dairy

Article

Cactus Cladodes and Sugarcane Bagasse Can Partially Replace Earless Corn Silage in Diets of Lactating Dairy Cows

Izaac P. S. Medeiros [1], Sebastião I. Guido [2], Marco A. S. Gama [3], Carlos H. M. Silva [4], Michelle C. B. Siqueira [1,*], Camila S. da Silva [1], Antonio J. Netto [1], Silas B. Felix [1], Milena N. Rabelo [1], Thayane V. M. Santos [1], Maria A. M. Leite [1] and Marcelo A. Ferreira [1]

[1] Department of Animal Science, Federal Rural University of Pernambuco, Dom Manoel de Medeiros Street, Recife 52171-900, Pernambuco, Brazil; izaac2014@gmail.com (I.P.S.M.); camilaszootecnia@gmail.com (C.S.d.S.); netto.zootecnia@gmail.com (A.J.N.); silasboaventura18@gmail.com (S.B.F.); mnrabelo1621@gmail.com (M.N.R.); monteirothayane84@gmail.com (T.V.M.S.); malice0015@gmail.com (M.A.M.L.); marcelo.aferreira@ufrpe.br (M.A.F.)

[2] Agronomic Institute of Pernambuco, KM 03 Capoeiras Street, São Bento do Una 55370-000, Pernambuco, Brazil; sebastiao.guido@ipa.br

[3] Embrapa Southeast Livestock, Washington Luiz Road, Km 234, São Carlos 13560-970, Minas Gerais, Brazil; marco.gama@embrapa.br

[4] Department of Animal Science, Federal University of Agreste of Pernambuco, Bom Pastor Avenue, Garanhus 55292-270, Pernambuco, Brazil; carloshenriquemelo94@gmail.com

* Correspondence: michelle.siqueira2@gmail.com

Simple Summary: Forage serves as the primary nutritional resource for livestock; however, the consistent availability of high-quality forage is hindered by seasonal variations in environmental conditions, particularly in semiarid regions. In response to this challenge, silage derived from corn plants without ears (hereafter referred to as earless corn silage or ECS) has emerged as a strategic means for enhancing the income of green corn producers in Brazil. Notably, ECS has transitioned from a byproduct to a marketable feed with prices comparable to those of conventional corn silage. Under this scenario, forages adapted to such arid conditions, such as cactus cladodes (CC), are imperative. However, CC must be associated with feedstuffs possessing elevated fiber content. Coproducts, such as sugarcane bagasse (SB), present a viable solution for ameliorating the low neutral detergent fiber (NDF) content in CC-based diets. While SB is classified as a low-quality roughage, its key advantage lies in its availability during periods of forage scarcity and its cost-effectiveness. Our research demonstrates the feasibility of substituting, even partially, ECS with a combination of CC and SB, offering an excellent alternative for milk producers. By embracing CC as the most readily producible forage in semiarid regions, producers can reduce their reliance on external inputs, leveraging the utilization of this forage alongside ingredients with increased fiber content, such as SB, which is both economically advantageous and accessible.

Abstract: This study aimed to evaluate the effects of replacing earless corn silage (ECS) with cactus cladodes (CC; *Opuntia* spp.) and sugarcane bagasse (SB) on nutrient intake, digestibility, feeding behavior, milk yield (MY), and composition of lactating dairy cows. Ten Holstein cows, weighing 571 ± 97.0 kg and producing 23.0 ± 4.4 kg of milk per day, were assigned to two contemporaneous 5 × 5 Latin squares. Treatments consisted of five levels of ECS replacement with CC plus SB (0, 25, 50, 75, and 100%). The results showed a linear increase in dry matter (DM) intake ($p < 0.05$) (15.98 and 18.73 kg/day) and a quadratic increase ($p < 0.05$) in crude protein and energy intake (2.97 kg/day and 27.52 Mcal/day at 95.4 and 88.6% substitution, respectively). Apparent DM digestibility increased ($p < 0.05$), but fiber digestibility decreased linearly ($p < 0.05$). Treatments had a quadratic effect ($p < 0.05$) on MY and fat-corrected MY (24.17 kg/day and 21.9 kg/day at 63.9% and 38.6% CC plus SB, respectively). Milk fat (3.26 and 2.35%) and total solids content decreased linearly ($p < 0.05$), whereas the percentages of protein, lactose, and nonfat solids increased ($p < 0.05$). Additionally, the CC–SB diets linearly reduced the time spent on feeding and rumination and total chewing time. For

check for updates

Citation: Medeiros, I.P.S.; Guido, S.I.; Gama, M.A.S.; Silva, C.H.M.; Siqueira, M.C.B.; Silva, C.S.d.; Netto, A.J.; Felix, S.B.; Rabelo, M.N.; Santos, T.V.M.; et al. Cactus Cladodes and Sugarcane Bagasse Can Partially Replace Earless Corn Silage in Diets of Lactating Dairy Cows. *Dairy* **2024**, *5*, 33–43. https://doi.org/10.3390/dairy5010003

Academic Editors: Finbar Mulligan and Robert Mikuła

Received: 3 October 2023
Revised: 27 November 2023
Accepted: 21 December 2023
Published: 23 December 2023

Holstein cows fed common semiarid diets, milk production can be maximized by replacing 38.6% of ECS with CC plus SB.

Keywords: cactaceae; coproducts; efficiency; energy; semiarid

1. Introduction

Forage is recognized as the most economically viable feed resource in animal production systems situated in tropical regions [1]. Nevertheless, in semiarid locations, the performance of livestock varies considerably in response to fluctuations in feed availability and quality, which are attributable to the adverse climatic conditions. As a result, producers commonly resort to the utilization of conserved forages, including but not limited to corn, sorghum, and Tifton grass hay, along with supplementary fiber sources such as oats, wheat, beans, cassava, sugarcane, and sugarcane bagasse, to mitigate the susceptibility of the livestock system during prolonged periods of drought [2,3].

