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Performance, costs, and blood indicators of dairy calves fed diets containing soybean hull and whole or ground corn

Aline Evangelista Machado Santana[1]*, Vera Lúcia de Araújo Bozorg[1], João Restle[2], Fabrícia Rocha Chaves Miotto[1], Luciano Fernandes Sousa[1], Tays Raniellen Miranda Feitosa[1], Ithálo Barros de Freitas[1], José Neuman Miranda Neiva[1]

[1] Universidade Federal do Tocantins, Escola de Medicina Veterinária e Zootecnia, Araguaína, TO, Brasil.
[2] Universidade Federal de Goiás, Departamento de Zootecnia, Goiânia, GO, Brasil.

***Corresponding author:**
aline1machado@uft.edu.br

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ABSTRACT - The objective of this study was to assess the effects of high-concentrate diets with and without the inclusion of soybean hull (SH; 0 or 500.8 g/kg) plus corn (whole or ground) on the performance, morphometric traits, and nutritional and metabolic parameters of crossbred dairy calves. We also aimed to assess the costs associated with the experimental diets employed. Thirty-six male calves with an average weight of 89±18.6 kg and age of 3.5 months were allocated to four treatments, with nine replicates of one calf/pen, in a completely randomized experimental design for 198 days. The inclusion of the SH and the physical form of corn did not influence animal performance or morphometric measurements; however, SH inclusion increased the digestibility of neutral detergent fiber and the intakes of dry matter and neutral detergent fiber, but did not affect total digestible nutrient intake. The physical form of corn did not influence nutrient intake or digestibility, which resulted in similar performance across the animals. Blood glucose levels as well as alkaline phosphatase and creatinine remained elevated regardless of the diet. The use of SH reduced the total plasma cholesterol content, and there was an interaction between the physical form of corn and SH inclusion in relation to creatinine levels, which were higher when using diets with whole corn and SH. Although the inclusion of up to 500.8 g/kg of SH in the diet reduces feed efficiency, its use decreases the cost per kilogram of weight gain. Dairy calves can exhibit satisfactory production performance when fed alternative ingredients such as whole corn or SH, which have a lower cost than ground corn, traditionally used in diet formulations.

Keywords: byproduct, digestibility, feedlot, glucose, high-concentrate diets, production cost

1. Introduction

The intensification of animal production has enabled the provision of forage-free diets to ruminants. These diets are distinguished by their high energy content that has the potential to reduce the age at which animals are slaughtered and enhance the productivity of dairy calves. However, adverse climatic conditions, instances of political conflicts, and the implementation of governmental biofuel policies exert significant impacts on global commodity prices (Popp et al., 2016; Esfandabadi et al., 2022) and the availability of grains for animal feed. This, in turn, could render animal production economically unviable. Consequently, the development of alternative production strategies that mitigate the rising input costs becomes imperative. A reduction in the extent of feed processing and the use of agroindustrial byproducts, such as soybean hulls (SH), becomes essential. Notably, these products have a lower price than ground corn, the conventional ingredient used in animal feed.

Studies have highlighted the favorable impacts of these ingredients (Anderson et al., 2009; Ferreira et al., 2011a; Corazzin et al., 2012; Caetano et al., 2015; Maia Filho et al., 2016; Poczynek et al., 2020; Santana et al., 2023; Valeriano et al., 2023), not only in terms of their positive effects on animal performance, but also in promoting sustainable production (Agarwal and Sharma, 2020).

The distinctive physical attributes and chemical composition of SH and whole corn offer several advantages in animal production, for facilitating the formulation of forage-free diets, leading to reductions in labor costs and favorable alterations in rumen fermentation (Owens, 2005), enhancing animal performance (Ferreira et al., 2011a). Nevertheless, to increase the production efficiency of young cattle, a careful investigation of the efficacy of dietary changes is warranted, as their inclusion in the diet may reduce dietary digestibility in some cases (NRC, 2001).

Our hypothesis posits that SH and whole corn represent substantial alternative sources of energy, capable of replacing ground corn in high-concentrate diets for dairy calves, based on the distinctive physical characteristics (particle size – whole corn) and chemical composition (neutral detergent fiber [NDF] content – SH) of these ingredients. Hence, our objective was to assess the performance, digestibility, blood indicators, and costs associated with diets incorporating whole corn and SH as substitutes for ground corn in the feeding regimen of dairy calves.

