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Effects of Replacing Corn Stover Silage with Sweet Sorghum Silage on Dry Matter Intake, Fibre Digestibility, and Milk Composition in Thai Holstein Crossbred Dairy Cows

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Simple Summary

Dairy farmers in tropical areas often face roughage shortages during the hot and dry season, and corn stover silage is commonly used but can be nutritionally variable. Sweet sorghum is drought-tolerant and may provide a more reliable silage for smallholder farms. We compared sweet sorghum silage with corn stover silage in 12 Holstein–Friesian crossbred cows fed the same concentrate, measuring feed intake, nutrient digestibility, milk yield, and milk composition on two sampling days. Cows fed sweet sorghum silage ate more feed and digested fibre components more effectively than cows fed corn stover silage. Milk yield and energy-corrected milk were similar between diets, indicating that sweet sorghum silage maintained production performance. Milk protein concentration was modestly higher with sweet sorghum silage, while milk fat and lactose did not change. These results support sweet sorghum silage as a practical roughage option for tropical smallholder dairy systems, helping improve fibre utilization and maintaining milk production during periods when high-quality forage is limited.

Abstract

Milk production in tropical smallholder systems is constrained by limited high-quality roughage during the hot–dry season. Sweet sorghum silage is drought-tolerant and may replace corn stover silage. Twelve Holstein–Friesian crossbred cows were assigned to the same commercial concentrate plus either corn stover silage or sweet sorghum silage as the primary roughage source (n = 6 per diet). Intake, apparent digestibility, milk yield and composition, and feed-use efficiency were evaluated on day 15 and 30 and analyzed using linear mixed-effects models with cow as a random effect. Compared with corn stover silage, sweet sorghum silage increased dry matter intake ($p < 0.05$) and improved the digestibility of fibre fractions, including crude fibre, NDF and ADF ($p \leq 0.003$), while crude protein- and nitrogen-free extract digestibility were not different ($p > 0.05$). Milk yield, 4% fat-corrected milk, energy-corrected milk, and feed-use efficiency indices were unaffected

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by silage source ($p > 0.05$). Milk protein concentration was higher with sweet sorghum silage (treatment effect $p < 0.05$), whereas milk fat and lactose were unchanged. Sweet sorghum silage can therefore replace corn stover silage in tropical dairy diets, improving intake and fibre utilization without compromising milk output.

Keywords: forage substitution; Holstein–Friesian crossbreds; milk composition; apparent nutrient digestibility; smallholder dairy systems

1. Introduction

The dairy sector in Thailand plays a crucial role in the nation's protein supply and is mainly operated by smallholder farmers, typically managing herds of 21 to 50 cows per farm [1]. The population of dairy cattle in Thailand was recorded as 623,427, comprising 283,089 cows across 17,925 farms [2]. Dairy production in Thailand is considerably hindered by a three-to-four-month hot–dry season (January to May), resulting in a substantial shortage of high-quality feed [3,4]. This situation reduces the nutritional content of available forages, resulting in inadequate nutrient intake among dairy cattle [5]. Forage crops and agricultural by-products serve as the main roughage resources used to sustain milk production [6]. Holstein crossbreds are commonly used because of their milk production potential under farmer-managed conditions [7].

Corn stover silage (CSS) is widely used as a roughage source derived from agricultural by-product in Thailand's dairy smallholder farmers [8]. As a major agricultural residue, corn stover represents a substantial global biomass resource and can support ruminant feeding programmes when preserved appropriately. However, using CSS to support optimal milk production and animal health remains challenging due to its variable nutrient composition and low digestibility [9]. Such variability arises from factors including cultivar type, harvest maturity, stem-to-leaf-to-cob ratio, and processing techniques which collectively affect its chemical composition and nutritional value. In maize plants, the ear contains most of the digestible dry matter, largely in the form of starch, while the stover represents a major portion of the total plant dry matter [10]. This difference underscores the lower nutritional quality of stover compared with grain, particularly due to the variable carbohydrate composition, which strongly influences its feeding value [11]. In addition, because stover has low bulk density and is sensitive to moisture, maintaining silage quality requires adequate storage and handling. On many smallholder farms, limited storage facilities increase the risk of aerobic deterioration and spoilage [12], which can further reduce silage quality and hinder year-round feeding management [13].

Sweet sorghum (*Sorghum bicolor* (L.) *Moench*) has emerged as a promising alternative roughage source, recognized for its drought tolerance, rapid growth, and high biomass yield [14]. Consequently, cultivating sweet sorghum has been suggested as an effective approach to stabilize forage availability and reduce reliance on maize-based roughages during periods of feed scarcity. Moreover, the global expansion of Sorghum spp. cultivation into continental regions underscores its role in climate-resilient agriculture. Beyond drought tolerance, sweet sorghum's reliable productive output and superior nutritional profile provide a strategic advantage for sustainable livestock production, supporting high performance in various environmental conditions. In terms of nutritional composition, sweet sorghum generally provides higher biomass yield than maize and contains lower starch but higher fibre, lignin, and ash concentrations [15]. Typically, when harvested at four months for silage production it contains about 26% dry matter (DM), 8% crude protein (CP), 56% neutral detergent fibre (NDF), and 36% acid detergent fibre (ADF) [16]. Addition-

ally, sweet sorghum contains substantial concentrations of water-soluble carbohydrates, which support efficient silage fermentation [17]. Studies using *Lactobacillus plantarum* and cellulase during ensiling have demonstrated improved fermentation quality, increased sugar content, enhanced rumen fermentation, and beneficial shifts in microbial populations [17]. Importantly, previous study reported that sweet sorghum silage can replace corn stover silage without compromising milk yield [18]. It can increase milk fat content and reduce somatic cell count, improving milk quality and potentially farm profitability and supporting higher producer income [19].