Traditional corn silage producers have commercialized earless corn silage (ECS) as a strategy to boost their income, leveraging the high demand for green corn in Brazil. Nonetheless, despite the lack of ears, the cost of producing this silage is comparable to that of traditional corn silage. Typically, conventional corn crops come with substantial implementation costs and demand a significant water supply, which can place a strain on the production system.

Cactus cladodes (CC, *Opuntia* sp. and *Nopalea* sp.) stand out as one of the primary forage resources in semiarid regions, often referred to as "the queen of forage plants" [4]. These cacti possess remarkable attributes such as high yield potential and substantial energy and water content. However, the low levels of fiber and protein in CC necessitate correction when incorporating it into the diets of ruminant animals, irrespective of CC gender [5,6]. Sugarcane bagasse (SB), a coproduct of the agribusiness sector, has emerged as an excellent choice for addressing the low fiber content of CC and for providing physically effective fiber to dairy herds in semiarid regions. Its appeal lies in its affordability and greater availability, especially during the dry season [7].

Sugarcane bagasse is largely available in Brazil due to the wide distribution of sugarcane-processing plants, including in states inserted into the semiarid region. Every ton of sugarcane processed yields about 0.3 ton of bagasse, which can be used as cheap roughage for cattle production. However, its utilization as a roughage source has mostly been investigated and aimed at improving the performance of beef cattle. Previous work [3,7] has demonstrated that sugarcane bagasse could be used as an exclusive source of roughage for beef cattle. Thus, the combination of sugarcane bagasse and cactus cladodes might be an attractive option for dairy cattle feeding in semiarid regions, especially for dairy farms located in the vicinity of sugar and alcohol industries [8]. Therefore, we hypothesize that CC and SB can partially or fully replace ECS in dairy cow diets without compromising lactation performance. This study aimed to evaluate the effects of replacing ECS with CC plus SB on feed intake, nutrient digestibility, milk yield and composition, and feeding behavior of lactating Holstein cows.

2. Materials and Methods

2.1. Animals and Diets

The experiment was conducted at the São Bento do Una Experimental Station (São Bento do Una, Brazil) of the Agronomic Institute of Pernambuco (IPA) in accordance with the guidelines and recommendations of the Committee of Ethics on Animal Studies of the Federal Rural University of Pernambuco (License N°. 4997300322).

Ten Holstein cows with an initial average body weight of 571 kg ± 97.0 kg (mean ± standard deviation), milk production of 23.0 ± 4.4 kg/day, and 109 ± 18 days in milk (DIM) were distributed into two contemporaneous 5 × 5 Latin squares. The experiment was conducted for 105 days and divided into five experimental 21-day periods. Cows were adapted to the diet for the first 14 days within each period (adaptation period), and the remaining 7 days were used for evaluation and sample collection (sampling period).

The cows were housed in individual pens equipped with a feed bunk and had ad libitum access to fresh water. The chemical composition and nutritional value of the dietary ingredients are shown in Table 1. Treatments consisted of five experimental diets containing different levels of cactus cladodes (CC, *Opuntia stricta* [Haw]. Haw) and sugarcane bagasse (SB) as a substitute for earless corn silage (ECS; Table 2). The diets were formulated to meet the nutritional requirements of lactating cows with a mean body weight of 570 kg and an average milk yield (MY) of 23.0 kg/day with 3.5% fat [9].

Table 1. Chemical composition of the experimental dietary ingredients (g/kg of DM, unless stated otherwise).

Item [1]	*Opuntia*	ECS [2]	Surgacane Bagasse	Wheat Bran	Ground Corn	Corn Gluten Meal	Corn Gluten Feed	Full-Fat Corn Germ
DM	140 (21.0)	293 (12.0)	658 (57.0)	882 (8.0)	884 (1.4)	922 (1.8)	888 (13.0)	957 (1.3)
OM	919 (9.6)	939 (2.7)	948 (13.0)	945 (2.5)	986 (1.3)	925 (10.0)	918 (4.3)	992 (12.0)
CP	54.0 (3.6)	65.2 (2.3)	16.1 (1.0)	165 (2.6)	89.0 (0.76)	661 (2.8)	263 (3.0)	108 (3.4)
EE	16.7 (3.5)	19.5 (2.3)	7.9 (1.7)	34.7 (3.2)	42.6 (2.5)	22.6 (3.6)	28.0 (3.1)	474 (7.0)
apNDF	280 (7.9)	616 (20.0)	799 (11.0)	387 (5.1)	117 (3.5)	65.3 (2.5)	357 (5.7)	247 (4.1)
NFC	569 (7.0)	238 (2.5)	124 (2.3)	358 (4.9)	737 (9.7)	177 (1.9)	270 (2.6)	163 (2.3)
iNDF	56.5 (3.4)	178 (4.8)	486 (11.0)	128 (1.3)	21.2 (2.5)	19.6 (1.5)	44.6 (2.2)	36.5 (2.5)

[1] DM—dry matter; OM—organic matter; CP—crude protein; EE—ether extract; apNDF—neutral detergent fiber corrected for ash and nitrogenous compounds; NFC—nonfibrous carbohydrates; iNDF—indigestible neutral detergent fiber; [2] Earless corn silage; Values in parentheses—standard deviation.

Table 2. Ingredient proportions and composition of experimental diets (g/kg DM).

