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Performance and behavior of dairy calves fed corn silage in the diet during the pre- and post-weaning periods

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A R T I C L E I N F O

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A B S T R A C T

Feeding strategies during the first months of calf life can be decisive for their future performance. The inclusion of fiber from different sources in the starter diet has proven effective in stimulating chewing and rumination early on. This study evaluated the effect of including corn silage in the diet of dairy calves during the pre-weaning period and its provision after weaning. Eighteen dairy calves with 37.7 ± 2.7 kg were assigned to two treatments at 30 days of age: (1) receiving concentrate and corn silage during milk replacer feeding (CISMA) and (2) receiving concentrate and corn silage after weaning (SOSMA). Dry matter (DMI) and nutrient intake, performance (average daily weight gain (ADG), and total weight gain), morphometrics, and behavior were evaluated. Mean comparisons were performed using Tukey's test (α=0.05). DMI, feed conversion, ADG, and protein intake did not differ between treatments ($P > 0.05$). Diets provided during pre-weaning alter the time rumination ($P < 0.05$) and frequency of feeding behaviors ($P < 0.005$) and standing time in calves ($P < 0.001$). Greater rumination efficiency ($P < 0.05$) was found in treatment CISMA. The inclusion of corn silage in the pre-weaning diet may have promoted the formation of structures that improved fiber degradation capacity after weaning. The inclusion of corn silage did not affect performance parameters, but represents a feeding alternative for calves.

Introduction

Growth and development during the early stages of life of a calf are critical to its future productive and reproductive performance. A detailed understanding of these phases represents a significant advance in the field of calf nutrition (Drackley, 2008). The preweaning period is a unique phase in which nutritional management exerts a decisive influence on animal health and growth potential. Therefore, the feeding plan adopted during this phase aims primarily to promote proper rumen development and achieve high growth rates (Khan et al., 2016).

To maintain optimal growth and achieve the recommended body weight at weaning, calves require adequate energy and protein support. In this context, the maturity of the gastrointestinal tract plays a crucial role, as it optimizes feed digestibility and maximizes the availability of essential nutrients for metabolism and tissue development (Xiao et al., 2025).

The results reported in the literature on the inclusion of roughage in the diet of pre-weaning calves remain inconclusive. Factors such as feed management, the physical form of the starter concentrate, as well as the levels of milk and forage supply, act as sources of variation in the biological response of calves to fiber inclusion (Nikkhah & Alimirzaei, 2022). This heterogeneity makes it difficult to establish uniform recommendations for practical application in the field (Xiao et al., 2025).

Given this inconsistency, the literature records both beneficial and

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detrimental effects. The inclusion of forage in the diet of dairy calves can influence the digestibility of dry matter (DMS) and organic matter (OM), as observed by Hill et al. (2019) when providing hay to animals under two months of age. Similarly, Daneshvar et al. (2015) found that calves fed forage had lower apparent total digestibility coefficients of DM, OM, and crude protein (CPD) compared to animals that did not receive roughage.

On the other hand, the traditional view argues that diets rich in starch and sugars increase ruminal butyrate production and accelerate papillae development, thus promoting higher growth rates (Świerk et al., 2024). From this perspective, the differentiation of the ruminal epithelium into papillae occurs markedly between the third and eighth week of the calf's life. This process is stimulated precisely by butyrate, a short-chain fatty acid produced by the fermentation of rapidly degradable carbohydrates, which induces enzymatic expression and cell differentiation in the ruminal tissue.

Therefore, the use of corn silage in the diet of pre-weaned calves constitutes a beneficial strategy due to the combined supply of starch and NDF. Furthermore, being a fermented feed, it contributes to the development of the rumen compartment through fermentative and digestive patterns distinct from those of fresh or dry forage (Mirzaei et al., 2017). Recent evidence obtained by Kanani et al. (2019) indicates that replacing alfalfa hay with corn silage increases feed efficiency post-weaning, although NDF digestibility was optimized only with the combined use of alfalfa hay and corn silage.

The development of the digestive compartment does not depend exclusively on the chemical stimulation of concentrates. The inclusion of fiber from different sources in the starter diet has proven equally effective, as it acts in a complementary way by stimulating chewing, rumination, salivation, and the maintenance of ruminal pH. Furthermore, the presence of fibrous material prevents epithelial alterations (such as parakeratosis) and promotes muscle and microbial development in the rumen (NASEM, 2021; Xu et al., 2023), additionally reducing the incidence of non-nutritive oral behaviors (Mirzaei et al., 2017).

This apparent contradiction between gains in feed efficiency and fluctuations in the digestibility of the fibrous fraction is supported by the dynamics of tissue maturation in the organ. As demonstrated by Kehoe et al. (2019), although the inclusion of corn silage during the suckling phase does not compromise intake and short-term weight gain, the exclusive supply of this forage can atrophy the length of the ruminal papillae and reduce the total thickness of the epithelium. Thus, the challenge lies in modulating the inclusion of corn silage in order to capitalize on its energy contribution (via starch) without compromising the mechanical stimulation necessary for the ruminal wall. This gap regarding the equilibrium point and the impact of this conserved forage on daily behavioral patterns justifies the relevance of the present study.

In this way, the hypothesis of this study is that the inclusion of corn silage in the diet of dairy calves before weaning improves rumen development and, consequently, increases rumination efficiency after weaning. Therefore, the objective of this study was to evaluate the effect of including corn silage in the diet of calves during the pre- and post-weaning periods on dry matter and nutrient intake, feed disappearance rate, performance, morphometric measurements, and animal behavior.

