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Effects of corn silage particle size on feeding behavior, growth performance, and carcass traits of finishing beef heifers

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ABSTRACT - The objective of this study was to assess the effect of corn silage particle size on feeding behavior, blood parameters, fecal characteristics, and growth performance of beef heifers. Corn silage was harvested at 37.9 ± 1.6% dry matter (DM) using a self-propelled harvester containing shredding rolls and set to either a 13-mm theoretical length of cut (TLC), designated as conventional particle size (CPS), or a 24-mm TLC, designated as long particle size (LPS). Ninety-six Nellore heifers (initial shrunk body weight = 248 ± 36 kg) were randomly assigned to one of two treatments [3 heifers per pen; 16 pens (replicates) per treatment]. Treatments consisted of a finishing diet containing either CPS or LPS. Heifers were fed for 101 days, with the first 15 days serving as the adaptation period. Feeding behavior was evaluated on days 47 and 69, fecal samples were collected on days 58 and 78, and ultrasound backfat thickness, ribeye area, and blood samples were assessed on the day of slaughter. Statistical analysis was performed using the MIXED procedure in SAS (α = 0.05). No differences were observed in initial body weight, final body weight, ADG, hot carcass yield, carcass traits, or feed efficiency (P≥0.05). However, the DM intake of heifers fed LPS (7.98 kg/d) was higher than that of heifers fed CPS (7.55 kg/d) (P = 0.031). Although treatments did not significantly affect ingestive behavior (P≥0.05), heifers receiving the LPS diet exhibited a 15% increase in NDF intake (P = 0.006). Fecal pH tended (P = 0.052) to be 1.3% higher in LPS-fed heifers. Overall, an increase in corn silage particle size led to higher intake without compromising feed efficiency. Nevertheless, the treatments had no significant effect on chewing activity or the performance of finishing beef heifers.

Keywords: feedlot, particle size, shredlage

1. Introduction

Long fiber particles in cattle diets can stimulate chewing, saliva production, and ruminal motility, thereby reducing the risk of acidosis (Allen, 1997; Zebeli et al., 2012; Plaizier et al., 2022). However, finishing diets often include forage at minimal levels (Fox and Tedeschi, 2002). This is mainly due to the lower digestibility (Mertens, 1997) and energy density of forage compared to cereal grains (NASEM, 2016). Considering that energy intake is positively associated with animal performance (Tedeschi et al., 2002; NASEM, 2016), beef cattle nutritionists face the challenge of formulating diets that maximize energy intake without compromising ruminal health.

Increasing particle size in finishing diets may be an effective strategy to mitigate ruminal acidosis (Weiss et al., 2017) without reducing dietary energy density (Gentry et al., 2016). The potential effects of increasing the theoretical length of cut (TLC) in corn silage for dairy cattle have been investigated over recent decades (Kononoff et al., 2003; Schadt et al., 2012; Piran Filho et al., 2023), particularly after the development of the shredding rolls (Zhang et al., 2003; Ferraretto and Shaver, 2012; Vanderwerff et al., 2015). However, little is known about the effect of this approach on finishing beef cattle. In Brazil, corn silage represents the main fiber source in finishing diets, typically included at an average of 20% (DM basis; Bernardes et al., 2022). Thus, the hypothesis of this study was that diets containing corn silage with a long particle size would increase rumination activity and performance. The objective of this study was to evaluate the effects of feeding corn shredlage with two TLC (13 or 24 mm) on feeding behavior, blood parameters, fecal characteristics, and growth performance of beef heifers.

2. Material and methods

The experiment was conducted at the Universidade Federal de Lavras, MG, Brazil (21°14'43" S, 44°59'59" W). The use of heifers, care, and sampling procedures in this study was reviewed and approved by the Ethics Committee on Animal Use of the Universidade Federal de Lavras (027/21).