Ingredient	Replacement Level				
	0	25	50	75	100
Earless corn silage	591	443	295	148	0.0
Sugarcane bagasse	0.0	70.9	142	213	284
Opuntia	0.0	76.8	153	230	306
Wheat bran	83.1	83.1	83.1	83.1	83.1
Ground corn	77.1	71.1	65.5	59.9	54.5
Full-fat corn germ	72.2	76.5	80.9	85.2	89.5
Gluten feed	81.9	81.9	81.9	81.9	81.9
Corn gluten meal	71.7	71.7	71.7	71.7	71.7
Urea/Ammonium sulfate [1]	3.0	4.6	6.2	7.8	9.4
Salt	5.1	5.1	5.1	5.1	5.1
Mineral blend [2]	15.2	15.2	15.2	15.2	15.2
Chemical composition					
Dry matter [3]	404 (8.8)	377 (14.0)	354 (26.0)	334 (34.0)	318 (40.0)
Organic matter	922 (1.5)	922 (2.2)	921 (3.3)	920 (4.6)	919 (5.9)
Crude protein	144 (3.3)	144 (2.8)	143 (2.2)	143 (1.6)	143 (1.2)
Ether extract	55.9 (2.2)	56.5 (1.6)	57.3 (1.2)	58.1 (1.1)	58.9 (1.4)
apNDF [4]	457 (14.0)	444 (11.0)	432 (8.3)	419 (6.3)	407 (6.3)
Nonfiber carbohydrates	395 (9.0)	406 (6.6)	417 (5.0)	428 (5.9)	439 (8.5)
iNDF [5]	124 (8.2)	138 (4.3)	152 (1.7)	165 (3.8)	177 (7.0)
Total digestible nutrients	638 (25.0)	653 (42.0)	669 (41.0)	684 (33.0)	665 (53.0)
Net energy of lactation (Mcal/kg DM)	1.44 (0.06)	1.48 (0.10)	1.52 (0.10)	1.56 (0.08)	1.51 (0.13)

[1] Urea + ammonium sulfate at 9:1 ratio. [2] Components: bicalcium phosphate, limestone, common salt, sulfur flower, zinc sulfate, copper sulfate, manganese sulfate, potassium iodate, and sodium selenite. [3] g/kg of fresh matter. [4] Neutral detergent fiber corrected for ash and protein. [5] Indigestible neutral detergent fiber. Values in parentheses—standard deviation.

The cactus variety selected for this study was Mexican elephant ear, cultivated at the experimental location in a dense arrangement (1 m × 0.25 m of plant spacing) and harvested after a two-year growth period. Cactus cladodes were processed using a conjugated crusher model MC-1001N (Laboremus, Campina Grande, Paraíba, Brazil), yielding a material with an average particle size of 5 cm. Similarly, the ECS used in this study was produced on site, whereas the SB was purchased from a sugarcane processing plant located in Lagoa of Itaenga/PE. Sugarcane bagasse exhibited a particle size between 8 and 1.18 mm.

The diet was fed as a total mixed ration (TMR) and split into two equal meals at 07:00 and 16:00 h, allowing ad libitum intake with 5–10% of the total DM offered as feed refusals. The CC was mixed with other ingredients immediately after crushing before morning and afternoon feedings.

2.2. Nutrient Intake and Digestibility Assay

Feed offered and feed refusals were weighed and recorded daily, from the 15th to the 21st day of each experimental period, to estimate nutrient intake. Samples of feedstuffs and refusals were collected throughout the sampling period, and individual refusal samples were composited for subsequent chemical analyses. Afterwards, the samples were pre-dried using a forced-air ventilation oven at 60 °C until they reached a constant weight, and ground in a Wiley mill through 2 and 1 mm sieves for nutrient analyses. Apparent nutrient digestibility and total digestible nutrients were assessed by collecting spot fecal samples (approximately 1000 g/animal/day) once a day, at 6:00 a.m., 8:00 a.m., 10:00 a.m., 12:00 p.m. and 14:00 p.m., from the 16th through the 20th day of each experimental period, respectively [10]. Fecal samples were grouped by animal at the end of the experimental period and stored at −20 °C. Fecal samples were pre-dried and processed as described for feedstuffs and refusals.

2.3. Milk Yield and Chemical Composition

Cows were machine milked at 05:30 and 15:00 h, and milk yield (MY) was individually recorded. Milk samples (460 mL/day) were collected from each animal on the 6th and 7th day of each sampling period. This sample volume was chosen to represent 2% of the average MY (23 kg/day), with 60% of the milk collected in the morning (276 mL) and 40% in the afternoon (184 mL) to form the 460 mL composite sample. A 50 mL aliquot of the composite sample was preserved in Bronopol® and sent to the Northeast Dairy Cattle Management Program's Milk Laboratory for determination of the levels of fat, protein, lactose, and total dry extract in milk following the methods described by [11]. Milk yield was corrected to 3.5% fat (fat-corrected milk yield, FCMY) using the equation proposed by [12], where FCMY (3.5%) = [(0.432 + 0.1625 × %milk fat) × MY kg/day].

2.4. Feeding Behavior

Feeding behavior was assessed using the instantaneous scanning method [13]. Cows were observed every 10 min for 24 h, starting immediately after morning feeding. The time spent feeding (FT), rumination (RT), idling (IT), and chewing (CT; feeding time + rumination time) was recorded for each animal within the sampling period. The feeding and ruminating efficiencies of DM and NDF (g/min) were calculated as in [14]. Feed bunk efficiency (g DM/feed bunk visit) equaled the amount of dry matter consumed during each feed bunk visit.

2.5. Chemical Analyses

Samples of feedstuffs, feed refusals, and feces were analyzed for DM (method 934.01), organic matter (OM; method 942.05), crude protein (CP; nitrogen × 6.25; method 984.13), and ether extract (EE; method 920.39) according to the procedures described by AOAC [15]. Neutral detergent fiber (NDF) was analyzed according to Mertens [16] using thermostable α-amylase without the addition of sodium sulfite. Analyses of acid detergent fiber and lignin (method 973.18) were performed according to AOAC [15]. NDF was corrected for neutral detergent-insoluble protein, acid detergent-insoluble protein, and nonprotein nitrogen according to Licitra et al. [17]. The concentration of indigestible neutral detergent fiber (iNDF) in feedstuffs, refusal, and fecal samples was also determined to estimate total fecal excretion (TFE). The iNDF concentration was obtained after the incubation of samples in the rumen of a fistulated cow for 288 h [18]. The diets' TDN content and its conversion into net energy for lactation (NEL) were estimated according to [9].