Materials and methods

The experimental protocol was approved by the Animal Use Ethics Committee (CEUA) of the Federal University of Goiás (protocol No 037/21). The experiment was conducted at the Department of Animal Science of the School of Veterinary Medicine and Animal Science, Federal University of Goiás, Samambaia Campus, Goiânia, Goiás, Brazil, at the geographic coordinates: latitude 16°35′52″ S and longitude 49°17′11″ W, with an altitude of 723 m. The region's climate is classified as Aw according to the Köppen-Geiger methodology, tropical with rainy summers and dry winters. It was carried out from February 17 to May 17, 2020, lasting 90 days.

The preparation of the animals began when the calves were three days old. During the pre-experimental period, all animals received 4 L/day of colostrum in two daily feedings until the second day of life. During this period, the calves were housed individually in mobile shelters with insulating panels on the roof. The shelters were placed at equal distances and equipped with a waterer and a feeder.

Throughout the experimental period, the calves were housed in individual, mobile tropical hutches covered with insulated roofing, with open sides to facilitate ventilation, equipped with waterers and feeders for concentrate and corn silage. The calves had permanent and ad libitum access to clean, fresh water through appropriate waterers from the third day of life. The calves were kept housed in the tropical hutches using special collars attached to a 1.68 m chain fixed to the ground with galvanized hooks from the beginning to the end of the experiment. The hutches were kept at a minimum distance from each other to avoid physical contact between the animals, and their location was changed whenever necessary to ensure that the animals were always in dry places free of feces.

Eighteen uncastrated male calves, with an average initial body weight of 37.7 ± 2.7 kg, of the ½ Holstein × ½ Jersey crossbreed, were used. At 30 days of age, the animals were weighed and distributed equally among the treatments. The treatments were: (1) corn silage offered during the suckling period, from 30 to 90 days of age (CISMA) and (2) no corn silage during the suckling period, with corn silage offered from 60 to 90 days of age (SOSMA). From the third day of life, all animals received 4 L/day of milk replacer, equally divided into two feedings (at 08:00 and 16:00 h), until weaning at 60 days of age. Concurrently, concentrate supplementation was provided from day 3 until 90 days of age.

The intake of concentrate and corn silage (Table 1) was calculated daily as the difference between the feed offered and the leftovers, expressed on a dry matter (DM) basis. Individual samples of concentrate, corn silage, and leftovers were collected on day 0 of the experiment and during the periods of 30–35, 45–50, 60–65, 75–80, and 85–90 days. Composite samples for each period were prepared in the same proportions as the individual samples. All feed samples were processed at the Animal Nutrition Laboratory – LANA/UFG.

Analyses of dry matter (*DM*, Method G-003/1), organic matter (*OM*), ash, ether extract (*EE*, Method G-004/1), and crude protein (*CP,* Method M001/02) were performed according to the INCT-CA methodologies, as described by Detmann et al. (2012). Neutral detergent fiber (*NDF*, Method 2002.04) and acid detergent fiber (*ADF*, Method 973.18) were determined as described by the AOAC (2019).

Total carbohydrates (*TC*) were calculated using Eq. (1) (Sniffen et al., 1992), and non-fiber carbohydrate (*NFC*) content was calculated using Eq. (2) by subtracting fibrous carbohydrates..

$$TC = 100 - (\%CP + \%EE + \%ash) \tag{Eq. 1}$$

Table 1
Bromatological composition of corn silage, concentrate, and milk replacer, g/kg DM.

Chemical Composition	Corn Silage	Concentrate	Milk Replacer
DM	269.8	916.6	938.9
MM	36.2	113.0	160.0
CP	58.8	219.1	200.0
EE	27.0	33.0	104.0
NDF	491.1	95.9	85.6
ADF	256.1	28.1	10.3
TC	878.1	634.4	536.2
NFC	387.0	538.5	450.6
OM	963.8	887.0	840.0

DM= Dry Matter; MM= Mineral Matter / Ash; CB= Crude Protein; EE= Ether Extract / Fat; NDF= Neutral Detergent Fiber; ADF= Acid Detergent Fiber; TC= Total Carbohydrates; NFC= Non-Fiber Carbohydrates; OM= Organic Matter.

$$NFC = TC - FC \quad \text{(Eq. 2)}$$

Nutrient intake (*NI*) was calculated according to Eq. (3), as described by Detmann et al. (2021).

$$NI = \frac{[(DM_o xNDM_o) - (DM_r xNDM_r)]}{100} \quad \text{(Eq. 3)}$$

Where: NI =nutrient intake (g); DM_o = dry matter offered (g); DM_r = dry matter in refusals (g); NDM_o = nutrient percentage in the dry matter offered (%); NDM_r = nutrient percentage in the dry matter in refusals (%).

The acceptability of corn silage was measured based on the average time it took calves to begin eating during morning feedings over five consecutive days, on day 30 for CISMA and on day 60 for SOSMA. Intake was considered to have occurred when the calf consumed at least three consecutive bites.

On days 50 and 80 of the experiment, feed disappearance rates were assessed for concentrate and/or corn silage, depending on the treatment. They were measured by the difference in weight every two hours, from 8:00 AM to 6:00 PM. Feed refusals were recorded 24 h after feed was offered for both treatments.

The calves were weighed on days 30, 60, and 90 of the experiment using a conventional scale to determine average daily gain (ADG), total weight gain (TWG), and body weight (BW).

Feed conversion ratio (FCR) was calculated as the ratio of average daily feed intake (g/animal/day on a dry matter basis) to ADG (g/animal/day). On days 30, 60, and 90 of the experiment, measurements of body development were taken, including body length (cm), withers height (cm), and rump width (cm), which were measured using a hipometer. Chest and rump circumferences (cm) were measured using a flexible tape measure.