2.1. Silage production

A corn hybrid (LG 3055; Limagrain, Curitiba, Brazil) was planted in October on a 10.6-ha field at a density of 70,000 plants per hectare. Fertilization consisted of single superphosphate, urea, potassium chloride, and micronutrients. In March 2021, whole plants were harvested using a self-propelled forage harvester (Claas Jaguar 870 equipped with an Orbis 600 header) at two theoretical lengths of cut (TLC): 13 mm (CPS) and 24 mm (LPS). The processor gap was adjusted to 2.5 mm for both treatments. At harvest (37.9 ± 1.6% DM), swaths were alternated between the two TLC to standardize field conditions, and each treatment was stored in separate bunkers. Particle size distribution and the kernel processing score are shown in Table 1.

Table 1 - Particle size distribution and kernel processing score of corn forage at ensiling (n = 6)

Item	Treatment	
	CPS	LPS
Particle size distribution[1]	% of the total	
> 19 mm	9.56 ± 0.9	35.1 ± 1.2
< 19 mm to > 8 mm	66.9 ± 0.4	39.3 ± 0.8
< 8 mm to > 4 mm	14.1 ± 0.3	15.3 ± 0.5
< 4 mm	9.44 ± 0.2	10.3 ± 0.2
Kernel processing score[2]	%	
	73.9 ± 3.3	72.8 ± 2.9

CPS - conventional particle size; LPS - long particle size.
[1] Conducted as described by Heinrichs and Jones (2013).
[2] Conducted as described by Ferreira and Mertens (2005).

2.2. Animals, housing, treatments, and diets

Ninety-six Nellore heifers (18 mo of age; 248.3 ± 36.3 kg BW) were used. Upon arrival, animals were ear-tagged, vaccinated, and treated for parasites. For acclimatation, all animals received a common diet (corn silage, rehydrated corn grain silage, soybean meal, and mineral premix) for 5 d (day −5 to −1). Heifers were housed in 32 pens (4 × 10 m; 3 heifers/pen), each with a water trough and a 4-m feed bunk. On day 1, pens were blocked by initial BW and randomly assigned to 2 treatments differing in silage TLC (16 pens/treatment): CPS or LPS. Diet composition and nutrient composition are shown in Table 2. Diets were fed for 101 d, including 15-d adaptation period with step-up concentrate (3 diets, 5 d each). The finishing diet was formulated according to NASEM (2016) to allow approximately 1.3 kg/d ADG. Diets were offered twice daily (08:00 and 16:00 h) as a TMR, weighed daily, and fed for *ad libitum* intake (3% orts).

Table 2 - Ingredients, chemical composition, particle size distribution, and physically effective neutral detergent fiber (peNDF) of the diets

Item	Treatment	
	CPS	LPS
Ingredient (% DM)		
Corn silage 13 mm	19.5	-
Corn silage 24 mm	-	19.5
Reconstituted corn grain silage	39.1	39.1
Ground corn	26.3	26.3
Cottonseed meal	7.10	7.10
Soybean meal	3.95	3.95
Urea	0.85	0.85
Mineral/vitamin supplement[1]	3.20	3.20
Chemical composition (n = 12)		
Dry matter (%)	56.0 ± 0.5	57.5 ± 0.6
Ash (% DM)	4.15 ± 0.1	4.41 ± 0.1
Crude protein (% DM)	13.9 ± 0.3	14.3 ± 0.1
Neutral detergent fiber (% DM)	20.3 ± 0.6	17.5 ± 0.8
Ether extract (% DM)	2.65 ± 0.4	2.90 ± 0.3
Starch (% DM)	51.7 ± 0.9	52.4 ± 1.1
Particle size distribution of diets (%)[2]		
> 19 mm	1.40 ± 0.2	3.63 ± 0.3
< 19 mm to > 8 mm	19.0 ± 0.3	20.8 ± 0.4
< 8 mm to > 4 mm	15.3 ± 0.1	12.8 ± 0.2
< 4 mm	64.3 ± 0.2	62.7 ± 0.2
peNDF[3]	6.27 ± 0.4	6.93 ± 0.6