2. Material and Methods

The experiment was carried out in an experimental farm located in Araguaína, TO, Brazil (07°11'28" S latitude and 48°12'26" W longitude). The research on animals was conducted according to the Institutional Committee on Animal Use (protocol number 23101.004142/2015-06).

Thirty-six crossbred bull calves (Holstein × Zebu) were used. From birth to the beginning of the experiment, the animals were fed 4 L of milk per day and received concentrate feed at will (feed with 837.27 g/kg total digestive nutrients [TDN] and 175.7 g/kg crude protein [CP]). All calves were weaned at 60 days of age. After weaning, the animals exclusively fed concentrated feed. The experiment began when the animals completed 3.5 months of age, with an initial mean weight of 89±18.6 kg. The confinement period was 198 days, consisting of 21 days of adaptation and 177 days of experimentation.

The animals were treated for endo- and ectoparasites using Abamectin 1%, and received injectable vitamins A, D, and E in variable amounts according to their weight. The dairy calves were identified with earrings and were housed in individual 7.6-m^2 covered stalls with concrete floors with access to a dirt paddock that contained individual feeders and drinkers for each two animals.

The experiment was conducted using a completely randomized design with treatments distributed in a 2 × 2 factorial arrangement, with nine repetitions per treatment. The two factors examined were the SH inclusion levels: 0 (NSH) or 500.8 g of soybean hull/kg of dry matter [DM] (WSH), and the physical forms of corn: whole corn (WC) or ground corn (GC).

During the experimental period, the animals were exclusively fed isonitrogen in concentrate containing whole or ground corn, soybean hull, and the commercial base mix Engordin Whole Grain (Agrocria Nutrição Animal e Sementes, Anápolis, Goiás, Brazil) in the form of pellets (Table 1). The diets were provided once a day at 08:00 h (Table 2) and adjusted to allow for 5% leftovers. The quantity supplied and the orts from each animal were recorded daily to estimate the DM and nutrient intakes, while feed and concentrate samples were collected during the preparation of diets. The animals had access to fresh water *ad libitum*.

Table 1 - Chemical composition of feedstuffs used to formulate the concentrates

Variable (g/kg DM)	Corn	Engordin[1]	Soybean hulls
Dry matter (g/kg NM)	833.4	885.8	861.3
Ash	11.2	197.1	45.2
Neutral detergent fiber	107.3	207.5	740.1
Hemicellulose	90.8	61.7	384.5
Acid detergent fiber	16.5	145.8	355.6
Cellulose	2.2	126.0	301.7
Lignin	14.3	19.8	53.9
Ether extract	37.0	23.8	10.8
Crude protein	90.1	386.2	127.5
NDIN (g/kg total N)	104.0	67.0	428.5
ADIN (g/kg total N)	47.3	25.7	143.8
Non-fibrous carbohydrates	754.4	129.3	76.4
Total carbohydrates	861.7	336.8	816.5

DM - dry matter; NM - natural matter; NDIN - neutral detergent insoluble nitrogen; ADIN - acid detergent insoluble nitrogen.
[1] Engordin whole grain: pelletized protein, mineral, and vitamin supplement (Agrocria Nutrition Animal) - guaranteed levels: Ca, 43 g/kg; P, 10 g/kg; S, 4 g/kg; Mg, 0.7 g/kg; K, 2.7 g/kg; Na, 9.7 g/kg; Co, 5 mg/kg; Cu, 175 mg/kg; Cr, 1.4 mg/kg; F, 130 mg/kg; I, 5 mg/kg; Mn, 182 mg/kg; Mo, 0.35 mg/kg; Ni, 0.3 mg/kg; Se, 1.8 mg/kg; Zn, 421 mg/kg; vitamin A, 21,000 IU; vitamin D, 3000 IU; vitamin E, 140 IU; monensin sodium, 150 mg/kg; virginiamycin, 150 mg/kg.