Behavioral observations were recorded on days 0, +2, +7, +30, and +60 of the experiment, corresponding to the animals' ages of 32, 37, 60, and 90 days, respectively. Visual observations were conducted every 10 min (Jamieson & Hodgson, 1979), beginning at 5:00 AM and ending at 8:00 PM. The calves were observed for their posture (standing or lying down), feed intake (concentrate or corn silage), and activities, including water consumption, rumination, and resting. The average duration of each activity (min/day) and the frequency of occurrence (number/day) were recorded during the observation periods.

The number of chewing cycles and the time spent ruminating (min) for each ruminal bolus were recorded on days 51 and 81 of the experiment using a digital stopwatch. Three boluses were monitored at three different times of the day (10:00–12:00, 14:00–16:00, and 19:00–21:00). The number of chewing cycles was counted between the swallowing and regurgitation of each bolus, following a methodology adapted from Rêgo et al. (2014).

Feeding efficiency (*FDE*), rumination efficiency (RE), total daily chewing time (TDC, min/day), Number of Rumen Boluses per Day (NRB), and Number of Chewing Cycles per Day (NCC/day) were calculated using the methodology described by Burger et al. (2000), using Equations 4 through 8, respectively:

$$FDE\ (g\ DMI\ /\ h) = DMI/FEEDT \quad \text{(Eq. 4)}$$

$$RE\ (g\ DMI\ /\ h) = DMI/TRU \quad \text{(Eq. 5)}$$

$$TDC\ (h\ /\ day) = FEEDT\ +\ RUMT \quad \text{(Eq. 6)}$$

$$NRB\ (n^\circ\ /\ day) = RUMT\ (s\ /\ day)/CCbolus) \quad \text{(Eq. 7)}$$

$$NCC\ (n^\circ\ /\ day)\ =\ NRB\ \times\ CCbolus \quad \text{(Eq. 8)}$$

Where: DMI = dry matter intake (g DM/day); $FEEDT$ = feeding time (h/day); $RUMT$ = rumination time (h/day); $CCbolus$ = number of chewing cycles per ruminal bolus (s/bolus).

The experiment was conducted in a completely randomized design (CRD), with two treatments and nine replicates per treatment, with the animal considered the experimental unit. Data were subjected to analysis of variance and the F test at the 5% significance level. Repeated measures over time were analyzed using a mixed model in a factorial arrangement (treatment × time). An autoregressive AR(1) variance–covariance structure was used. Mean comparisons were performed using Tukey's test at the 5% significance level. Statistical analyses were carried out in the R software using the easyanova package, as described by Arnhold (2013). The interaction was further analyzed according to the significance indicated by the statistical model.

$$Y_{ijk} = \ \mu + treatment_i + \delta_{ij} + time_k + (treatment * time)_{ik} + \ \varepsilon_{ijk} \quad \text{(Eq. 9)}$$

Where: Y_{ijk} = observation ijk i = 1,…,a; j = 1,…,b; k = 1,…,n; μ is the overall mean; $treatment_i$ is the fixed effect of treatment I; δ_{ij} is the random error with mean 0 and variance σ^2; $time_k$ is the fixed effect of time k; $(treatment * time)_{ik}$ is the fixed effect of interaction between treatment i and time k; ε_{ijk} is random error with the mean 0 and variance σ^2.

Results

The dietary treatments (CISMA and SOSMA) had no effect ($P > 0.05$) on feed intake during any of the experimental periods (Tables 2 and 3). On the other hand, dry matter intake (total, forage, and concentrate) increased gradually over the course of the measurement days ($P < 0.05$), reflecting the animals' growth and adaptation.

Up to 60 days of age, during the pre-weaning period, treatments (CISMA and SOSMA) did not affect dry matter or concentrate intake (g DM/day) ($P > 0.05$) (Table 3).

No treatment effect was observed on crude protein intake (*CP* g DM/day) during the pre- (Tables 4) and post-weaning (Table 5) periods. CP intake was higher ($P < 0.001$) at days 30, 45, and 90.

During the pre-weaning period, *NDF* and *ADF* intake (29.36 and 11.32 g DM/day, respectively) was higher ($P < 0.01$) in the CISMA group compared with the SOSMA group (means of 18.02 and 4.90 g DM/day, respectively). The highest NDF and ADF intake in the CISMA group occurred at 30 days of age (62.62 and 27.93 g DM/day), whereas in the SOSMA group it occurred at 30 and 45 days. A significant treatment × day interaction was observed for these variables ($P < 0.001$) (Table 4).

No treatment effect was observed on nutrient intake (EE, TC, and NFC; g DM/day) during the pre-weaning period (Table 6). However, an

Table 2
Feed and total dry matter intake of calves submitted to CISMA and SOSMA treatments from day 0 to 45 of the experimental period.

Day[1]	Treatments		Mean	SEM[2]	P-value		
	CISMA	SOSMA			T	D	T * D
Concentrate intake (gDM/day)							
0	47.78	72.26	60.02 B	20.998	0.071	0.001	0.118
15	88.90	87.15	88.03 B	20.998			
30	135.23	211.03	173.13 A	21.685			
45	173.05	287.72	230.39 A	20.408			
Mean	111.24	164.54					
Total Dry Matter intake (gDM/day)							
0	47.78	72.12	59.95 B	21.708	0.473	0.001	0.260
15	88.9	87.01	87.96 B	21.708			
30	206.1	211.85	222.42 A	22.427			
45	232.98	287.72	246.91 A	21.094			
Mean	143.94	164.68					

[1]Day= Experimental day. CISMA = With inclusion of corn silage during the pre-weaning period; SOSMA = Without corn silage supply during the pre-weaning period. [2]SEM: Standard error of the mean. P-value = P-value of the F-test from the analysis of variance, T = Treatment effect, D = Days effect, T x D = Interaction effect of treatment × day. Means followed by the same uppercase letter in the same column do not differ statistically. Means followed by the same lowercase letter in the same row do not differ statistically ($P < 0.05$).