While sweet sorghum is gaining global importance as a forage crop in both tropical and temperate regions, its drought tolerance and rapid biomass production make it particularly valuable for smallholder systems in hot–dry tropical environments, where conventional maize-based roughages become unreliable during the extended dry season. However, despite its potential to substitute maize-based roughages, data from tropical hot dry smallholder systems is scarce, especially concerning fermentation quality, nutritional content, and impacts on intake, nutrient utilization, and milk yield. We hypothesize that replacing CSS with sweet sorghum silage (SSS) will maintain or improve milk yield in lactating cows managed under Thai smallholder conditions. This study analyzed feed composition and assessed its effects on intake, apparent digestibility, milk output and composition, and feed-use efficiency in nursing cows on smallholder farms in Thailand. These outcomes are relevant to forage security and dairy resilience under increasing climate variability [20].

2. Materials and Methods

2.1. Study Area and Forage Production

Corn stover and sweet sorghum were cultivated on commercial farms in Phitsanulok Province, Thailand (16.82° N, 100.26° E), 350 m above sea level, during the dry season (January–May 2025). The region has a tropical savanna climate with mean annual temperature of 28.5 °C, relative humidity of 73.0%, and rainfall of 1237.9 mm. Hot–dry months typically account for less than 10% of the total annual precipitation, around 125 mm over three months, resulting in significant soil moisture deficiencies [21]. The peak ambient temperatures, often reaching 37–40 °C, make the production of high-water-demanding crops such as corn unsustainable during the dry months without substantial irrigation [22]. Both crops were harvested 80 days after planting, when sweet sorghum reached approximately 2.5–3.5 m height and sweet corn stover was at the dough stage. Plants were cut 25 cm above ground level and chopped to 2.54–5.08 cm theoretical length using a tractor mounted forage harvester for ensiling [23].

2.2. Silage Preparation and Fermentation Procedure

The chopped forage was packed into low-density polyethylene silage bags (70 × 100 cm, 0.15 mm thickness). Each bag (25 kg fresh weight per bag; ~20–30% DM) was manually compacted to achieve a target packing density of 650–700 kg fresh matter/m^3, thereby minimizing oxygen entrapment and promoting stable anaerobic fermentation. Then, they were heat-sealed to be airtight and stored under shade at ambient temperature (28–32 °C). Fermentation proceeded for a minimum of 21 days. Bags were opened sequentially for daily feeding according to the experimental timeline (Figure 1), ensuring all silage fed to cows had undergone at least 21 days of ensiling. Silage samples for chemical analysis were collected from the centre of each bag immediately upon opening [19].

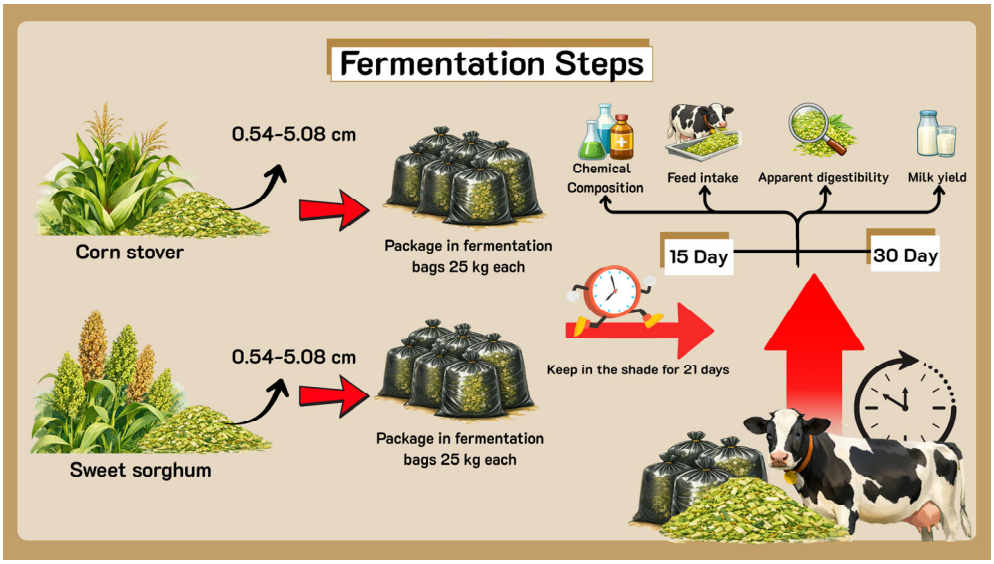


Figure 1. Schematic illustration of silage preparation and the sampling schedule. Corn stover and sweet sorghum were chopped to a theoretical length of 2.54–5.08 cm, packed into 25 kg fermentation bags, and ensiled under shade for 21 days. The resulting silages were used as the primary roughage sources during the feeding trial. Measurements of chemical composition, feed intake, apparent digestibility, and milk yield were collected on days 15 and 30.