Table 2 - Proportion of ingredients and chemical composition of the experimental diets

Item	Ground corn		Whole corn	
	NSH	WSH	NSH	WSH
Ingredient (g/kg DM)				
Whole corn	-	-	758.6	333.8
Ground corn	758.6	333.8	-	-
Soybean hull	-	500.8	-	500.8
Engordin	241.4	165.4	241.4	165.4
Chemical composition (g/kg DM)				
Dry matter (g/kg NM)	852.5	847.5	847.9	855.2
Ash	64.5	63.3	56.1	62.4
Neutral detergent fiber	131.5	440.8	132.7	441.5
Hemicellulose	84.7	238.4	85.0	242.5
Acid detergent fiber	46.8	202.4	47.7	199.0
Cellulose	31.7	167.4	30.9	164.2
Lignin	15.1	35.0	16.8	34.8
Ether extract	33.8	21.7	34.3	22.0
Crude protein	163.5	162.9	163.8	163.0
NDIN (g/kg total N)	95.1	261.1	94.9	261.4
ADIN (g/kg total N)	42.1	91.7	42.1	91.4
Non-fibrous carbohydrates	595.1	300.5	602.7	292.6
Total carbohydrates	726.6	741.3	735.4	736.1

NSH - no soybean hull; WSH - with soybean hull; NDIN - neutral detergent insoluble nitrogen; ADIN - acid detergent insoluble nitrogen.

Animals were weighed individually in the morning, without previous fasting, at the beginning (after the 21 days of adaptation) and end of the experimental period (after 198 days of confinement). These were considered the initial and final weights, respectively, which were used to determine the average daily gain (ADG; kg/d), calculated as follows:

$$\text{ADG} = (\text{Final body weight} - \text{Initial body weight})/177 \text{ days} \quad (1)$$

During these weighing events, the following morphometric measurements were recorded: withers height (measured as the vertical distance from the thoracic vertebrae to the ground); rump height (measured as the vertical distance from the anterior region of the sacrum to the ground); heart girth (measured by following the contour of the chest, looping the tape behind the foreleg and then extending it perpendicularly to the line of the back); arm circumference (measured at the midpoint of the anterior arm, specifically at its narrowest point); and body length (measured from humerus joint to ilio-ischial joint). These measurements were always performed on the left side of the animals while the young bulls were standing. A horse-measuring cane and a measuring tape graduated in centimeters were employed, with an adaptation to the methodology proposed by Schramme (2003).

Concentrate and feed samples were collected weekly and frozen (−20 °C). The samples were homogenized to form composite samples, for each period of 28 days, and subsequently dried in a forced-ventilation oven at 55 °C for 72 h. The samples were ground in a Wiley-type mill™ (Thomas Scientific®) fitted with a 1-mm-sieve and stored in a plastic container for subsequent determination DM (oven-drying at 105 °C until no further weight loss - Method 930.15; AOAC, 2000), crude protein (Method 984.13; AOAC, 2000), and ash (Method 942.05; AOAC, 2000).

The levels of NDF, acid detergent fiber (ADF), and lignin were determined as described by Van Soest et al. (1991) and by Mertens (2002). Ether extract (EE) was determined by washing with petroleum ether at 90 °C for 1 h (Ankom, 2009). The non-fibrous carbohydrates (NFC) content was estimated based on the method described by Mertens (1997), and the total carbohydrates (TC) and TDN values were calculated as per Sniffen et al. (1992), as follows:

$$\text{NFC} = 100 - (\text{NDF\%} + \text{EE\%} + \text{CP\%} + \text{Ash\%}) \quad (2)$$

$$\text{TC} = 100 - (\text{CP\%} + \text{EE\%} + \text{Ash\%}) \quad (3)$$

$$\text{Observed TDN} = \text{CPD} + (\text{EED} \times 2.25) + \text{TCD} \quad (4)$$

in which CPD = crude protein apparent digestibility, EED = ether extract apparent digestibility, and TCD = total carbohydrates digestibility.

Based on the analyses performed, the intakes of DM (DMI), CP (CPI), ether extract (EEI), NDF (NDFI), NFC (NFCI), and TDN (TDNI) were determined considering the amount of nutrient consumed per day during the experimental evaluation, and expressed in kg/d and/or g/kg of live weight. These data were later used to calculate the conversion efficiencies of DM (DME), in kg ADG/kg DM intake; CP (CPE), in kg ADG/kg CP intake; and TDN (TDNE), in kg ADG/kg TDN intake.