Table 3
Feed and total dry matter intake of calves submitted to CISMA and SOSMA treatments from day 60 to 90 of the experimental period.

Day[1]	Treatments		Mean	SEM[2]	P-value		
	CISMA	SOSMA			T	D	T * D
Concentrate intake (gDM/day)							
60	883.43	1049.54	966.49 C	86.816	0.761	0.001	0.314
75	1361.23	1270.51	1315.88 B	86.816			
90	1485.87	1545.81	1515.84 A	88.270			
Média	1243.51	1288.62					
Corn silage intake (gDM/day)							
60	157.64	155.45	156.55 B	41.567	0.979	0.001	0.884
75	134.82	156.7	145.76 B	41.567			
90	350.21	336.37	343.29 A	42.156			
Mean	214.22	216.17					
Total Dry Matter intake (gDM/day)							
60	1041.07	1204.99	1123.03 C	104.325	0.796	0.001	0.423
75	1496.06	1427.22	1461.64 B	104.325			
90	1836.07	1885.6	1860.84 A	105.71			
Mean	1457.74	1505.94					

[1]Day= Experimental day. CISMA = With inclusion of corn silage during the pre-weaning period; SOSMA = Without corn silage supply during the pre-weaning period. [2]SEM: Standard error of the mean. P-value = P-value of the F-test from the analysis of variance, T = Treatment effect, D = Days effect, T x D = Interaction effect of treatment × day. Means followed by the same uppercase letter in the same column do not differ statistically. Means followed by the same lowercase letter in the same row do not differ statistically ($P < 0.05$).

Table 4
Crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) intake of calves submitted to CISMA and SOSMA treatments from day 0 to 45.

Day[1]	Treatments		Mean	SEM[2]	P-value		
	CISMA	SOSMA			T	D	T * D
CP intake (g DM/day)							
0	10.17	15.35	12.76 B	6.370	0.130	0.001	0.190
15	18.98	18.51	18.74 B	6.370			
30	34.31	44.77	39.54 A	6.569			
45	38.38	61.14	49.76 A	6.194			
Mean	25.46	34.94					
NDF intake (g DM/day)							
0	6.17 aC	7.67 aC	6.92 B	4.132	0.005	0.001	0.001
15	11.12 aC	9.33 aBC	10.22 B	4.132			
30	62.62 aA	23.01 bAB	42.82 A	4.272			
45	37.50 aB	32.07 aA	34.79 A	4.013			
Mean	29.36 a	18.02 b					
ADF intake (g DM/day)							
0	1.44 aC	2.10 aB	1.77 C	1.386	0.004	0.001	0.001
15	2.69 aC	2.65 aB	2.67 C	1.434			
30	27.93 aA	6.15 bAB	17.04 A	1.433			
45	13.22 aB	8.69 bA	10.95 B	1.346			
Mean	11.32 a	4.90 b					

[1]Day= Experimental day. CISMA = With inclusion of corn silage during the pre-weaning period; SOSMA = Without corn silage supply during the pre-weaning period. [2]SEM: Standard error of the mean. P-value = P-value of the F-test from the analysis of variance, T = Treatment effect, D = Days effect, T x D = Interaction effect of treatment × day. Means followed by the same uppercase letter in the same column do not differ statistically. Means followed by the same lowercase letter in the same row do not differ statistically ($P < 0.05$).

Table 5
Crude protein (CP), neutral detergent fiber (NDF), and acid detergent fiber (ADF) intake of calves submitted to CISMA and SOSMA treatments from day 60 to 90.

Day[1]	Treatments[2]		Mean	SEM[3]	P-value[4]		
	CISMA	SOSMA			T	D	T * D
CP intake (g DM/day)							
60	194.64	231.26	212.95 C	26.821	0.700	0.001	0.350
75	294.25	279.55	286.90 B	26.821			
90	332.67	348.81	340.74 A	27.266			
Mean	273.86	286.54					
NDF intake (g DM/day)							
60	196.62	185.86	191.24 B	35.254	0.543	0.001	0.688
75	244.11	210.79	227.45 B	35.254			
90	362.04	320.95	341.50 A	35.628			
Mean	267.59	239.20					
ADF intake (g DM/day)							
60	64.61	67.97	66.29 B	15.115	0.974	0.001	0.856
75	73.79	74.68	74.23 B	15.115			
90	129.88	123.73	126.81 A	15.314			
Mean	89.43	88.80					

[1]Day= Experimental day. [2]CISMA = With inclusion of corn silage during the pre-weaning period; SOSMA = Without corn silage supply during the pre-weaning period. [3]SEM: Standard error of the mean. [4]P-value = P-value of the F-test from the analysis of variance, T = Treatment effect, D = Days effect, T x D = Interaction effect of treatment × day. Means followed by the same uppercase letter in the same column do not differ statistically. Means followed by the same lowercase letter in the same row do not differ statistically ($P < 0.05$).

increase in intake was observed at 30 and 45 days ($P < 0.05$).

During the post-weaning period, intake of EE, TC, and NFC did not differ ($\underline{P} > 0,05$) between CISMA and SOSMA. However, all variables increased with age ($P < 0.001$), with the highest values observed at 90 days of age (EE: 54.37 ± 3.439 g DM/day; TC: 1261.37 ± 72.652 g DM/day; NFC: 922.66 ± 50.635 g DM/day) compared with earlier observation days (Table 7).

Significant effects of days were observed ($P < 0.01$) on FC, ADG, BW, and FE of calves throughout the experimental period (Table 8).

Regarding body measurements, significant differences were observed with advancing calf age for body length, withers height, rump width, and thoracic circumference ($P < 0.05$). All these variables increased over the course of the experimental period ($P = 0.001$) (Table 9).