CPS - conventional particle size; LPS - long particle size.
[1] Mineral/vitamin supplement: Ca (13% DM), P (1.5% DM), Mg (6.8% DM), Na (8% DM), S (2.5% DM), Co (32 mg/kg), Cu (330 mg/kg), I (24 mg/kg), Mn (1152 mg/kg), Se (6 mg/kg), Zn (1220 mg/kg), vit. A (67 IU/g), vit. D (9.5 IU/g), vit. E (0.95 IU/g), monensin (650 mg/kg), thiamine (3.49 mg), pantothenic acid (17.67 mg), pyridoxine (11.29 mg), folic acid (1.92 mg), cobalamin (176.75 mcg), biotin (1427.26 mcg).
[2] Conducted as described by Heinrichs and Jones (2013).
[3] Percent peNDF was estimated by multiplying the percentage of sample larger than 8 mm in particle size (top 2 sieves) by the percent NDF of those particle sizes.

2.3. Chemical analyses

For diet adjustment, ingredient samples were collected weekly to determine dry matter (DM) and stored at −20 °C until analysis. In addition, monthly, samples of individual components were collected. All samples were subjected to pre-drying in a forced-air oven at 55 °C for 72 h and ground to pass through a 1-mm screen in a Wiley mill (model TE-680, USA). The analyses of dry matter (DM), crude protein (CP), ash, ether extract (EE), and neutral detergent fiber (NDF) were performed as described by Detmann et al. (2021). Starch quantification was carried out as established by Hall (2015).

2.4. Performance, intake, and efficiency measurements

Heifers were weighed on days 0 and 101 after 16 h feed withdrawal to calculate average daily gain (ADG; weight gain/101 days). Diet and ort samples were collected, weighed, and dried daily. Dry matter intake (DMI, kg/animal/day) was the difference between offered DM and orts per pen, divided by animals. Feed efficiency (G:F) was calculated as ADG/DMI.

2.5. Fecal parameters

Fecal samples were collected during two periods: days 58 to 60 and days 78 to 80. Within each period, collection was performed for three consecutive days, always immediately after defecation, at two distinct times per day: 08:00 and 12:00; 10:00 and 16:00; and 14:00 and 18:00, respectively on the first, second, and third day of each period. Fecal pH was determined immediately after collection. Samples were dried, ground, and analyzed for concentrations of NDF, nitrogen, and starch concentrations.

2.6. Chewing behavior

Feeding behavior was visually evaluated on days 47 and 69, starting at 06:00 h, with observations every 5 min over a 24 h (Johnson and Combs, 1991). Oral activities (eating, rumination, and idle) were recorded, and chewing time was defined as eating + rumination. Eating, rumination, and chewing times per unit of DM and NDF were calculated from intake on evaluation days. Particle sorting was also assessed on days 47 and 69 by measuring particle size distribution in the TMR and orts (Silva et al., 2022). Predicted and observed particle intakes were compared, and a sorting index was calculated following Leonardi and Armentano (2003).

2.7. Blood parameters and ultrasonic measurements

Blood samples (10 mL) were collected on the last experimental day after morning feeding by coccygeal puncture into heparin-free sodium Vacutainer tubes. After 30 to180 min of clotting and serum separation, samples were centrifuged (2,500 × *g*, 30 min, 4 °C), transferred to microtubes, and stored at −80 °C. Aspartate aminotransferase (K034; Kinetic AST Transaminase, Bioclin, Belo Horizonte, Brazil) and gamma-glutamyl transferase (K080; Gamma GT, Bioclin) were quantified using commercial colorimetric kits. Intra- and interassay coefficients of variation was 4.11% and 4.87% for aspartate aminotransferase, and 3.9% and 4.2% for gamma-glutamyl transferase. On the last day, ultrasonography was performed on the right side of each animal with an Aloka 500 V (Corometrics Medical Systems, Wallingford, CT, USA) and a 3.5 MHz, 17.2 cm linear probe. Measurements included the *longissimus* muscle area (12th–13th rib, cm^2), subcutaneous fat thickness (mm), rump muscle length (cm), and rump fat thickness (cm). Images were analyzed with ImageJ (v1.52a; NIH, Bethesda, MD, USA).