At the 160th-day mark following the commencement of the experiment, samples of feed, leftovers, and feces were collected to determine the apparent total-tract digestibility of the diets. These were collected after the animals were given titanium dioxide (as a marker substance), which had been supplied for 10 days (10 g/day), before the beginning of collections, in paper cartridges wrapped in leaf grass. Fecal grab samples from each animal were collected on four consecutive days directly from the rectum (at 08:00 h on the first day; at 11:00 h on the second day; at 14:00 h on the third day; and 17:00 h on the fourth day).

These samples were dried in a forced-ventilation oven at 55 °C for 72 h, followed by grinding in a knife mill and sieving through a 2-mm sieve. These processed samples were then used to determine the total fecal production by the method described by Detmann et al. (2012). The apparent digestibility (AD) of DM and nutrients within the diet were calculated using the following equations:

$$\text{Fecal output (g/day)} = \text{Marker supply (g/day)}/\text{Marker concentration in feces (g/g DM)} \quad (5)$$

$$\text{AD (kg/kg)} = 1 - (\text{Ingested nutrient (kg)} - \text{Excreted nutrient (kg)})/\text{Ingested nutrient (kg)} \quad (6)$$

At the end of the experimental period, 10-mL blood samples were collected via jugular vein puncture in the morning without prior fasting, using vacuum tubes (Labtest Diagnóstica SA, Lagoa Santa, MG, Brazil). For blood glucose level determination, samples were collected in tubes containing 10 µL of sodium fluoride, while other analyses involved 10 µL of EDTA as an anticoagulant. The samples were then sent to the laboratory, where they underwent centrifugation at 2000 × *g* for 15 min at 37 °C, to separate plasma and serum. These aliquots were placed in labeled Eppendorf® tubes and frozen at −20 °C for subsequent analysis of glucose, triglycerides, total cholesterol, total protein, albumin, urea, aspartate aminotransferase (AST), alkaline phosphatase (ALP), and creatinine, performed at 37 °C using commercial kits from Labtest Diagnostica SA (Lagoa Santa, MG, Brazil) (test reference numbers: 84, 87, 76, 99, 19, 104, 109, 79, and 96, respectively). Readings were conducted using a spectrophotometer (Bioplus® model Bio-2000 IL-A).

To assess the costs associated with different diets, information was collected on the per-kilogram cost of each food item used in generating the concentrates during the experimental evaluation period. This data collection coincided with a time when the exchange rate was 1 US dollar (USD) to 2.329 Brazilian Reais (BRL). Using this information, we calculated the cost per kilogram of diet (CKD), the daily cost of feeding (CFD), and the cost per kilogram of gain (CKG):

$$CFD = CKD \times DMI/d \quad (7)$$

$$CKG = CFD/ADG \quad (8)$$

The gathered data underwent homoscedasticity and normality tests. For all continuous variables with a normal distribution, analysis of variance was performed using SAS software (Statistical Analysis System, version 9.1). The initial weight was employed as a covariate, and when its significance was not established, it was excluded from the model. The mathematical model utilized was as follows:

$$\gamma ijk = \mu + Ꚍi + £j + (Ꚍ£)ij + (\delta)k + \varepsilon ijk \quad (9)$$

in which γijk = dependent variable, μ = overall mean, Ꚍi = effect of factor *i* (SH inclusion level), £j = effect of factor *j* (corn physical form), (Ꚍ£)ij = interaction effect between factor *i* and factor *j*, (δ)k = effect of initial weight, and εijk = residual experimental error associated with the factorial SH inclusion level and corn physical form. When the interaction of the studied factors was not significant (i.e., above 5% significance), a t-test at the 5% significance level was employed to compare means.

3. Results

There was an interaction effect between SH inclusion and the physical form of corn grain on CPI (P = 0.04) (Table 3). Specifically, the provision of whole corn without soybean hull led to a reduction in CPI compared with the other evaluated diets. Similarly, an interaction effect surfaced between the physical form of corn and the SH inclusion level for NFCI (P = 0.04). In this context, animals fed WC combined with SH exhibited lower NFCI than those consuming the other experimental diets.