No significant differences ($P > 0.05$) were observed between CISMA and SOSMA for time-based patterns of nibbling (44.32±11.743) and 66.00±9.589) and eating corn silage.

The rate of concentrate disappearance on days 50 and 80 of the experiment was similarly higher ($P < 0.05$) during the 18:00 to 24:00 h period compared with the other observation periods (Table 10). A significant treatment × time interaction was observed on both evaluation days ($P < 0.05$). Likewise, the rate of corn silage disappearance at 80 days was higher during the 18:00 to 24:00 h period; however, no treatment × day interaction was detected.

Animals in the SOSMA treatment spent more time consuming corn silage and concentrate than those in the CISMA treatment ($P < 0.01$) (Table 11), with a higher frequency of concentrate intake ($P < 0.05$) (Table 12).

Idle time was higher ($P < 0.05$) in the CISMA group (10.08 h) and

Table 6
Ether extract (EE), total carbohydrate (TC), and non-fibrous carbohydrate (NFC) intake of calves submitted to CISMA and SOSMA treatments from day 0 to 45.

Day[1]	Treatments[1]		Mean	SEM[2]	P- value[3]		
	CISMA	SOSMA			T	D	T * D
EE intake (g DM/day)							
0	1.38	2.22	1.80 B	0.949	0.434	<0.001	0.403
15	2.60	2.79	2.70 B	0.979			
30	6.75	6.37	6.56 A	0.979			
45	6.09	8.37	7.23 A	0.923			
Mean	4.21	4.94					
TC intake (g DM/day)							
0	30.23	45.86	38.05 B	19.867	0.712	<0.0001	0.155
15	56.13	59.39	57.77 B	20.513			
30	171.03	134.67	152.85 A	20.513			
45	138.43	183.65	161.04 A	19.313			
Mean	98.96	105.89					
NFC intake (g DM/day)							
0	24.06	38.40	31.23 B	16.099	0.234	<0.0001	0.282
15	45.01	49.85	47.43 B	16.615			
30	108.41	112.56	110.49 A	16.615			
45	100.93	152.70	126.82 A	15.655			
Mean	69.60	88.38					

[1]Day= Experimental day. CISMA = With inclusion of corn silage during the pre-weaning period; SOSMA = Without corn silage supply during the pre-weaning period. [2]SEM: Standard error of the mean. [3]P-value = P-value of the F-test from the analysis of variance, T = Treatment effect, D = Days effect, T x D = Interaction effect of treatment × day. Means followed by the same uppercase letter in the same column do not differ statistically. Means followed by the same lowercase letter in the same row do not differ statistically ($P < 0.05$).

Table 7
Ether extract (EE), total carbohydrate (TC), and non-fibrous carbohydrate (NFC) intake of calves submitted to CISMA and SOSMA treatments from day 60 to 90.

Day[1]	Treatments[1]		Mean	SEM[2]	P- value[3]		
	CISMA	SOSMA			T	D	T * D
EE intake (g DM/day)							
60	30.02	35.62	32.82 C	4.799	0.735	<0.001	0.344
75	43.58	41.44	42.51 B	4.799			
90	52.95	55.80	54.37 A	4.799			
Mean	42.18	44.28					
TC intake (g DM/day)							
60	697.96	804.20	751.08 C	101.277	0.791	<0.0001	0.498
75	979.63	946.92	963.28 B	101.277			
90	1246.66	1276.08	1261.37 A	102.623			
Mean	974.75	1009.07					
NFC intake (g DM/day)							
60	507.09	620.76	563.93 C	70.397	0.462	<0.0001	0.476
75	735.52	739.46	737.49 B	70.397			
90	884.63	960.69	922.66 A	71.534			
Mean	709.08	773.64					

[1]Day= Experimental day. CISMA = With inclusion of corn silage during the pre-weaning period; SOSMA = Without corn silage supply during the pre-weaning period. [2]SEM: Standard error of the mean. [3]P-value = P-value of the F-test from the analysis of variance, T = Treatment effect, D = Days effect, T x D = Interaction effect of treatment × day. Means followed by the same uppercase letter in the same column do not differ statistically. Means followed by the same lowercase letter in the same row do not differ statistically ($P < 0.05$).

lower in the SOSMA group (8.81 h). Rumination time was lower ($P < 0.01$) in the CISMA group (0.71 h) and higher in the SOSMA group (1.10 h) (Table 11). Total frequencies of idling and rumination were also significantly affected ($P < 0.05$) (Table 12). The CISMA group showed a higher idling frequency (60.49 events/day) and a lower rumination frequency (4.24 events/day). In contrast, the SOSMA group showed a lower idling frequency (52.85 events/day) and a higher rumination frequency (6.61 events/day) (Table 12).

Animals in the SOSMA treatment spent 2.1 h more standing ($P = 0.001$) than those in the CISMA treatment (Table 11). The opposite pattern was observed for lying time. The frequency of standing was lower ($P < 0.05$) in the CISMA group (32.19 events/day), with a higher frequency of lying (40.32 events/day), whereas the SOSMA group had a higher frequency of standing (44.82 events/day) and a lower frequency of lying (28.19 events/day) (Table 12).

SOSMA animals showed higher ($P = 0.001$) rumination chewing activity per hour and per day (3.46 h/day and 4414.81 chews/day) after weaning (Table 13), while lower values were observed in the CISMA group (1.83 h/day and 2919.78 chews/day). Lower feed and rumination efficiency of NDF was detected in the SOSMA group, showing lower efficiency (0.51 and 0.19 kg NDF/h), whereas the CISMA group exhibited higher efficiency (0.77 and 0.42 kg NDF/h) (Table 13).