2.6. Calculations

Total carbohydrates (TCH) were estimated according to Sniffen et al. [19], whereas nonfibrous carbohydrate (NFC) content was estimated according to Detmann and Valadares Filho [20]. Organic matter was calculated as OM = 1000 g/kg DM-g ash/kg DM. Dry matter, OM, CP, NDF, TCH, and NFC intakes were calculated by subtracting the amount of each nutrient in the refusals from the daily nutrient offer. Dry matter fecal production (FP) was estimated using the following equation: FP = amount of iNDF provided (g/day)/iNDF in fecal DM (g/kg). The apparent digestibility of nutrients was estimated using the following equation: (nutrient intake − nutrient excretion)/nutrient intake.

2.7. Statistical Analysis

The studied variables were analyzed using the MIXED procedure of SAS (Version 9.4; SAS Inst., Inc., Cary, NC, USA) according to a replicated 5 × 5 Latin square design. The following mathematical model was used:

$$Yijkl = \mu + Ti + Qj + Pk + (A/Q)lj + T^*Qij + \varepsilon ijkl$$

where Yijkl = observation ijkl; μ = overall mean; Ti = fixed effect of treatment i; Qj = fixed effect of square j; Pk = fixed effect of period k; (A/Q)lj = random effect of animal l within square j; T*Qij = fixed effect of the interaction treatment i and square j; and εijkl = random error with mean 0 and variance σ2.

The linear and quadratic effects of ECS replacement were analyzed using polynomial orthogonal contrasts and adjustments of the regression equations. Linear and quadratic effects were considered statistically significant when $p < 0.05$.

3. Results

DM, OM, NFC, and iNDF intakes exhibited a clear linear increase with the replacement of ECS ($p < 0.05$; Table 3). In contrast, the intake of CP, EE, and NEL followed a quadratic pattern, with the highest estimated CP, EE, and NEL intake values (2.79 kg/day, 1.11 kg/day, and 27.52 Mcal/day, respectively) achieved at 95.38%, 73.87%, and 88.6% of ECS substitution ($p < 0.05$; Table 3). NDF intake was unaffected by the dietary treatments ($p > 0.05$).

Table 3. Effects of replacement levels of ECS by CC plus SB on nutrient intake.

Item (kg/day) [1]	Replacement Level (%)					SEM [2]	*p*-Value [3]		
	0	25	50	75	100		L	Q	C
Dry matter	15.98	17.32	17.86	18.55	18.73	0.618	<0.0001	0.1323	0.8115
Dry matter (% BW [4])	2.82	3.03	3.11	3.26	3.34	0.125	<0.0001	0.4353	0.7700
Organic matter	14.74	15.91	16.36	16.92	17.05	0.578	<0.0001	0.1412	0.7806
Crude protein	2.37	2.56	2.69	2.79	2.79	0.092	<0.0001	0.0470	0.8528
Ether extract	0.91	1.02	1.08	1.13	1.08	0.039	<0.0001	<0.0001	0.3495
apNDF	7.00	7.31	7.15	7.15	7.02	0.274	0.8331	0.2535	0.5323
apNDF (% BW [4])	1.24	1.28	1.24	1.26	1.25	0.053	0.8940	0.6396	0.5000
Non-fibrous carbohydrates	4.46	5.03	5.44	5.84	6.16	0.201	<0.0001	0.3048	0.8785
NEL (Mcal/day [5])	21.32	24.28	25.93	28.01	27.31	1.104	<0.0001	0.0245	0.7877
iNDF [6]	2.00	2.26	2.43	2.63	2.82	0.112	<0.0001	0.7224	0.7366

[1] Dry matter; [2] Standard error of the mean. [3] L: linear effect; Q: quadratic effect. C: cubic effect. Linear, quadratic, and cubic effects were considered statistically significant when $p < 0.05$. [4] Body weight. [5] Net energy of lactation. [6] Indigestible neutral detergent fiber.

The apparent digestibility of DM, OM, CP, and NFC increased ($p < 0.05$), whereas the digestibility of apNDF linearly decreased ($p < 0.05$; Table 4) with the progressive substitution of ECS. There was no effect of ECS replacement on EE digestibility ($p > 0.05$).

Table 4. Effects of replacement levels of ECS by CC plus SB on apparent digestibility of dietary chemical components (g/kg).

Item	Replacement Level (%)					SEM [1]	*p*-Value [2]		
	0	25	50	75	100		L	Q	C
Dry matter	598.79	622.36	636.21	655.62	636.12	15.054	0.0120	0.1012	0.4735
Organic matter	618.57	640.99	658.78	675.48	660.33	14.378	0.0061	0.1163	0.4991
Crude Protein	604.39	662.69	706.17	751.05	745.03	15.407	<0.0001	0.0810	0.3469
Ether extract	857.14	874.32	880.81	894.89	884.03	8.801	0.0940	0.1354	0.5970
apNDF [3]	425.99	430.44	413.31	420.49	357.34	24.789	0.0252	0.1434	0.4401
Nonfibrous carbohydrates	881.81	888.72	914.90	918.82	927.13	11.549	0.0003	0.5823	0.6183

[1] Standard error of the mean. [2] L: linear effect; Q: quadratic effect; C: cubic effect. Linear, quadratic, and cubic effects were considered statistically significant when $p < 0.05$. [3] Neutral detergent fiber corrected for ash and protein.

The time spent on feeding, ruminating, and chewing activities decreased linearly ($p < 0.05$; Table 5), whereas idling and the feeding and rumination efficiencies of DM and NDF increased linearly ($p < 0.05$).

Table 5. Effects of replacement levels of ECS by CC plus SB on ingestive behavior.