2.3. Animals, Housing, and Experimental Design

The use and care of animals were in accordance with the guidelines for the animal care of the Committee of Institutional Animal Care, School of Agriculture and Natural Resources, University of Phayao, approval No. 1-013-68. The study included twelve lactating Holstein–Friesian crossbred cows (87.5% Holstein–Friesian × 12.5% Thai Native) crossbred cows with average body weights of 450 ± 10 kg, body condition scores of 3 ± 0.5, days in milk of 60 ± 10, and lactation days of 3 ± 1. The cows had unlimited access to drinking water and were kept separately in tie-stall pens under traditional farm management. Prior to the start of sample collection, all animals experienced an acclimation period of 14 days. Following adaptation, the cows were divided into two dietary treatments (n = 6 per treatment) using a fully randomized design. Care was taken to ensure that body weight, body condition score, lactation stage, and parity were distributed similarly between groups. To assess the feeding value of the experimental diets, measurements of feed intake, apparent nutritional digestibility, milk yield, and milk composition were carried out under realistic local farm settings.

The experiment was conducted on one commercial dairy farm in Chiang Mai Province, northern Thailand (19°45′13.3″ N 99°07′39.8″ E). Before the experiment, all cows were provided with CSS as the primary roughage source. Cows were thereafter assigned to one of two nutritional treatments (n = 6 per treatment) following adjustments for body weight, lactation number, and stage of lactation to assure group comparability at the trial's commencement. The experimental diets varied solely in the source of roughage, which, specifically was either CSS or SSS. A 14-day acclimatization period was instituted prior to sample collection to facilitate proper adaptation to the designated diets, especially for cows transitioning from CSS to SSS. Both groups received the identical commercial concentrate, with the roughage source being the only planned nutritional distinction between the treatments. Measurements were collected during the feeding study to assess feed intake, apparent nutrient digestibility, milk yield, and milk composition including fat, protein, and lactose [19].

Roughage and concentrate were provided separately. Roughage was offered ad libitum, aiming for around 5–10% refusal rates, with the daily allocation divided into two feedings. Daily records of feed provided, and refusals were maintained for each cow to ascertain actual intake for digestibility assessments. Concentrate feed was administered in two equal portions daily; any refusal of concentrate was documented. Daily measurements of individual meals provided and refusals were recorded at a consistent time prior to the morning feeding. The daily dry matter intake (DMI) was computed using the formula: DMI (kg/d) = (feed offered × DM) − (refusals × DM) for each cow. The dry matter content of silage and refusals was assessed weekly (and revised when silage batches were altered), and these dry matter values were utilized to convert as fed weights to a dry matter basis. Feed samples (concentrate, silage, and refusals) were collected weekly, aggregated by period and treatment, and subsequently subsampled for chemical analysis (Table 1).

Table 1. Nutritional profiles of concentrate feed, CSS, and SSS.

Items (% DM Basis)	Concentrate	CSS	SSS
Dry matter	92.23	20.75	26.41
Organic matter	93.47	95.07	95.49
Crude protein	19.04	8.00	3.72
Ether extract	8.88	0.85	1.32
NFE	57.56	64.64	50.82
Crude fibre	7.98	26.49	44.15
NDF	33.43	60.04	77.61
ADF	15.45	33.66	55.65
ADL	3.76	6.87	11.91
Cellulose	11.69	26.79	43.74
Hemicellulose	17.98	26.37	21.96
pH			
Day 0	-	6.74 ± 0.07	6.74 ± 0.11
Day 14	-	3.99 ± 0.18	4.28 ± 0.05

CSS = corn stover silage; SSS = sweet sorghum silage; NFE = nitrogen-free extract; NDF = neutral detergent fibre; ADF = acid detergent fibre; ADL = acid detergent lignin.

2.4. Nutrient Digestibility

Feed intake, feed refusals, and total fecal output were recorded daily during the last 5 days after adaptation period for 25 days of the experimental period. Approximately 5% of fresh fecal weight was randomly sampled, pooled, and stored for subsequent chemical composition analysis. Samples were immediately stored in sealed plastic containers and frozen at −20 °C to prevent degradation until chemical analysis. Prior to analysis, samples were dried in a forced-air oven at 60 °C for 72 h and ground to pass through a 1 mm sieve using a Cyclotech Mill (Tecator, Hoganas, Sweden). The DM, organic matter (OM), and crude protein (CP) contents were determined following AOAC [24]. Additionally, cell wall contents, neutral detergent fibre (NDF) and acid detergent fibre (ADF) were analyzed as described by Van Soest et al. [25]. The apparent total tract digestibility coefficients of nutrients were calculated as the difference between nutrient intake and nutrient excretion, divided by nutrient intake, and expressed as a percentage.

$$\text{Digestibility}(\%) = \frac{\text{Feed intake}(\text{kg per day}) - \text{Fecal}(\text{kg per day})}{\text{Feed intake (kg per day)}} \times 100 \quad (1)$$