4. Discussion

The hypothesis that the inclusion of corn silage in the pre-weaning diet affects the performance, intake, and behavior of calves post-weaning was partially supported by our results. Although performance and total dry matter intake remained similar across treatments, the most pronounced effects were observed in feeding behavior, which showed significant changes. These behavioral changes are consistent with previous studies reporting that the provision of corn silage during the pre-weaning period increases chewing and rumination time after weaning, particularly while the animals are lying down (Mirzaei et al., 2017).

In dairy cows, longer standing time is considered detrimental to welfare and performance (Tucker et al., 2021). In calves, standing can

Table 8
Average daily gain (ADG), feed conversion (FC), total weight gain (TWG), and body weight (BW) of dairy calves across treatments.

Day[1]	Treatments[2]		Mean	SEM[3]	P-value[4]		
	CISMA	SOSMA			T	D	T * D
ADG (kg)							
30–60	0.21	0.34	0.28	0.067	0.196	0.439	0.527
60–90	0.32	0.35	0.34	0.069			
Média	0.27	0.34					
FC (kg/kg)							
30–60	0.43	0.78	0.60 B	0.763	0.226	0.001	0.445
60–90	4.22	5.85	5.04 A	0.824			
Mean	2.33	3.32					
TWG (kg)							
30–60	6.33	10.18	8.26	1.992	0.191	0.431	0.521
60–90	9.73	10.53	10.13	2.056			
Mean	08.03	10.36					
BW (kg)							
30	37.78	37.59	37.68 C	2.063	0.337	0.001	0.364
60	44.11	47.44	45.78 B	2.021			
90	54.16	57.98	56.07 A	2.115			
Mean	45.35	47.67					

[1]Day= Experimental day. [2] CISMA = With inclusion of corn silage during the pre-weaning period; SOSMA = Without corn silage supply during the pre-weaning period. [3]SEM: Standard error of the mean. [4]P-value = P-value of the F-test from the analysis of variance, T = Treatment effect, D = Days effect, T x D = Interaction effect of treatment × day. Means followed by the same uppercase letter in the same column do not differ statistically. Means followed by the same lowercase letter in the same row do not differ statistically ($P < 0.05$).

Table 9
Morphometric parameters: body length, withers height, rump width, and heart girth of dairy calves across treatments.

Day[1]	Treatments[1]		Mean	SEM[2]	P-value[3]		
	CISMA	SOSMA			T	D	T * D
Body Length (cm)							
30	59.56	61.93	60.74 B	1.237	0.085	0.001	0.735
60	59.89	62.93	61.41 B	1.237			
90	68.12	70.17	69.14 A	1.269			
Mean	62.52	65.00					
Withers Height (cm)							
30	70.00	69.99	69.99 B	1.027	0.597	0.001	0.283
60	70.00	71.61	70.81 B	1.027			
90	73.85	74.39	74.12 A	1.038			
Mean	71.28	71.99					
Rump Width (cm)							
30	19.11	19.23	19.17 B	0.431	0.427	0.001	0.527
60	19.17	19.73	19.45 B	0.431			
90	21.68	22.28	21.98 A	0.439			
Mean	19.99	20.41					
Heart Girth (cm)							
30	74.89	74.89	74.89 C	1.254	0.341	0.001	0.193
60	79.78	82.39	81.01 B	1.254			
90	87.35	89.33	88.34 A	1.272			
Mean	80.67	82.20					

[1]Day= Experimental day. CISMA = With inclusion of corn silage during the pre-weaning period; SOSMA = Without corn silage supply during the pre-weaning period. [2]SEM: Standard error of the mean. [3]P-value = P-value of the F-test from the analysis of variance, T = Treatment effect, D = Days effect, T x D = Interaction effect of treatment × day. Means followed by the same uppercase letter in the same column do not differ statistically. Means followed by the same lowercase letter in the same row do not differ statistically ($P < 0.05$).

also indicate discomfort, and time spent standing is inversely related to rumination time (Wang et al., 2022). In this study, calves that did not receive corn silage during the pre-weaning period ruminated more, spent more time standing, and consumed less corn silage. This behavior suggests lower rumination efficiency compared with calves that received silage early.

Feeding conditions during the pre-weaning period determine future performance. Inadequate morphophysiological development, combined with an immature ruminal microbiota, reduces the capacity to degrade fibrous material (Xu et al., 2023). Consequently, ingested feed remains in the rumen longer, while physical, enzymatic, and microbial mechanisms are still underdeveloped. At the same time, this delay in fiber degradation physically limits rumen capacity and prevents the animal from meeting its chemical nutrient requirements, leading to feeding discomfort.

The first rumination in a calf can occur between 9 and 28 days of age (Wang et al., 2022). Therefore, at 30 days, when corn silage was first provided to the CISMA treatment, the calves could already exhibit some rumination. This likely promoted the development of ruminal structures and the establishment of an appropriate microbial community for fermentation.

Additionally, Muruz and Aksu (2024) note that scientific speculations on calf nutrition and ruminal development often confuse the type of feed with the age at which it is first provided. Xiao et al. (2023) showed that offering hay during the first week negatively affects future calf development. Recently, Toledo et al. (2024) found that NDF/ADF content has little effect on rumination time in calves from 28 days of age, which is the age used in this study. Late feed introduction also has negative effects. Kehoe et al. (2019) reported that calves receiving corn silage only at 60 days of age exhibited reduced ruminal crypt depth and epithelial thickness, as well as intestinal alterations. It is also important to consider the particle selection capacity of calves, which favors larger particles at 65 days of age and reverses after 70 days (Costa et al., 2016).

From 30 to 60 days of age, the ruminal epithelium of calves is not yet fully developed to utilize fibrous feeds. During this period, nutrients from milk or milk replacer serve as the main energy source through abomasal digestion and intestinal absorption (Bergman, 1990). Short-chain fatty acids (SCFAs) are produced by the fermentation of carbohydrates by the ruminal microbiota. SCFAs interact with the ruminal epithelium, altering the energy metabolism of the host animal in transition. This alteration reduces glucose absorption in the small intestine and increases glucose production via gluconeogenesis (Otterby & Linn, 1981; Kozloski, 2016).

