain more reliable and precise estimates. Therefore, future studies should evaluate higher levels of FB inclusion in diets of moderate- and high-producing dairy cows, using larger sample sizes to generate more comprehensive and robust results.

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CRediT AUTHORSHIP CONTRIBUTION STATEMENT

Conceptualization: Hassan Khamisabadi and Alireza Ashkvari; Methodology: Hassan Khamisabadi and Alireza Ashkvari; Software: Hassan Khamisabadi and Alireza Ashkvari; Investigation: Hassan Khamisabadi and Alireza Ashkvari; Resources: Hassan Khamisabadi; Data curation: Alireza Ashkvari; Writing—original draft preparation: Hassan Khamisabadi; Writing—review and editing: Alireza Ashkvari; Project administration: Hassan Khamisabadi.

DECLARATION OF COMPETING INTEREST

The authors declare that there are no conflicts of interest.

ETHICAL STATEMENT

The experiment was conducted according to the guidelines set forth in “The Care and Use of Agricultural Animals in Research and Teaching” (FASS, 2010). The Animal Experiment Committee at Animal Science Research Institute of Iran approved all procedures and protocols with animals (approval NO.128.13.13.004.0003.03002.030075).

DATA AVAILABILITY

All data analyzed and generated during this study are included in this published article.

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