2.5. Milk Composition Analysis

Milk yield was automatically recorded at each milking (05:00 and 16:00 h) on days 15 and 30 of the experimental period utilizing individual milk metres. The selected sampling days were to assess the first reaction following dietary modification and the short-term

sustainability of that response. Due to the cows' adaptation to the experimental diets for 14 days prior to the initial assessment, day 15 served as the first post-adaptation sampling point, whereas day 30 was utilized to evaluate the persistence of treatment effects over time [26]. Representative milk samples (25 mL each milking) were obtained from both morning and afternoon milkings on each sampling day to achieve a daily composite assessment of milk composition. These samples were preserved in plastic bottles and stored at 2–4 °C until analysis of their milk composition. Raw milk samples were placed in insulated coolers with ice packs and delivered to the laboratory within 4 h of collection. Milk fat, protein, lactose, solids-not-fat (SNF), and total solids were determined by Fourier transform infrared spectroscopy (FTIR) using a MilkoScan FT6000 (Foss Analytics, Hillerød, Denmark). Somatic cell count was measured with a Fossomatic 5000 (Foss Analytics, Hillerød, Denmark). Milk composition was analyzed for protein, fat, solids-not-fat, and lactose, and the following equations were used to calculate standard milk yield. Energy-corrected milk (ECM) and 4% fat-corrected milk (4% FCM) were calculated to standardize milk yield for milk composition. ECM was calculated as milk yield × ((0.38 × % fat) + (0.24 × % protein) + (0.17 × % lactose))/3.17, whereas 4% FCM was calculated as (0.4 + 0.15 × % milk fat) × milk yield [27].

2.6. Statistical Analysis

Statistical analyses were performed in R (version 4.4.1). Variables measured on days 15 and 30 were analyzed using a linear mixed-effects model for repeated measures:

$$Yijk = \mu + Ti + Dj + (T \times D)\,ij + Ck + \varepsilon ijk \quad (2)$$

Yijk denotes the response variable measured in cow *k*, assigned to treatment; *i*, at sampling time *j*; μ is the overall mean; *Ti* is the fixed effect of dietary treatment (corn stover silage or sweet sorghum silage); *Dj* the fixed effect of sampling time (Day 15 or Day 30); $(T \times D)ij$ represents the interaction between treatment and sampling time; *Ck* is the random effect of cow; and εijk is the residual error. Repeated observations were specified within cow, and cow was treated as the experimental unit. Significance was declared at $p < 0.05$.

3. Results

3.1. Dry Matter Intake

Total DMI, determined by summing concentrate and roughage intakes following the individual recording of feed offered and refusals for each component, was higher in cows consuming SSS compared to those receiving CSS. On day 15, total DMI was greater in the SSS group compared to the CSS group (9.51 vs. 8.34 kg DM/day; $p < 0.05$). On day 30, a comparable trend was noted, with cows administered SSS exhibiting a higher total DMI than those receiving CSS (9.53 vs. 8.33 kg DM/day; $p < 0.05$). In each treatment, total DMI did not vary between day 15 and day 30, signifying that intake was consistent throughout the trial duration (Figure 2).

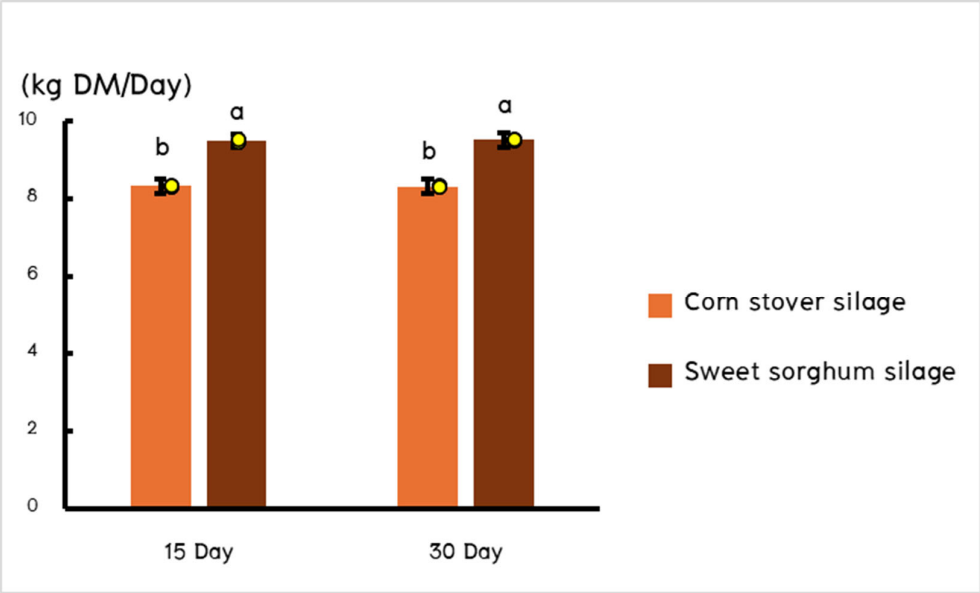


Figure 2. Dry matter intake of lactating dairy cows fed CSS vs. SSS on days 15 and 30 of the experimental period. Bars represent least-squares means with error bars indicating SEM. [a,b] Different superscript letters denote significant differences between silage treatments on the same sampling day ($p < 0.05$).