Butyrate levels in contact with the ruminal wall of the calf can trigger gene transcription and protein synthesis processes related to cell proliferation, ketogenesis, and maintenance of cellular pH (Mortazavi et al., 2025). Furthermore, Nakamura et al. (2018) reported that higher concentrations of propionate and butyrate stimulate the expression of enzymes such as MCT1 and MCT4, monocarboxylate transporters responsible for the passage of SCFAs across the ruminal wall in calves. These cellular modifications are essential to enable the ruminal wall to absorb SCFAs and maintain blood pH homeostasis, particularly during ruminal acidosis, throughout life (Kozloski, 2002).

Given this, the starch level in the diet of calves during the experimental period may have been another factor influencing ruminal epithelial cell differentiation in the pre-weaning phase. Ruminal starch degradability depends not only on the presence of corn in silage but also on the chemical and physical characteristics of the cereal (Grant & Ferraretto, 2018), such as the degree of processing, which exposes starch to ruminal bacterial action (Ferraretto et al., 2018). In the present study, starch content in the corn silage provided could not be analyzed. However, it may have influenced dry matter intake (DMI), especially post-weaning, potentially limiting the effect of pre-weaning corn silage in CISMA. Wu et al. (2023) observed higher DMI in 15-day-old calves fed diets with lower starch content until weaning.

Forage contributes little to the growth of ruminal papillae; however, it promotes muscular layer development by stimulating rumination and maintaining rumen health (Kanani et al., 2019; Liu et al., 2022). Ruminal muscular development is important for regurgitation and remastication of the feed bolus, known as rumination, which is absent at birth. This contributed to the higher rumination efficiency observed in the CISMA treatment. It has long been known that offering hay or concentrate in this early phase allows detection of rumination

Table 10
Disappearance rate of concentrate and corn silage from the bunk for dairy calves across treatments measured on days 50 and 80 of the experiment.

Assessment periods	Treatments[1]		Mean	SEM[2]	P-value[3]		
	CISMA	SOSMA			T	H	T * H
Concentrate (%) 50th							
08:00 a.m.–10:00 a.m.	0.19 aB	0.23 aB	0.21 B	0.058	0.214	0.001	0.040
10:00 a.m.–12:00 pm.	0.10 aB	0.08 aB	0.09 B	0.058			
12:00 pm.–14:00 pm.	0.13 aB	0.11 aB	0.12 B	0.058			
02:00 pm.–04:00 pm.	0.08 aB	0.17 aB	0.13 B	0.058			
04:00 pm.–06:00 pm.	0.16 aB	0.24 aB	0.20 B	0.058			
06:00 pm.- 12:00 a.m.	0.51 bA	0.76 aA	0.64 A	0.058			
Mean	0.19	0.27					
Concentrate (%) 80th							
08:00 a.m.–10:00 a.m.	0.34 aAB	0.35 aB	0.34 B	0.093	0.516	0.001	0.041
10:00 a.m.–12:00 pm.	0.23 aB	0.19 aB	0.21 B	0.093			
12:00 pm.–14:00 pm.	0.23 aB	0.31 aB	0.27 B	0.093			
02:00 pm.–04:00 pm.	0.37 aAB	0.16 aB	0.27 B	0.093			
04:00 pm.–06:00 pm.	0.47 aAB	0.14 bB	0.31 B	0.093			
06:00 pm.- 12:00 a.m.	0.58 aA	0.76 aA	0.67 A	0.093			
Mean	0.37	0.32					
Corn silage (%) 80th							
08:00 a.m.–10:00 a.m.	0.17	0.22	0.20 B	0.090	0.356	0.001	0.544
10:00 a.m.–12:00 pm.	0.17	0.13	0.15 B	0.090			
12:00 pm.–14:00 pm.	0.18	0.16	0.17 B	0.090			
02:00 pm.–04:00 pm.	0.22	0.38	0.30 B	0.090			
04:00 pm.–06:00 pm.	0.25	0.46	0.36 B	0.090			
06:00 pm.- 12:00 a.m.	0.57	0.64	0.61 A	0.090			
Mean	0.26	0.33					

[1]CISMA = With inclusion of corn silage during the pre-weaning period; SOSMA = Without corn silage supply during the pre-weaning period. [2]SEM: Standard error of the mean. [3]P-value = P-value of the F-test from the analysis of variance, T = Treatment effect, D = Days effect, T x D = Interaction effect of treatment × day. Means followed by the same uppercase letter in the same column do not differ statistically. Means followed by the same lowercase letter in the same row do not differ statistically ($P < 0.05$).

Table 11
Time spent on concentrate, corn silage, and water intake; behavioral activities time; and posture time of dairy calves across treatments.

Parameter	Treatments[1]		SEM[2]	P-value[3]
	CISMA	SOSMA		
Feeding time (hour)				
Concentrate	0.49 b	0.90 a	0.055	0.001
Corn silage	0.43 b	0.77 a	0.075	0.002
Water	0.28	0.27	0.041	0.865
Behaviour activities (hour)				
Idleness	10.08 a	8.81 b	0.134	0.001
Rumination	0.71 b	1.10 a	0.094	0.005
Position (hour)				
Standing	5.37 b	7.47 a	0.204	0.001
Lying	6.72 a	4.70 b	0.207	0.001

[1]CISMA = With inclusion of corn silage during the pre-weaning period; SOSMA = Without corn silage supply during the pre-weaning period. [2]SEM= Standard error of the mean. [3]P-value = P-value of the F-test from the analysis of variance. Means followed by the same lowercase letter in the same row do not differ statistically ($P < 0.05$).