2.8. Slaughter and sample collection

Heifers were slaughtered at a commercial plant (Supremo Carnes, Campo Belo, MG, Brazil). Carcasses were weighed to determine hot carcass weight (HCW), and dressing percentage was calculated as the ratio of HCW to final BW. The carcass was chilled for 24 h at 2 °C and subcutaneous fat thickness was then measured between the 12th and 13th ribs of the *longissimus thoracis* muscle using digital calipers. Ribeye area was outlined on acetate film and subsequently determined using an LI-3100 area meter (LI-COR Inc., Lincoln, NE, USA).

2.9. Statistical analysis

Data were analyzed in a randomized complete block design using the MIXED procedure of SAS (SAS Inst., Inc., Cary, NC, USA), with pen as the experimental unit. Pens were blocked by initial BW (four blocks). The statistical model included treatment (CPS vs. LPS) as a fixed effect and block as a random effect:

$$y_{(ij)} = \mu + \tau_i + b_j + \varepsilon_{(ij)},$$

in which $y_{(ij)}$ = response variable, μ = overall mean, τ_i = fixed effect of treatment, b_j = random effect of block, and $\varepsilon_{(ij)}$ = residual error. For fecal parameters, collection period (1st and 2nd) and its interaction with treatment were included. Results are presented as least squares means ± SEM. The covariance structure was selected by the lowest Akaike information criterion. Model residuals were assessed for normality using the Shapiro–Wilk test, and homogeneity of variances was verified by visual inspection of residual plots. Statistical significance was declared at P≤0.05, and trends at 0.05 ≤ P ≤ 0.10.

3. Results

Regarding the corn forage at ensiling, particles retained on the 19-mm screen were 9.56 ± 4.6% (CPS) and 35.1 ± 4.8% (LPS; Table 1). Kernel processing scores were 73.9 (CPS) and 72.8% (LPS).

No differences were obtained for initial BW, final BW, ADG, gain: feed ratio, and carcass traits (Table 3). Heifers fed the LPS corn silage showed 5.4% higher DMI (+0.43 kg/d; P = 0.031; Table 3). During ingestive behavior evaluations, LPS-fed animals exhibited 0.4 kg/d higher neutral detergent fiber (NDF) intake (P = 0.006; Table 4). Regardless of the treatment, animals preferentially selected long diet particles (> 8 mm). No significant effects of the treatments were observed on the other feeding behavior parameters (eating time, rumination, and chewing; Table 4).

Similarly, dietary treatments did not influence the blood parameters gamma-glutamyl transferase and aspartate aminotransferase (Table 5).

Heifers fed LPS silage tended (P = 0.052) to have a higher fecal pH (Table 6). Fecal starch concentration was 37.6% higher (P<0.001) during the first collection period (5.75%; days 58-60) compared with the second (3.59%; days 78-80). The opposite pattern was observed for fecal NDF (9.87% vs. 10.2%; P = 0.023).

Table 3 - Performance and carcass traits of beef heifers fed diets containing corn silage with two particle sizes

Item	Treatment		SEM	P-value
	CPS	LPS		
Feedlot performance				
Initial body weight (kg)	250	247	7.64	0.707
Final body weight (kg)	370	371	7.64	0.825
ADG (kg/d)	1.22	1.25	0.04	0.464
DMI (kg/d)	7.55	7.98	0.19	0.031
G:F	0.16	0.16	0.01	0.881
Ultrasonic carcass measurements				
LMA (cm^2)	69.3	69.2	1.65	0.972
SFT (mm)	1.44	1.46	0.11	0.813
RML (cm)	30.9	31.4	0.71	0.451
RF (mm)	2.92	2.68	0.36	0.509
Slaughterhouse carcass measurements				
HCW (kg)	193	193	4.60	0.930
Dressing (%)	52.2	52.0	0.31	0.517
Ribeye area (cm^2)	59.6	58.5	2.05	0.597
Back fat (mm)	4.60	4.44	0.36	0.661

CPS - conventional particle size; LPS - long particle size; LMA - *longissimus* muscle area; SFT - subcutaneous fat thickness of the *longissimus* muscle; RML - rump muscle length; RF - rump fat thickness.