3.2. Nutrient Digestibility

Although the overall digestibility of the diet was broadly comparable between treatments, SSS was associated with modest numerical increases in both DMD (78.19 vs. 74.16%) and OMD (80.63 vs. 77.06%), with both variables being numerically elevated, and no significant treatment impact was seen ($p = 0.077$ and $p = 0.076$, respectively). In contrast, CPD was unaffected by silage source (SSS: 74.71% vs. CSS: 77.38%; $p = 0.414$), indicating that protein utilization was maintained when SSS replaced CSS. Clear treatment effects were evident on fibre fraction digestibility. Cows receiving SSS exhibited substantially higher CFD (76.66 vs. 63.68%; $p = 0.003$), accompanied by marked improvements in NDFD (71.25 vs. 59.59%; $p = 0.003$) and ADFD (71.44 vs. 57.80%; $p = 0.002$) than those without SSS. The apparent digestibility of ADL was greater in the SSS group compared to the CSS group (42.65% vs. 39.57%; $p = 0.001$). However, this result should be approached with caution due to the high indigestibility of lignin and the potential for methodological artefacts in total tract digestibility measurements. These reactions should be taken with caution, as nutrient digestibility and ruminal fermentation may be affected by variations in nutrient intake, including the supply of degradable protein, rather than only veing affected by fibre properties.

In contrast to the fibre responses, EED was slightly but significantly lower for SSS compared with CSS (95.29 vs. 97.29%; $p = 0.046$), although the magnitude of this difference was small. The digestibility of NFED did not differ between silage sources (74.88 vs. 71.47%; $p = 0.131$), implying that the utilization of readily fermentable carbohydrate fractions was not materially altered by the change in roughage source. Overall, these findings indicate that SSS can improve fibre fraction digestibility, particularly NDF, ADF, and lignin-associated fractions, while maintaining comparable digestibility of crude protein and nitrogen-free extract, and with only minor differences in ether extract utilization (Table 2).

Table 2. Comparative apparent digestibility (%) of CSS and SSS in lactating dairy cows.

Items (%)	CSS	SSS	SEM	*p*-Value
DMD	74.16	78.19	1.34	0.077
OMD	77.06	80.63	1.17	0.076
CPD	77.38	74.71	2.15	0.414
CFD	63.68	76.66	1.86	0.003
EED	97.29	95.29	0.57	0.046
NFED	71.47	74.88	1.38	0.131
NDFD	59.59	71.25	1.74	0.003
ADFD	57.80	71.44	1.75	0.002
ADLD	39.57	42.65	4.04	0.001

Least-squares means (LS Means) were obtained from linear mixed-effects models, including treatment as a fixed effect and cow as a random effect. SEM is the pooled standard error of the LS Means. CSS = corn stover silage; SSS = sweet sorghum silage; SEM, standard error of the mean.

3.3. Feed Conversion Efficiency

The feed conversion efficiency indices were broadly comparable between the silage sources at both sampling times. For kg milk/kg feed, values were similar between treatments on day 15 (CSS: 0.90; SSS: 0.90) and day 30 (CSS: 0.88; SSS: 0.87), and the main effect of silage source was not significant (p = 0.985). Likewise, 4% FCM/kg feed did not differ between CSS and SSS (day 15:0.86 vs. 0.90; day 30:0.82 vs. 0.85), with no treatment effect detected (p = 0.702). Consistent with these results, ECM/kg feed remained statistically comparable between silage sources (day 15:0.80 vs. 0.86; day 30:0.87 vs. 0.88; p = 0.582). Feed conversion efficiency (FCE) was also similar between treatments on days 15 (1.14 vs. 1.15) and 30 (1.17 vs. 1.18), and the main effect of silage source was not significant (p = 0.958). In contrast to the treatment comparisons, time significantly affected several efficiency traits. The kg milk/kg feed ratio decreased from day 15 to day 30 across both treatments (p = 0.007), indicating a modest reduction in milk output relative to feed intake as the study progressed. Conversely, ECM/kg feed increased over time (p = 0.003), suggesting an improved energy-corrected output per unit feed later in the experimental period. FCE also increased slightly from days 15 to 30 (p = 0.029). Importantly, the silage source × time interaction was not significant for any response variable (p = 0.109–0.871), indicating that temporal changes in efficiency occurred similarly in cows fed CSS and those fed SSS (Table 3).

Table 3. Impacts of CSS vs. SSS in different times (d 15, 30) on feed conversion efficiency of lactating dairy cows.

Item	CSS	SSS	*p*-Value
Kg milk/Kg feed			
Day 15	0.900 ± 0.064	0.898 ± 0.062	0.977
Day 30	0.880 ± 0.068	0.873 ± 0.060	0.943
4% FCM Kg/Kg feed			
Day 15	0.855 ± 0.088	0.897 ± 0.059	0.689
Day 30	0.815 ± 0.095	0.850 ± 0.059	0.760
ECM/Kg feed			
Day 15	0.803 ± 0.083	0.863 ± 0.053	0.055
Day 30	0.870 ± 0.100	0.880 ± 0.063	0.934
Feed conversion efficiency			
Day 15	1.138 ± 0.077	1.145 ± 0.092	0.888
Day 30	1.170 ± 0.091	1.180 ± 0.097	0.942

CSS = corn stover silage; SSS = sweet sorghum silage.