Item	Replacement Level (%)					SEM [1]	*p*-Value [2]		
	0	25	50	75	100		L	Q	C
Feeding time (min/day)	358	346	345	339	322	15.937	0.0028	0.5989	0.3708
Rumination time (min/day)	561	523	453	448	418	23.257	<0.0001	0.2446	0.8974
Idle time (min/day)	521	571	642	653	700	29.631	<0.0001	0.4398	0.8376
Total chewing time (min/day)	906	869	798	787	740	29.631	<0.0001	0.4398	0.8376
Efficiencies, (g/min)									
Feeding efficiency (DM) [3]	44	51	53	57	61	3.194	<0.0001	0.9332	0.7020
Rumination efficiency (DM) [3]	28	33	40	42	47	2.283	<0.0001	0.3697	0.7053
Rumination efficiency (apNDF) [3]	12	14	16	16	18	0.889	<0.0001	0.2935	0.5162

[1] Standard error of the mean. [2] L: linear effect; Q: quadratic effect C: cubic effect. Linear, quadratic, and cubic effects were considered statistically significant when $p < 0.05$. [3] Dividing the intake of each of these nutrients by the total feeding time (feed efficiency) and rumination time (rumination efficiency).

The increasing levels of CC plus SB had a quadratic effect on both milk yield and FCMY (kg/day; Table 6). The highest milk yield (24.17 kg/day) and FCMY (21.9 kg/day) were achieved at CC plus SB levels of 63.9% and 38.6%, respectively. Furthermore, milk fat and total solids content declined linearly ($p < 0.05$), whereas protein, lactose, and nonfat solids content displayed a consistent linear increase ($p < 0.05$).

Table 6. Effects of replacement levels of ECS by CC plus SB on milk yield and composition.

Item	Replacement Level (%)					SEM [1]	*p*-Value [2]		
	0	25	50	75	100		L	Q	C
Milk yield, kg/day	21.31	23.24	23.55	24.32	22.85	1.420	0.0543	0.0146	0.7684
FCMY [3]	20.44	22.17	21.20	21.11	18.48	1.320	0.0560	0.0132	0.9475
Milk composition, %									
Fat	3.26	3.09	2.95	2.77	2.35	0.263	<0.0001	0.1320	0.6797
Protein	2.87	2.91	2.96	2.94	3.02	0.049	<0.0001	0.8171	0.1976
Lactose	4.32	4.38	4.44	4.41	4.54	0.068	<0.0001	0.6592	0.1025
Total solids	11.12	11.28	10.91	10.83	10.61	0.314	0.0028	0.3726	0.3844
Nonfat solids	7.87	7.97	8.10	8.07	8.26	0.119	<0.0001	0.9142	0.2786

[1] Standard error of the mean. [2] L: linear effect; Q: quadratic effect; C: cubic effect. Linear, quadratic, and cubic effects were considered statistically significant when $p < 0.05$. [3] Fat-corrected milk, calculated according to the equation proposed by [12].

4. Discussion

The replacement of ECS with CC plus SB resulted in important changes in diet composition, such as decreases in DM (from 404 to 318 g/kg of fresh matter) and NDF content (from 457 to 407 g/kg DM) and increases in NFC (from 395 to 439 g/kg DM) and iNDF (from 124 to 177 g/kg DM).

Excess or lack of moisture in the TMR are the primary reasons for limitations in feed consumption. As highlighted by Schingoethe et al. [21], diet DM should range between 45% and 60% to avoid interference with feed intake. Interestingly, despite our experimental diets having a lower average DM content (35.73%, Table 3) than the ideal range indicated above, there was no negative impact of CC plus SB on DM intake (Table 3). Excess moisture can physically limit DM intake through rumen fill, most commonly in cows fed conventional roughages, such as fresh grasses and silages. Despite possessing a substantial amount of water, cactus cladodes stand out from other forage sources because of their rapid ruminal degradation rates, which immediately release the water contained therein and minimize rumen fill.

Another noteworthy aspect of our intake results is related to the quality of the silage, particularly the absence of grains. We observed that the highest intake of NDF as a function of BW was found for the diet without any CC and SB (1.2%), indicating that the presence or absence of this constituent did not significantly influence intake. Rather, the increased DM intake can be explained by the decrease in NDF content and increase in NFC as corn silage was replaced by CC and SB, with a consequent increase in digestibility. In addition, cactus cladodes are highly acceptable to animals and contain mucilage, which easily agglutinates and homogenizes TMR particles, thereby avoiding the selection of the least acceptable ingredients [22].

The increased digestibility of DM and OM can be explained by the progressive inclusion of CC in the diet. Previous observations have shown that diets containing CC promote high degradation rates and ruminal fermentation [8,22]. In addition, the dramatic increase in CP digestibility (+23.34%) probably contributed to the greater digestibility of DM and OM in cows fed CC plus SB. Nonprotein nitrogen (NPN) can be quickly and quantitatively converted into NH_3 due to its high solubility in the rumen. The NPN can then be used by microorganisms [23] or transferred to the blood through the ruminal wall, not being detected in feces, which probably led to improved CP digestibility. In contrast, the linear decline in NDF digestibility, corresponding to 16.98%, can be associated with greater concentration of indigestible fractions from sugarcane bagasse in CC/SB-based diets (Tables 1 and 2); however, there was compensation for the increase in NCF levels and no change in EE digestibility.

The reduction in feeding, rumination, chewing time, and the increase in idling time can be justified, in part, by the slightly lower NDF content of CC+SB diets (−8%; Table 2). However, as there were no significant effects of ECS substitution on absolute (g/kg DM) or relative (%BW) NDF intake, these altered behavior patterns can be associated with the increase in DM intake (i.e., cows fed CC+SB diets compensated the lower levels of NDF in their diet by increasing DM intake). Particle size may also have played a role in these responses because ECS had a larger particle size than bagasse. Cactus cladodes, despite having a very large particle size, have low fiber effectiveness [24].