The use of SH reduced EEI but increased DMI and NDFI (P<0.01), in contrast with diets in which corn served as the primary energy source. The only variable unaffected by the physical form of corn or SH inclusion in the diet was TDNI (P>0.05), which averaged 4.37 kg/day.

Table 3 - Nutrient intake of very young bulls fed experimental diets

Variable (kg/d)	Ground corn		Whole corn		CV (%)	P-value		
	NSH	WSH	NSH	WSH		PF	SH	PF × SH
DMI	5.14b	6.03a	4.70b	5.86a	15.99	0.29	<0.01	0.66
DMI (g/kg LW)	24.25b	27.52a	23.37b	27.76a	8.72	0.48	<0.01	0.26
NDFI	0.96b	2.78a	0.63b	2.96a	19.65	0.53	<0.01	0.05
CPI	1.22a	1.25a	0.96b	1.25a	16.65	0.04	0.01	0.04
EEI	0.21a	0.16b	0.19a	0.16b	15.38	0.48	<0.01	0.47
NFCI	2.36a	1.40b	2.66a	1.07b	15.93	0.90	<0.01	<0.01
TDNI	4.36	4.60	3.99	4.52	15.62	0.32	0.10	0.53

NSH - no soybean hull; WSH - with soybean hull; CV - coefficient of variation; PF - physical form; DMI - dry matter intake; LW - live weight; NDFI - neutral detergent fiber intake; CPI - crude protein intake; EEI - ether extract intake; NFCI - non-fibrous carbohydrates intake; TDNI - total digestible nutrient intake.
Means followed by different letters within the same factor differ by the t test (P<0.05).

No interaction manifested between the physical form of corn and SH inclusion in the diet with respect to the apparent digestibility of the evaluated nutrients (Table 4). In addition, when these factors were evaluated independently, only SH inclusion influenced variables linked to diet digestibility. The incorporation of this byproduct increased the digestibility of NDF (NDFD) (P<0.01), despite a decrease in the amount of digestible nutrients available for animal utilization (TDN) (P<0.01). Only the apparent digestibility coefficients of DM, CP, EE, and NFC remained unaffected by the evaluated factors (P>0.05), with respective mean values of 0.80, 0.81, 0.75, and 0.87.

The inclusion of SH and the physical form of corn had no discernible impact on final weight (328 kg), total weight gain (243.56 kg), or ADG (1.35 kg/d) (P>0.05) (Table 5). Conversely, DME results were influenced by the SH inclusion level, which led to a reduction in the efficiency of DM utilization (P<0.01) compared with diets in which corn was the sole energy source.

Another interaction effect was observed between the physical form of corn and SH inclusion level for CPE (P<0.01). In this case, the provision of WC without soybean hull increased the efficiency of CP utilization in comparison with the other evaluated diets. Regarding nutrient utilization efficiency, only TDNE remained unaffected by the evaluated factors (P>0.05), maintaining an average of 0.31 kg ADF/kg TDN consumed.

Changing the physical form of corn had no impact on any of the analyzed blood indicators (Table 6) (P>0.05). However, the use of SH altered the total plasma cholesterol content, as the animals receiving diets containing SH exhibited a total cholesterol level 29.72% higher than that of the calves that were fed diets without SH (64.86 and 45.58 mg/dL, respectively).

Table 4 - Apparent digestibility coefficients and total digestible nutrient (TDN) values of the diets

Variable (kg/kg)	Ground corn		Whole corn		CV (%)	P-value		
	NSH	WSH	NSH	WSH		PF	SH	PF × SH
DMAD	0.80	0.81	0.79	0.80	3.73	0.82	0.58	0.47
NDFD	0.53b	0.64a	0.66b	0.72a	3.41	0.81	<0.01	0.85
CPAD	0.80	0.81	0.82	0.81	3.16	0.93	0.90	0.41
EEAD	0.75	0.74	0.76	0.75	4.32	0.57	0.73	0.76
NFCD	0.88	0.87	0.88	0.87	2.49	0.60	0.41	0.99
TDN (g/kg)	848.90a	763.70b	849.00a	771.30b	2.01	0.34	<0.01	0.36

NSH - no soybean hull; WSH - with soybean hull; CV - coefficient of variation; PF - physical form; DMAD - dry matter apparent digestibility; NDFD - neutral detergent fiber digestibility; CPAD - crude protein apparent digestibility; EEAD - ether extract apparent digestibility; NFCD - non-fibrous carbohydrate digestibility.
Means followed by different letters within the same factor differ by the t test (P<0.05).