Across all feed-use efficiency indices, silage source had no effect (P-Treatment = 0.582–0.985), and no Treatment × Time interactions were detected (P-Interaction = 0.109–0.871), indicating that the response patterns were comparable between diets over the sampling periods. In contrast, sampling time influenced several outcomes, with significant period effects for kg milk/kg feed ($p = 0.007$), ECM/kg feed ($p = 0.003$), and overall feed conversion efficiency ($p = 0.029$). The 4% FCM/kg feed ratio showed only a trend toward a time effect ($p = 0.056$). Overall, these results suggest that temporal variation (day 15 vs. day 30), rather than silage source, was the primary driver of changes in feed-use efficiency (Table 4).

Table 4. Effects of fixed-effect from the repeated-measures mixed model on the feed conversion efficiency of lactating dairy cows.

Item	P-Treatment	P-Time	P-Interaction
Kg milk/Kg feed	0.985	0.007	0.636
4% FCM Kg/Kg feed	0.702	0.056	0.822
ECM/Kg feed	0.582	0.003	0.109
Feed conversion efficiency	0.958	0.029	0.871

Note: Significant effects ($p < 0.05$); P-treatment = effect of silage source; P-time = effect of sampling time (day 15 vs. day 30); P-interaction = treatment × time interaction, based on the repeated-measures mixed model.

3.4. Milk Composition

On day 15, cows fed SSS produced numerically more milk than those fed CSS (15.16 vs. 14.14 kg/d), but the difference was not significant ($p = 0.495$). A comparable pattern was observed for 4% fat-corrected milk (4% FCM), which did not differ between silage sources (15.13 vs. 13.42 kg/d; $p = 0.340$). Similarly, milk fat concentration and lactose content were not affected by the silage source (fat: 4.01 vs. 3.62%, $p = 0.198$; lactose: 4.85 vs. 4.62%, $p = 0.188$), and energy-corrected milk (ECM) remained comparable between treatments (14.59 vs. 12.62 kg/d; $p = 0.246$). The milk crude protein concentration was higher in cows receiving SSS than in those fed CSS on day 15 (2.99 vs. 2.70%; $p = 0.050$), indicating an early improvement in milk protein content with SSS. On day 30, milk yield remained to be statistically similar between the treatments (SSS: 14.77 vs. CSS: 13.83 kg/d; $p = 0.538$). Likewise, 4% FCM did not differ between the diets (14.88 vs. 13.67 kg/d; $p = 0.538$), and the milk fat percentage remained comparable (4.07 vs. 3.83%; $p = 0.469$). Lactose concentration also did not differ between treatments (4.78 vs. 4.50%; $p = 0.119$), and ECM output remained statistically unchanged by silage source (14.41 vs. 12.81 kg/d; $p = 0.397$). Notably, the protein response persisted, with crude protein tending to be higher in SSS-fed cows than in CSS-fed cows on day 30 (3.12 vs. 2.81%; $p = 0.073$). Overall, substituting CSS with SSS did not alter milk yield, 4% FCM, ECM, milk fat, or lactose at either sampling time, but it was associated with a consistent improvement in milk crude protein concentration, reaching borderline significance on day 15 and remaining as a positive tendency on day 30. These findings suggest that SSS can enhance the protein fraction of milk in tropical dairy cows without compromising overall milk production, as shown in Table 5.

Table 5. Effects of fixed effects from the repeated-measures mixed model on milk yield and milk composition of lactating dairy cows.

Item	CSS	SSS	*p*-Value
Milk yield (kg/d)			
Day 15	14.14 ± 1.00	15.16 ± 1.04	0.495
Day 30	13.83 ± 1.06	14.77 ± 1.03	0.538
4% FCM (kg/d)			
Day 15	13.42 ± 1.38	15.13 ± 0.99	0.340
Day 30	13.67 ± 1.58	14.88 ± 1.07	0.538
Fat (%)			
Day 15	3.62 ± 0.24	4.01 ± 0.16	0.198
Day 30	3.83 ± 0.24	4.07 ± 0.20	0.469
Crude protein (%)			
Day 15	2.70 ± 0.09	2.99 ± 0.09	0.050
Day 30	2.81 ± 0.12	3.12 ± 0.09	0.073
Lactose (%)			
Day 15	4.62 ± 0.14	4.85 ± 0.09	0.188
Day 30	4.50 ± 0.14	4.78 ± 0.09	0.119
ECM (kg/d)			
Day 15	12.62 ± 1.32	14.59 ± 0.90	0.246
Day 30	12.81 ± 1.50	14.41 ± 1.01	0.397

SEM is the pooled standard error of the LSMeans. Within a row, means with different superscripts differ at $p < 0.05$. CSS = corn stover silage; SSS = sweet sorghum silage.