Table 4 - Feeding behavior of beef heifers fed diets containing corn silage with two particle sizes

Item	Treatment		SEM	P-value
	CPS	LPS		
NDFI (kg/d)[1]	2.27	2.67	0.13	0.006
Eating (min/d)	169	169	9.12	0.995
Eating (min/kg of DMI)	18.5	18.7	1.58	0.915
Eating (min/kg of NDF)	75.0	66.8	6.56	0.221
Rumination (min/d)	208	214	19.8	0.767
Rumination (min/kg of DMI)	22.8	22.9	2.52	0.962
Rumination (min/kg of NDF)	92.2	82.3	10.0	0.330
Chewing (min/d)[2]	377	388	24.6	0.676
Chewing (min/kg of DMI)	41.3	41.6	3.66	0.937
Chewing (min/kg of NDF)	167	149	15.1	0.239
Particle sorting, arbitrary units				
> 19 mm	109	108	1.29	0.449
< 19 mm to > 8 mm	109	108	1.19	0.445
< 8 mm to > 4 mm	37.1	30.6	4.24	0.136
< 4 mm	96.1	96.4	0.56	0.606

CPS - conventional particle size; LPS - long particle size.
[1] NDF intake.
[2] Chewing = eating + rumination.

Table 5 - Blood parameters of beef heifers fed diets containing corn silage with two particle sizes

Item	Treatment		SEM	P-value
	CPS	LPS		
Gamma-glutamyl transferase (U/L)	13.1	13.3	0.52	0.754
Aspartate aminotransferase (U/L)	8.4	8.9	0.43	0.316

CPS - conventional particle size; LPS - long particle size.

Table 6 - Fecal traits of beef heifers fed diets containing corn silage with two particle sizes

Item	Collection	Treatment		Mean	SEM	P-value		
		CPS	LPS			Treatment	Collection	Treatment × Collection
Starch (% DM)	Fist	5.66	5.85	5.75	0.178	0.804	<0.0001	0.321
	Second	3.75	3.43	3.59				
	Mean	4.70	4.64		0.251			
pH	Fist	6.26	6.31	6.29	0.028	0.052	0.542	0.520
	Second	6.26	6.36	6.31				
	Mean	6.26	6.34		0.039			
Nitrogen (% DM)	Fist	2.48	2.46	2.47	0.029	0.416	0.945	0.643
	Second	2.50	2.45	2.47				
	Mean	2.49	2.45		0.409			
NDF (% DM)	Fist	9.89	9.84	9.87	0.109	0.173	0.023	0.185
	Second	9.99	10.5	10.2				
	Mean	9.94	10.2		0.154			

CPS - conventional particle size; LPS - long particle size.

4. Discussion

Nutritionally, fiber plays a key role in proper rumen function, supporting animal health and, consequently, performance (Allen, 1997). This occurs through the ability of fiber to maintain acid-base balance in the rumen by stimulating rumination, salivation, and motility (Zebeli et al., 2012). In dairy cows, both eating and rumination times increase when the diet contains larger particle sizes (Kononoff et al., 2003).

In this context, we hypothesized that diets with long particles (> 19 mm) would result in greater chewing activity and improved performance. However, final BW, ADG, feed efficiency (G:F), and carcass traits were not affected by treatments. Similarly, feeding behavior did not differ, with heifers averaging 383 min/d of chewing activity. Thus, finishing diets containing 19.5% corn shredlage with different theoretical lengths of cut (13 or 24 mm) did not alter animal behavior patterns, likely maintaining similar digestive dynamics, which led to the observed performance. The diets had comparable peNDF levels (6.27 ± 0.4% CPS vs. 6.93 ± 0.6% LPS). Given that peNDF is the dietary component responsible for stimulating rumination, salivation, and motility (Mertens, 1997; Zebeli et al., 2012), differences between treatments may have been mitigated. Although particle retention on the 19-mm sieve differed markedly between treatments, the proportion of particles > 8 mm, which contributes to peNDF, was relatively similar across diets, likely due to the low corn silage inclusion in the diet (19.5% DM basis).