Table 12
Frequency of concentrate, corn silage, and water intake; frequency of behavioral activities; and postures of dairy calves across treatments.

Parameter	Treatments[1]		SEM[2]	P-value[3]
	CISMA	SOSMA		
Frequency Intake (n°/day^{-1})				
Concentrate	2.93 b	5.37 a	0.327	0.001
Corn silage	2.58 a	4.44 b	0.453	0.005
Water	1.69	1.63	0.243	0.849
Frequency of behavioral activities (n°/day^{-1})				
Idleness	60.49 a	52.85 b	0.804	0.001
Rumination	4.24 b	6.61 a	0.565	0.005
Frequency of postures (n°/day^{-1})				
Standing	32.19 b	44.82 a	1.226	0.001
Lying	40.32 a	28.19 b	1.241	0.001

[1]CISMA = With inclusion of corn silage during the pre-weaning period; SOSMA = Without corn silage supply during the pre-weaning period. [2]SEM= Standard error of the mean. [3]P-value = P-value of the F-test from the analysis of variance. Means followed by the same lowercase letter in the same row do not differ statistically ($P < 0.05$).

movements from the third week of life (Van Soest, 1994), whereas in calves fed exclusively milk, these movements appear later (Quigley et al., 2018).

It is important to highlight that the corn silage used in this study had NDF and ADF levels within recommended ranges and therefore was not a limiting factor for intake between treatments. According to Mertens (1994), the physical fill mechanism regulates feed intake and is related to the rumen-reticulum distension capacity based on the dietary NDF content. In this way, corn silages with high NDF and ADF levels and large particle size can limit intake and alter feeding behavior (Grant & Ferraretto, 2018).

The lack of difference in average daily gain (ADG) between treatments may be related to stable nutrient intake, which was also reflected in feed conversion, and aligns with the advancing age of the calves. Weight gain in animals is primarily associated with muscle or fat deposition (Abdelsamei et al., 2005). Therefore, it can be inferred that diet conformity was balanced by variations in ingestive behavior between treatments (Mirzaei et al., 2017). Similarly, Toledo et al. (2024) found no differences in ADG in calves fed only concentrate or corn silage from 28 days of age.

In addition to weight gain, morphometric measurements were used to monitor the development of body structures in the animals. Consistent with our results, Pazoki et al. (2017) reported no differences in body length, hip height, hip width, or withers height when comparing different physical forms of starter feed and forage provision. Other feeds, such as alfalfa hay and beet pulp, also had no effect on the morphology of supplemented calves (Kargar et al., 2019).

Finally, some limitations of this study should be acknowledged. First, the relatively small sample size (n) used for behavioral data collection represents a limitation, since individual behavioral measures are

Table 13
Number and time of chews, ruminated boluses, rumination chews, and efficiencies of dairy calves across treatments after weaning.

Parameter	Treatments[1]		SEM[2]	P-value[3]
	CISMA	SOSMA		
Numbers chews. day	170.07	149.36	28.045	0.611
Time of chews.bolus.secund	24.15	27.97	2.176	0.228
Rumination chews				
Hour.day	1.83 b	3.46 a	0.216	0.001
Number.bolus	27.54	30.80	2.371	0.344
Number.day	2919.78 b	4414.81 a	385.447	0.009
Efficiencies activities				
Feeding. kg DM.hour	3.98	3.27	0.487	0.309
Feeding. kg NDF. hour	0.77	0.51	0.095	0.058
Rumination. kg DM. hour	2.13	1.20	0.349	0.069
Rumination. kg NDF.hour	0.42 a	0.19 b	0.067	0.019

[1]CISMA = With inclusion of corn silage during the pre-weaning period; SOSMA = Without corn silage supply during the pre-weaning period. [2]SEM= Standard error of the mean. [3]P-value = P-value of the F-test from the analysis of variance. Means followed by the same lowercase letter in the same row do not differ statistically ($P < 0.05$).

inherently susceptible to substantial daily and individual variations, which can influence the significance of the reported results. Furthermore, we clarify that our statistical modeling prioritized characterizing general seasonal behavioral patterns and trends rather than establishing rigid individual biological thresholds. Second, parameters related to ruminal fermentation (e.g., volatile fatty acids and pH) were not evaluated due to experimental and logistical limitations. Furthermore, there were no data available on the starch content of corn silage. As starch is a critical dietary component that strongly influences the development of ruminal papillae through propionate production, the lack of this precise nutritional value limits a more in-depth discussion of the chemical stimulation of tissues. Thus, to compensate for the absence of some parameters, the discussions and conclusions presented here are based on evidence reported in the literature on the subject. Future long-term studies with larger sample sizes, complete bromatological profiles, and ruminal fluid sampling are encouraged to expand on these findings.

5. Conclusion

The provision of corn silage during the pre-weaning period altered feeding behavior post-weaning compared to calves without access to this feed before 60 days. CISMA calves showed higher rumination efficiency and greater capacity to consume and utilize corn silage. In this study, no differences were observed in dry matter intake, nutrient intake, weight gain, or morphometric measurements between treatments.

However, corn silage proves to be a good feeding alternative for calves from 30 days of age, without negative effects on the development of ruminal structures. Furthermore, it is an accessible and cost-effective ingredient for composing the diet of dairy calves during both pre-weaning and post-weaning periods. To expand upon these findings, future research utilizing a larger sample size, comprehensive dietary starch profiling, and precise ruminal fermentation analyses is recommended to fully elucidate the physiological mechanisms behind early corn silage exposure in calves.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the authors used Gemini Google in order to refine English composition. After using this tool/service, the authors reviewed and edited the content as needed and takes full responsibility for the content of the published article.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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