A repeated-measures mixed model (cow as a random effect; fixed effects of treatment, time, and treatment × time) indicated that sampling time significantly affected milk yield and lactose concentration, whereas silage source influenced milk protein. Specifically, milk yield decreased from day 15 to day 30 in both treatments (P-time = 0.014) without evidence of a treatment effect or treatment × time interaction (P-treatment = 0.485; P-interaction = 0.657). Lactose concentration also declined over time (P-time = 0.001) and was not altered by treatment or the interaction (P-treatment = 0.151; P-interaction = 0.423). In contrast, milk protein was higher overall in cows fed SSS than CSS (P-treatment = 0.038) and increased with time (P-time = 0.015), with a consistent response pattern across sampling days (P-interaction = 0.923). No significant fixed effects were detected for 4% fat-corrected milk, energy-corrected milk, or milk fat percentage (all $p > 0.05$) Table 6.

Table 6. Effects of fixed-effects from the repeated-measures mixed model on milk yield and milk composition of lactating dairy cows.

Item	P-Treatment	P-Time	P-Interaction
Milk yield (kg/d)	0.485	0.014	0.657
4% FCM (kg/d)	0.345	0.466	0.299
Milk fat (%)	0.188	0.098	0.402
Milk protein (%)	0.038	0.015	0.923
Lactose (%)	0.151	0.001	0.423
Energy-corrected milk (kg/d)	0.24	0.513	0.382

Note: Significant effects ($p < 0.05$); P-treatment = effect of silage source; P-time = effect of sampling time (day 15 vs. day 30); P-interaction = treatment × time interaction, based on the repeated-measures mixed model.

4. Discussion

4.1. Consumption of Dry Matter

This study sought to evaluate the effects of replacing CSS with SSS on DMI in lactating dairy cows, given that DMI is a primary driver of nutrient supply, milk production efficiency, and metabolic health [28]. Diet composition, and particularly the nature of the

fibre fraction, is well recognized to influence voluntary intake and downstream productive responses in ruminants [29]. The increased total DMI in cows consuming SSS was likely due to the roughage component, given the concentrate provided was identical in both treatments. Consequently, the disparity in total DMI likely indicated variations in silage consumption rather than concentrate consumption. This conclusion aligns with prior reports suggesting that sorghum-based silages may facilitate increased voluntary fodder intake [30]. The elevated digestibility of NDF and ADF noted with sweet sorghum silage in this study is significant, as sorghum silage is frequently shown to possess higher concentrations of NDF and lignin compared to corn silage, potentially restricting fibre use. Although elevated DMI may enhance digesta passage rate and potentially diminish ruminal fibre breakdown, the passage rate was not assessed in this investigation. The improved fibre digestibility, especially in NDF and ADF, is significant considering that sorghum silage typically contains greater lignin and NDF levels than corn silage, which may restrict its overall digestibility [31]. The retention of structural carbohydrates and proteins from microbial breakdown by phenolic compounds and tannins in sorghum silage may enhance digestive efficiency [32].

The high sugar concentration in sweet sorghum silage may provide a more favourable ruminal environment for fibre-degrading bacteria, hence facilitating the degradation of structural carbohydrates despite accelerated transit [33]. The inclusion of certain phenolic compounds and tannins in sorghum silage may safeguard dietary proteins and structural carbohydrates against microbial breakdown, resulting in enhanced utilization in the lower digestive tract [32]. Palatability may have played a role, as the elevated sugar content often linked to sweet sorghum could enhance forage acceptability. Nonetheless, this effect did not result in a substantial increase in consumption in the current investigation [34]. In addition, intake is sensitive to silage fermentation qualities such as pH, lactic acid concentration, and the extent of spoilage microorganisms because these traits influence odour, taste, and nutrient availability [35]. The markedly elevated dry matter intake noted in the sweet sorghum silage group is attributable to the advantageous nutritional and fermentation characteristics intrinsic to sweet sorghum. Sweet sorghum is distinguished by a significant concentration of water-soluble carbohydrates, reaching up to 327 g/kg DM [34]. This plentiful sugar source promotes a swift and effective lactic acid fermentation process, which markedly enhances the water-soluble carbohydrate content in the resulting silage as the ratio of sweet sorghum in the blend rises [32].

4.2. Nutrient Digestibility

In this investigation, the administration of sweet sorghum silage produced a more favourable physiological response than maize stover silage, evidenced by markedly increased total dry matter intake and improved digestibility of structural carbs. We recognize that the provision of silages ad libitum in conjunction with a predetermined concentrate allowance resulted in the final diets being non-isonitrogenous. The elevated voluntary consumption of SSS, attributed to its substantial water-soluble carbohydrate content [34], modified the dietary roughage-to-concentrate ratio and augmented the total intake of nitrogen and fermentable energy [32]. This alteration likely promoted a better-coordinated supply of nutrients in the rumen, thereby driving microbial growth and collectively improving total meal digestibility [35]. The enhanced fibre utilization and increased milk protein content associated with SSS are directly attributable to this optimal nutritional intake profile, even in non-isonitrogenous circumstances.