Table 5 - Performance of very young bulls fed experimental diets

Variable	Ground corn		Whole corn		CV (%)	P-value		
	NSH	WSH	NSH	WSH		PF	SH	PF × SH
IW (kg)	88.39	92.89	85.00	89.72	22.79	0.63	0.50	0.98
FW (kg)	324.78	341.67	316.33	329.22	37.78	0.41	0.25	0.87
TWG (kg)	247.11	252.39	232.06	242.67	11.26	0.18	0.39	0.77
ADG (kg/d)	1.33	1.40	1.30	1.35	11.5	0.44	0.27	0.82
DME (kg/kg)	0.26a	0.24b	0.28a	0.23b	12.72	0.62	<0.01	0.32
CPE (kg/kg)	1.10b	1.14b	1.36a	1.08b	12.65	0.06	0.02	<0.01
TDNE (kg/kg)	0.31	0.30	0.32	0.30	12.22	0.71	0.42	0.34

NSH - no soybean hull; WSH - with soybean hull; CV - coefficient of variation; PF - physical form; IW - initial live weight; FW - final live weight; TWG - total weight gain; ADG - average daily gain; DME - dry matter conversion efficiency; CPE - crude protein conversion efficiency; TDNE - total digestible nutrient conversion efficiency.
Means followed by different letters within the same factor differ by the t test (P<0.05).

Furthermore, an interaction effect was observed between the physical form of corn and the SH inclusion level (P = 0.02) in relation to creatinine levels. When GC was provided, the results appeared to be unaffected by the inclusion of SH. However, when WC was supplied (whole corn and soybean hull), the presence of SH led to an elevation in blood creatinine levels.

For the remaining variables associated with blood biochemical indicators, there were no apparent interaction effects between the analyzed factors. The mean values observed were as follows: glucose, 103.2 mg/dL; triglycerides, 27.61 mg/dL; total protein, 6.55 g/dL; albumin, 2.77 g/dL; urea, 21.98 mg/dL; AST, 177.75 U/L; and ALP, 147.26 U/L.

The treatments did not affect (P>0.05) morphometric measurements (Table 7). The daily feeding cost (Table 8) remained unaffected by the incorporation of SH (P>0.05). Nonetheless, when considering ADG for determining costs (cost per kilogram of diet), a decrease in expenses was noted with the addition of the byproduct (P = 0.03). Conversely, altering the physical form of corn did not appear to be a determining factor in changing feeding costs.

Table 6 - Biochemical indicators in the blood of very young bulls fed experimental diets

Variable	Ground corn		Whole corn		CV (%)	P-value		
	NSH	WSH	NSH	WSH		PF	SH	PF × SH
GL (mg/dL)	99.22	104.33	102.67	106.56	21.41	0.37	0.55	0.56
TCL (mg/dL)	47.94b	65.94a	43.22b	63.78a	36.09	0.98	<0.01	0.07
TG (mg/dL)	26.89	26.89	26.22	30.44	32.00	0.88	0.56	0.81
TP (g/dL)	6.60	6.21	6.53	6.86	19.66	0.26	0.37	0.10
ALB (g/dL)	2.61	2.83	2.79	2.85	23.19	0.57	0.58	0.66
UR (mg/dL)	21.44	24.11	22.28	20.11	39.69	0.69	0.85	0.32
AST (U/L)	94.50	168.83	91.28	116.39	53.74	0.56	0.06	0.56
ALP (U/L)	140.56	178.61	144.61	125.28	29.80	0.07	0.45	0.29
CRT (mg/dL)	2.40b	2.14b	2.22b	3.20a	31.54	0.31	0.25	0.02

NSH - no soybean hull; WSH - with soybean hull; CV - coefficient of variation; PF - physical form; GL - glucose; TCL - total cholesterol; TG - triglycerides; TP - total protein; ALB - albumin; UR - urea; AST - aspartate aminotransferase; ALP - alkaline phosphatase; CRT - creatinine.
Means followed by different letters within the same factor differ by the t test (P<0.05).