In the current study, DMI and NDF intake (measured during feeding behavior evaluation) were 5% and 15%, respectively, higher, for LPS-fed heifers. The greater NDF intake was likely associated with the increased DMI. However, two additional factors may explain these results. First, LPS silage contained a higher proportion of particles >19 mm (35.1% vs. 9.56% in CPS; Table 1). Second, heifers exhibited a preference for long particles regardless of treatment (Table 4). This combination suggests that LPS silage may have facilitated animal recognition of larger, non-uniform particles (>19 mm; Piran Filho et al., 2023), which are known to enable selective feeding (Heinrichs and Jones, 2013). Long particles often contain higher NDF concentrations than the total diet (Leonardi and Armentano, 2003), potentially reducing the energy density of the ingested feed (Gentry et al., 2016; NASEM, 2016) and influencing intake patterns. These results may further explain the tendency toward higher fecal pH in heifers receiving the LPS diet. Greater forage intake relative to concentrate limits the flow of highly fermentable carbohydrates to the intestines (Trotta et al., 2021), reducing the extent of fermentation and subsequent fecal acidification (Owens et al., 2016).

With respect to fecal characteristics, starch concentration declined from the first to the second collection in both treatments, while fecal pH remained unchanged across the sampling periods. Cordeiro et al. (2024) also assessed two sampling periods during the feedlot phase and observed results opposite to those of the present study, with fecal starch concentrations increasing and fecal pH decreasing over time. Because fecal starch is inversely related to starch digestibility (Zinn et al., 2007), these results suggest that the gastrointestinal tract may either lose or enhance its ability to digest starch over the course of the feedlot period. Plaizier et al. (2022) noted that the rumen, in particular, requires a period of microbial and epithelial adaptation to optimize nutrient digestion and absorption under high-starch feeding conditions. Nevertheless, in this study, the first sampling occurred after 58 d on feed, which is generally considered ample time for the gastrointestinal tract to adapt to the diet.

Overall, although the diets did not affect heifer performance, the LPS diet is recommended due to the increased DM and NDF intake without compromising the gain-to-feed ratio. Importantly, increasing particle size from 13 mm to 24 mm does not incur additional costs, and the kernel processing score remained high.

5. Conclusions

Feeding long particle size corn shredlage (24 mm) in finishing diets increased dry matter intake by 5% without compromising feed efficiency. However, long particle size did not significantly influence chewing activity, daily gain, or carcass traits in finishing beef heifers.

Data availability

All data are available in the manuscript.

Author contributions

Conceptualization: Bernardes, T. F. **Data curation:** Costa, G. F.; Dias Júnior, W. C.; Domingues, E. H. R.; Cordeiro, M. W. S. and Bernardes, T. F. **Formal analysis:** Dias Júnior, W. C.; Domingues, E. H. R.; Cordeiro, M. W. S. and Bernardes, T. F. **Funding acquisition:** Bernardes, T. F. **Investigation:** Costa, G. F.; Dias Júnior, W. C.; Domingues, E. H. R. and Bernardes, T. F. **Project administration:** Bernardes, T. F. **Supervision:** Bernardes, T. F. **Writing – original draft:** Costa, G. F.; Dias Júnior, W. C.; Domingues, E. H. R.; Cordeiro, M. W. S. and Bernardes, T. F. **Writing – review & editing:** Costa, G. F.; Dias Júnior, W. C.; Domingues, E. H. R.; Cordeiro, M. W. S. and Bernardes, T. F.

Conflict of interest

The authors declare no conflict of interest.

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