The major purpose of this study was to undertake a complete comparative examination of the digestibility profiles of sweet sorghum silage and corn stover silage when introduced into the diets of dairy cattle, consequently evaluating their potential as sustainable feed

alternatives. This entailed a rigorous examination of dry matter intake, nutrient use, and ruminal fermentation dynamics to ascertain their respective efficiencies in sustaining cattle performance [2]. The findings seek to provide significant insights for feed formulation techniques, encouraging the sustainable intensification of dairy cattle production systems [3]. Previous research has revealed that the in vitro digestibility of sorghum fodder silage may be lower than that of corn fodder silage, suggesting potential differences in nutrient uptake efficiency. Dairy cattle indicates that sorghum silage can successfully substitute corn silage at levels of up to 100% without markedly affecting nutritional digestibility or production performance. This is principally due to the nutritional and physiological disparities between the two forages. Sweet sorghum silage often exhibits a lower calorie density due to its reduced starch content compared to corn silage, as sorghum has not been genetically optimized for a high grain-to-stover ratio. Secondly, sorghum silage frequently possesses elevated levels of structural carbohydrates, notably neutral detergent fibre and lignin, which might enhance ruminal fullness and restrict voluntary intake. Lignin's negative correlation with organic matter degradability suggests that increased concentrations may further diminish the rate and extent of ruminal digestion, thereby leading to reduced feed intake [26]. These varying outcomes underscore the necessity for further research to clarify the specific digestibility characteristics and feeding values of sweet sorghum silage compared to corn stover silage, especially given sweet sorghum's desirable roughage effect and potential for improved fibre and grain degradability [36]. In a broader context, these findings reinforce SSS as a high-quality forage that transcends its role as a mere survival feed. Given the global shift toward Sorghum spp. in both tropical and continental zones, SSS should be viewed as a proactive strategy for enhancing dairy resilience and productivity year-round. This approach addresses the challenges of climate change and seasonal transitions more effectively than reliance on lower-quality agricultural by-products.

4.3. Feed Conversion Efficiency

Research indicates that although particular sorghum silages may cause fluctuations in dry matter intake or nutrient digestibility, the overall feed conversion and efficiency in livestock are similar to those consuming corn silage [37]. This substitution is especially beneficial due to sweet sorghum's superior drought and high-temperature tolerance, diminished fertilizer needs, and fewer specific soil requirements compared to maize, making it a dependable choice for mitigating roughage shortages in livestock production [38]. Research has shown that triticale silage can entirely replace sorghum silage in beef cattle diets without compromising nutritional and metabolic indices, hence reinforcing the interchangeability of different forage silages in livestock feed [39]. Additionally, brown midrib (bmr) cultivars of sorghum, characterized by modified lignin composition, offer potential for improving the nutritional quality of sorghum silages; nevertheless, the relationship between bmr genes and environmental adaptability necessitates further research [40]. This highlights the necessity for ongoing investigation into cultivar-specific traits and their effects on digestibility and nutrient utilization, particularly in light of the extensive adoption of alternate fodder sources. Consequently, enhancing silage quality via suitable ensiling methods and hybrid selection is essential for maximizing the advantages of sweet sorghum as a feed alternative [16].

4.4. Milk Composition

The variations in milk protein concentration among different silage types require a thorough analysis of food usage and metabolic pathways. Although previous research has indicated inconsistent impacts of forage source on milk composition, the current study demonstrated that sweet sorghum silage enhanced milk protein content without influencing

milk fat, lactose, milk yield, or feed-use efficiency [35]. Studies indicate that completely substituting corn silage with sorghum silage can achieve similar milk production, albeit with observed alterations in milk fat and protein percentages [16].

5. Conclusions

Sweet sorghum silage may serve as a more suitable physiological and nutritional substitute for corn stover silage during the challenging macroclimatic conditions of Thailand's four-month hot–dry season (mid-February to May), which are marked by elevated ambient temperatures and a seasonal moisture deficit. Feeding SSS augmented total dry matter intake compared to CSS, with average intakes of 9.51 and 9.53 kg DM/day on days 15 and 30, respectively. Cows given SSS exhibited enhanced apparent NDF and ADF digestibility, signifying superior fibre utilization. These nutritional advantages were achieved without compromising milk yield, energy-corrected output, feed efficiency, and milk quality indicators. The concentration of crude protein in milk was numerically elevated in cows consuming SSS, indicating a possible benefit for milk solids production in tropical environments, although this did not reach statistical significance. Given the relatively low crude protein content of SSS, future applications should ensure an adequate dietary nitrogen supply to maximize microbial protein synthesis and sustain milk protein responses. Collectively, these findings support SSS as a feasible and potentially more sustainable roughage alternative for dairy production in hot–dry regions where conventional maize-derived residues may be nutritionally limiting.

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Abbreviations

The following abbreviations are used in this manuscript:

ADF	Acid detergent fibre
ADFD	Acid detergent fibre digestibility
ADL	Acid detergent lignin
ADLD	Acid detergent lignin digestibility
CFD	Crude fibre digestibility
CPD	Crude protein digestibility
CSS	Corn stover silage

DMD	Dry matter digestibility
ECM	Energy-corrected milk
EED	Ether extract digestibility
F:P	Fat:protein
FCE	Feed conversion efficiency
FCM	Fat-corrected milk yield
NDF	Neutral detergent fibre
NDFD	Neutral detergent fibre digestibility
NFE	Nitrogen-free extract
NFED	Nitrogen-free extract digestibility
OMD	Organic matter digestibility
SCC	Somatic cell count
SEM	Standard error of the mean
SSS	Sweet sorghum silage
TS	Total solids
WSC	Water-soluble carbohydrate

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