Table 7 - Morphometric measurements of very young bulls fed experimental diets

Variable (cm)	Ground corn		Whole corn		CV (%)	P-value		
	NSH	WSH	NSH	WSH		PF	SH	PF × SH
IWH	91.33	88.56	89.06	89.06	6.69	0.66	0.49	0.49
IRH	96.39	94.44	92.44	93.61	6.97	0.28	0.86	0.48
IAC	13.28	12.94	12.50	12.83	7.67	0.19	1.00	0.32
IBL	81.44	79.11	77.44	78.17	8.94	0.31	0.74	0.52
IHG	106.17	102.89	102.28	105.28	8.34	0.79	0.96	0.29
WHG	30.33	30.22	29.39	32.61	15.81	0.66	0.35	0.31
RHG	30.39	32.22	31.61	31.94	12.36	0.72	0.41	0.57
ACG	5.94	5.94	6.06	6.28	13.92	0.44	0.69	0.69
BLG	34.22	35.78	36.89	40.61	16.27	0.07	19.64	0.59
HGG	51.17	57.00	52.17	50.61	12.36	0.72	0.41	0.57
FWH	121.67	118.78	118.44	121.67	4.85	0.93	0.92	0.13
FRH	126.78	126.67	124.06	125.56	4.03	0.26	0.68	0.64
FAC	19.22	18.89	18.56	19.11	3.91	0.38	0.66	0.08
FBL	115.67	114.89	114.33	118.78	5.66	0.56	0.41	0.24
FHG	157.33	159.89	154.44	155.89	4.42	0.15	0.39	0.82

NSH - no soybean hull; WSH - with soybean hull; PF - physical form; CV - coefficient of variation; IWH - initial withers height; IRH - initial rump height; IAC - initial arm circumference; IBL - initial body length; IHG - initial heart girth; WHG - withers height gain; RHG - rump height gain; ACG - arm circumference gain; BLG - body length gain; HGG - heart girth gain; FWH - final wither height; FRH - final rump height; FAC - final arm circumference; FBL - final body length; FHG - final heart girth.

Table 8 - Costs associated with the feeding of very young bulls fed experimental diets[1]

Variable	Ground corn		Whole corn		CV (%)	P-value		
	NSH	WSH	NSH	WSH		PF	SH	PF × SH
CKD (USD/kg DM)	0.41	0.33	0.39	0.32	-	-	-	-
CFD[2] (USD/d)	2.09	1.97	1.86	1.87	15.64	0.12	0.49	0.48
CKG[3] (USD/kg)	1.58a	1.40b	1.45a	1.38b	12.75	0.29	0.03	0.33

NSH - no soybean hull; WSH - with soybean hull; PF - physical form; CV - coefficient of variation.
[1] Price quotation (in US dollars) performed during the experimental period: ground corn - USD 0.22/kg; whole corn - USD 0.20/kg; soybean hull - USD 0.16/kg; and Engordin Whole Grain - USD 0.79/kg DM.
[2] Cost of feeding per day = (CKD × DMI), in which CKD = cost per kilogram of diet in United States dollars per kilogram of dry matter and DMI = dry matter intake.
[3] Cost per kilogram of gain = (CFD/ADG), in which ADG = average daily gain.
Means followed by different letters within the same factor differ by the t-test (P<0.05).

4. Discussion

The findings observed in this study align with the work of Forbes (1995), in which the authors established that, when particle size is not constraining, DMI is influenced by the energy needs of the animal and shows a positive correlation with the percentage of NDF in the diet (Waldo, 1986). This concept is reinforced by the DMI observed in animals fed the SH diets. Despite the high fiber content of this diet, which resulted in reduced energy content (767.5 and 848.95 g/kg of TDN, respectively), its small particle size facilitated the increased DMI and a consistent TDNI across all treatments.