The greater feeding and rumination efficiency (g DM/min) observed for diets with CC plus SB can be explained by several aspects of CC+SB diets, mainly the increased intake of DM within a shorter period (Table 5), the higher palatability and rumen degradability of CC compared to ECS [8], and possibly an increase in passage rate [25]. Another striking characteristic of CC is its succulence, which favors the process of chewing, swallowing, and regurgitation [26]. Lastly, the changes in rumination efficiency (g apNDF/min) observed herein could be explained by the processing of sugarcane: pressing the sugarcane generates a material with smaller particles, thus affecting rumination. Our results agree with those of Siqueira et al. [27], who observed that the feeding efficiency of steers improved by 364 g/kg DM when cactus cladodes, containing 277 g/kg of DM, replaced Tifton grass hay (654 g of NDF/kg DM).

Lactating cows fed CC exhibit greater DM intake and milk production [28]. However, previous studies have reported that high levels of CC, usually above 400 g/kg DM, can compromise NDF digestibility because of an increment in the NFC levels of the diet and a consequent drop in ruminal pH [3,29]. The significant increase in diet NFC content and reduction in particle size with the replacement of ECS by CC+SB, which is implicated in fiber digestibility, may explain the decline in MY when CC+SB inclusion was increased above 75% (Table 6). Siqueira et al. [7] observed lower rumen fluid pH in sheep fed CC plus SB compared to those fed corn silage. In addition, the NRC [9] indicates that NCF levels above 42% can lead to ruminal acidosis and a consequent drop in milk production in lactating cows because of an excess of rapidly fermenting carbohydrates in the rumen. Based on the composition of the feedstuffs included in the experimental diets (Table 1) and their respective proportions (Table 2), we estimated that the concentration of NFC increased from 417 to 428 g/kg DM, approaching the NRC's threshold.

The significant effects of CC plus SB on milk lactose and protein concentrations can be attributed to the sharp decrease in milk fat content (Table 6). As the decline in milk fat was much more pronounced than the increase in protein and lactose content, the proportion of total solids also followed a linear drop (Table 6). The milk fat depression observed in the present study may be associated with several factors, such as low effective fiber content, dietary fats, a high proportion of NFC, finely ground foods, and moist diets (>50% humidity) [30,31]. It is worth pointing out that all diets had a high percentage of concentrate (40%), cactus cladodes had a low fiber content (±277 g/kg DM), and SB was finely ground, as previously stated.

Modifications in fermentation or rumen metabolism can interfere with the synthesis and fat content of milk. Several theories have been proposed to explain how milk fat depression (MFD) occurs, but they have not yet been fully elucidated [31]. However, it has been generally accepted that alterations in the ruminal fermentation pattern lower the amount of lipid precursors required for fat synthesis in the mammary gland [32,33].

Milk fat depression occurred in cows fed diets containing added oil and short forage particle size. The combination of oil and short forage particle size results in a faster passage rate, lower milk fat concentration and yield, and higher concentration of *trans*-10,*cis*-12 CLA [34], a potent inhibitor of milk fat synthesis in the mammary gland [35]. In our study, this fact is demonstrated by the feeding behavior and milk fat content of cows fed CC plus SB: the time spent on rumination and the milk fat decreased linearly. Together, these results suggest that high levels of CC+SB fail to provide ideal rumen fermentation conditions, favoring the synthesis of rumen fatty acids associated with MFD. The presence of full-fat corn germ in the diets in our study appears to have been key to this behavior. In another experiment where cows were fed a diet containing CC (400 k/kg DM), SB (300 g/kg DM), and concentrate (300 g/ kg DM) [8], no changes in milk composition were detected.

Although corn crops can be recommended for forage supplementation in semiarid regions, maize production has been highly affected by climate change in dry regions. Water deficits negatively impact corn yield across growth phases, indicating that corn crops should be irrigated; however, water availability is a crucial element for the adoption of this technology. Cactus cladodes, on the other hand, not only present a low cultivation risk in semiarid regions but can be cultivated through easily applicable technologies (spacing, fertilization, and cultural treatments), yielding up to 40 to 60 tons of DM every two years. According to the present results, CCs are an ideal agronomic culture for semiarid regions; however, because CCs have a low NDF content and should be fed in association with a fiber source, the usage of silage cannot be discarded, particularly for cows with milk yields similar to those observed in this study. Other researchers have shown that the association of CC with other low-quality roughage sources, such as SB, promotes satisfactory milk yields [8].

5. Conclusions

For Holstein cows fed common semiarid diets, milk production can be maximized by replacing 38.6% of ECS with CC plus SB.

Author Contributions: Conceptualization, M.A.F. and M.A.S.G.; resources, M.A.F., S.I.G. and M.A.S.G.; methodology, M.A.F., S.I.G. and M.A.S.G.; investigation, I.P.S.M., A.J.N., C.H.M.S., S.B.F., M.N.R., T.V.M.S. and M.A.M.L.; data curation, I.P.S.M. and M.A.F.; supervision, S.I.G. and M.A.F.; formal analysis, C.S.d.S.; writing, I.P.S.M.; review and editing, M.A.F., M.A.S.G., M.C.B.S. and C.S.d.S.; funding acquisition, M.A.F.; project administration, M.A.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by CAPES and CNPq—Finance Code 001.

Institutional Review Board Statement: The animal study protocol was approved by the Ethics Committee of the Federal Rural University of Pernambuco (license No. 4997300322).

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article.

Acknowledgments: This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior—Brasil (CAPES)—Finance Code 001. The authors are grateful to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Agronomic Institute of Pernambuco for donating the cactus cladodes, and Ingredion™ (Cabo de Santo Agostinho, Brazil) for ingredient donation.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Paula, T.; Ferreira, M.A.; Véras, A.S.C. Utilização de Pastagens Em Regiões Semiáridas: Aspectos Agronômicos E Valor Nutricional—Revisão. *Arquivos Mudi* **2020**, *24*, 140–162. [CrossRef]
2. Siqueira, T.D.Q.; Monnerat, J.P.I.S.; Chagas, J.C.C.; Conceição, M.G.; de Siqueira, M.C.B.; Farias, L.R.; Oliveira, J.P.F.; Ferreira, M.A. Palatability and Nycterohemeral Patterns of Ingestive Behavior of Sheep Fed Different Roughage Sources. *Trop. Anim. Health Prod.* **2022**, *54*, 145. [CrossRef] [PubMed]
3. Almeida, G.A.P.; Ferreira, M.A.; Silva, J.L.; Chagas, J.C.C.; Véras, A.S.C.; Barros, L.J.A.; Almeida, G.L.P. Sugarcane Bagasse as Exclusive Roughage for Dairy Cows in Smallholder Livestock System. *Asian-Australas. J. Anim. Sci.* **2018**, *31*, 379–385. [CrossRef] [PubMed]
4. Rocha Filho, R.R.; Santos, D.C.; Véras, A.S.C.; Siqueira, M.C.B.; Monteiro, C.C.F.; Mora-Luna, R.E.; Farias, L.R.; Santos, V.L.; Chagas, J.C.C.; Ferreira, M.A. Miúda (*Nopalea cochenillifera* (L.) Salm-Dyck)—The Best Forage Cactus Genotype for Feeding Lactating Dairy Cows in Semiarid Regions. *Animals* **2021**, *11*, 1774. [CrossRef] [PubMed]
5. Batista, A.M.V.; Ribeironeto, A.C.; Lucena, R.B.; Santos, D.C.; Dubeux, J.C.B., Jr.; Mustafa, A.F. Chemical Composition and Ruminal Degradability of Spineless Cactus Grown in Northeastern Brazil. *Rangel. Ecol. Manag.* **2009**, *62*, 297–301. [CrossRef]
6. Ferreira, M.A.; Conceição, M.G.; Monteiro, C.C.F.; Mora-Luna, R.E.; Bispo, S.V. Utilização da palma forrageira na alimentação de bovinos leiteiros. In *Palma Forrageira: Potencial e Perspectivas*, 2nd ed.; Santos, M.V.F., Carvalho, F.F.R., Ferreira, M.A., Eds.; Suprema Grafica: Visconde do Rio Branco, Brazil, 2022; 384p.

7. Siqueira, M.C.B.; Chagas, J.C.C.; Monnerat, J.P.I.S.; Monteiro, C.C.F.; Mora-Luna, R.E.; Felix, S.B.; Rabelo, M.N.; Mesquita, F.L.T.; Ferreira, J.C.; Ferreira, M.A. Cactus Cladodes Opuntia or Nopalea and By-Product of Low Nutritional Value as Solutions to Forage Shortages in Semiarid Areas. *Animals* **2022**, *12*, 3182. [CrossRef] [PubMed]
8. Freitas, W.R.; Ferreira, M.D.A.; Silva, J.L.; Véras, A.S.C.; Barros, L.J.A.; Alves, A.M.S.V.; Chagas, J.C.C.; Siqueira, T.D.Q.; Almeida, G.A.P.D. Sugarcane bagasse as only roughage for crossbred lactating cows in semiarid regions. *Pesqui. Agropecu. Bras.* **2018**, *53*, 386–393. [CrossRef]
9. NRC (National Research Council). *Nutrient Requirements of Dairy Cattle*; National Academy Press: Washington, DC, USA, 2001.
10. Torres, L.C.L.; de Andrade Ferreira, M.; Guim, A.; da Silva Vilela, M.; Guimarães, A.V.; Silva, E.C. Substituição Da Palma-Gigante Por Palma-Miúda Em Dietas Para Bovinos Em Crescimento E Avaliação de Indicadores Internos. *Rev. Bras. Zootec.* **2009**, *38*, 2264–2269. [CrossRef]
11. *ISO 9622/IDF 141C*; Determination of Milk Fat, Protein, Lactose, and Urea Content: Guidance on the Operation of Mid-Infrared Instruments. ISO: Geneva, Switzerland, 2013.
12. Sklan, D.; Ashkenazi, R.; Braun, A.; Tabori, K. Fatty Acids, Cacium Soaps of Fatty Acids and Cottonseeds Fed to High Yielding Cows. *J Dairy Sci.* **1992**, *75*, 2463–2472. [CrossRef]
13. Martin, P.; Bateson, P. *Measuring Behaviour*, 3rd ed.; Cambridge University Press: Cambridge, UK, 2007; ISBN 9781139643757.
14. Bürger, P.J.; Pereira, J.C.; de Queiroz, A.C.; da Silva, J.F.C.; de Campos Valadares Filho, S.; Cecon, P.R.; Casali, A.D.P. Comportamento Ingestivo Em Bezerros Holandeses Alimentados Com Dietas Contendo Diferentes Níveis de Concentrado. *Rev. Bras. Zootec.* **2000**, *29*, 236–242. [CrossRef]
15. AOAC. Animal Feed. In *Association of Official Analytical Chemists (AOAC)*; Helrich, K., Ed.; Association of Official Analytical Chemists, Inc.: Arlington, VA, USA, 1990; Volume I, pp. 69–90.
16. Mertens, D.R. Gravimetric Determination of Amylase-Treated Neutral Detergent Fiber in Feeds with Refluxing in Beakers or Crucibles: Collaborative Study. *J. AOAC Int.* **2002**, *85*, 1217–1240. [PubMed]
17. Licitra, G.; Hernandez, T.M.; Van Soest, P.J. Standardization of Procedures for Nitrogen Fractionation of Ruminant Feeds. *Anim. Feed Sci. Technol.* **1996**, *57*, 347–358. [CrossRef]
18. Valente, T.N.P.; Detmann, E.; Sampaio, C.B. Review: Recent Advances in Evaluation of Bags Made from Different Textiles Used in Situ Ruminal Degradation. *Can. J. Anim. Sci.* **2015**, *95*, 493–498. [CrossRef]
19. Sniffen, C.J.; O'Connor, J.D.; Van Soest, P.J.; Fox, D.G.; Russell, J.B. A Net Carbohydrate and Protein System for Evaluating Cattle Diets: II. Carbohydrate and Protein Availability. *J. Anim. Sci.* **1992**, *70*, 3562–3577. [CrossRef] [PubMed]
20. Detmann, E.; Valadares Filho, S.C. On the Estimation of Non-Fibrous Carbohydrates in Feeds and Diets. *Arq. Bras. Med. Vet. Zootec.* **2010**, *62*, 980–984. [CrossRef]
21. Schingoethe, D.J. A 100-Year Review: Total Mixed Ration Feeding of Dairy Cows. *J. Dairy Sci.* **2017**, *100*, 10143–10150. [CrossRef] [PubMed]
22. Siqueira, T.D.Q.; Monnerat, J.P.I.S.; Chagas, J.C.; Conceição, M.G.; Siqueira, M.C.B.; Viana, T.B.L.; Ferreira, M.A. Cactus Cladodes Associated with Urea and Sugarcane Bagasse: An Alternative to Conserved Feed in Semi-Arid Regions. *Trop. Anim. Health Prod.* **2019**, *51*, 1975–1980. [CrossRef] [PubMed]
23. Getahun, D.; Tewodros Alemneh, T.; Akeberegn, D.; Getabalew, M.; Zewdie, D. Urea Metabolism and Recycling in Ruminants. *Biomed. J. Sci. Tech. Res.* **2019**, *20*, 14790–14796. [CrossRef]
24. Conceição, M.G.; Ferreira, M.A.; Campos, J.M.S.; Silva, J.L.; Detmann, E.; Siqueira, M.C.B.; Barros, L.J.A.; Costa, C.T.F. Replacement of Wheat Bran with Spineless Cactus in Sugarcane-Based Diets for Steers. *Rev. Bras. Zootec.* **2016**, *45*, 158–164. [CrossRef]
25. Siqueira, M.C.B.; Ferreira, M.A.; Monnerat, J.P.I.S.; Silva, J.L.; Costa, C.T.F.; Conceicão, M.G.; Andrade, R.P.X.; Barros, L.J.A.; Melo, T.T.B. Optimizing the use of spineless cactus in the diets of cattle: Total and partial digestibility, fiber dynamics and ruminal parameters. *Anim. Feed Sci. Technol.* **2017**, *226*, 56–64. [CrossRef]
26. Munhame, J.A.; Batista, Â.M.V.; Monnerat, J.P.I.S.; Maciel, M.V.; Lopes, L.A.; Silva, T.G.P.; Andrade, R.B.; Cardoso, D.B.; Carvalho, F.F.R. Intake, Digestibility, Ingestive Behavior and Performance of Goats Fed Spineless Cactus Genotypes Resistant to Carmine Cochineal. *Arq. Bras. Med. Vet. Zootec.* **2021**, *73*, 1209–1216. [CrossRef]
27. Siqueira, M.C.B.; Ferreira, M.A.; Monnerat, J.P.I.S.; Silva, J.L.; Costa, C.T.F.; Conceição, M.G.; Soares, A.A.; Andrade, I.B.; Chagas, J.C.C. Nutritional Performance and Metabolic Characteristics of Cattle Fed Spineless Cactus. *J. Agric. Sci. Technol.* **2018**, *20*, 13–22.
28. Sánchez, B.M.S.; Véras, A.S.C.; Freitas, E.V.; Farias, L.R.; Albuquerque, J.G.S.S.; Almeida, G.A.P.; Mora-Luna, R.E.; Monteiro, C.C.F.; Gama, M.A.S.; Ferreira, M.A. Partial Replacement of Sugarcane with Cactus (Opuntia Stricta) Cladodes Improves Milk Yield and Composition in Holstein Dairy Cows. *Anim. Prod. Sci.* **2022**, *62*, 691–699. [CrossRef]
29. Monteiro, C.C.F.; Melo, A.A.S.; Ferreira, M.A.; Campos, J.M.S.; Souza, J.S.R.S.; Silva, E.T.S.; Andrade, R.D.P.X.; Silva, E.C. Replacement of Wheat Bran with Spineless Cactus (Opuntia Ficus Indica Mill Cv Gigante) and Urea in the Diets of Holstein X Gyr Heifers. *Trop. Anim. Health Prod.* **2014**, *46*, 1149–1154. [CrossRef]
30. Erickson, P.S.; Kalscheur, K.F. Nutrition and Feeding of Dairy Cattle. In *Animal Agriculture*; Academic Press: Cambridge, MA, USA, 2020; pp. 157–180. [CrossRef]
31. Griinari, J.M.; Dwyer, D.A.; McGuire, M.A.; Bauman, D.E.; Palmquist, D.L.; Nurmela, K.V.V. Trans-Octadecenoic Acids and Milk Fat Depression in Lactating Dairy Cows. *J. Dairy Sci.* **1998**, *81*, 1251–1261. [CrossRef]
32. Davis, C.L.; Brown, R.E. Low-Fat Milk Syndrome. In *Digestion and Metabolism in the Ruminant*; Phillipson, A.T., Ed.; Oriel Press: Newcastle upon Tyne, UK, 1970; pp. 545–565.

33. Sutton, J.D. Altering Milk Composition by Feeding. *J. Dairy Sci.* **1989**, *72*, 2801–2814. [CrossRef]
34. Leskinen, H.; Ventto, L.; Kairenius, P.; Shingfield, K.J.; Vilkki, J. Temporal Changes in Milk Fatty Acid Composition during Diet-Induced Milk Fat Depression in Lactating Cows. *J. Dairy Sci.* **2019**, *102*, 5148–5160. [CrossRef]
35. Ramirez Ramirez, H.A.; Harvatine, K.J.; Kononoff, P.J. Short Communication: Forage Particle Size and Fat Intake Affect Rumen Passage, the Fatty Acid Profile of Milk, and Milk Fat Production in Dairy Cows Consuming Dried Distillers Grains with Solubles. *J. Dairy Sci.* **2016**, *99*, 392–398. [CrossRef]