Similar TDN intake was also observed in a study conducted by Poczynek et al. (2020) involving Holstein calves. The authors attributed this result to the high digestibility of NDF in SH and their low lignin content since they also observed an increase in NDFI.

This similar energy intake yielded comparable morphometric development across animals, despite the different diets evaluated. This resulted in the formation of uniform groups of animals, leading to significant body gains as evident from the comparison of measurements taken at the beginning and end of the experimental period.

Aside from having a lower TDN value than corn, SH also exhibits a low EE content (10.80 g/kg DM), which contributed to reduced EE intake of the animals fed SH diets. These results mirror those seen in animals fed solely forage diets (Costa et al., 2012). Thus, soybean hulls might offer an alternative for studying diets incorporating additional lipid sources (Ludden et al., 1995), as they have a similar EE content to forage feedstuffs and enhance practicality in diet manipulation due to their concentrate nature.

Although earlier studies have indicated that CPI remains constant when whole grains are used in diet preparation (Gorocica-Buenfil and Loerch, 2005; Caetano et al., 2015; Santana et al., 2015; Santana et al., 2023), the reduction in CPI observed with the WC-no-SH diet could be due to animals favoring corn over the base mix used for diet preparation, leading to leftovers rich in protein.

In addition, since the efficiency of CP utilization represents the relationship between the intake of this nutrient and weight gain, the decrease in CPI without a corresponding change in weight gain led to an increase in CP utilization efficiency for animals on the WC-no-SH diet, consistent with previous research showing a negative correlation between CPI and CPE (r = −0.9603; Santana et al., 2015).

These results were not observed in the WC-SH diet. The inclusion of SH led to a dilution of corn in the diet, diminishing selection by the animals and rendering CPI in this diet akin to those with GC. Additionally, soybean hulls have higher CP content than corn (NRC, 2001), causing intake of SH diets to result in greater CPI compared with intake of corn kernels (Fieser and Vanzant, 2004; Ferreira et al., 2011b).

Furthermore, SH diets featured elevated NDF but reduced NFC content, favoring increased NDF intake and decreased NFC intake in the SH diets versus no SH diets. This trend aligns with common findings in the literature when SH replaces concentrate energy sources (Galloway et al., 1993; Richards et al., 2006). Consequently, SH has been explored as a substitute for forage feed sources (Costa et al., 2012; Cannas et al., 2013; Rezende et al., 2018; Poczynek et al., 2020) in ruminant diets or in studies evaluating the importance of fiber inclusion in diets for monogastric animals (Oh et al., 2020).

Given that SH includes a high-quality structural carbohydrate (pectin) in its composition (Van Soest, 1994), its use in forage-free diets is considered advantageous as it mitigates the risk of metabolic diseases linked to the rapid fermentation of high NFC levels (Cannas et al., 2013).

The advantageous impact of SH on the rumen environment becomes more apparent when assessing diet digestibility, as evidenced by the 15.25% increase in NDF digestibility observed in WSH diets (Table 5). This enhancement signifies a more stable rumen environment, attributed to increased activity of cellulolytic bacteria, responsible for digesting the fibrous component of the diet. These bacteria are sensitive to ruminal pH reductions (Russel, 1987; Russel and Wilson, 1996), and the heightened NDFD suggests augmented bacterial activity.

In addition, the low content of lignin in SH—the main cell wall component limiting rumen structural carbohydrate digestion (Van Soest, 1994)—favored its rumen digestion, contributing to increased NDFD. This contrasts with diets high in corn grain, which often face associative negative effects due to high lignin content (Hoover, 1986). This trend aligns with the study by Rezende et al. (2018), which revealed augmented NDFD upon completely replacing corn with SH in steer diets. The researchers attributed this to the fiber characteristics and improved rumination observed in SH-fed animals.

The uniform digestibility results, irrespective of the physical form of corn, stem from the ability of animals to break down kernels during ingestion and rumination. Nutrients within the kernel are only released when the grain cuticle is ruptured (Kotarski et al., 1992), corroborating literature data in which DM digestibility does not significantly vary between whole and ground corn diets (Gorocica-Buenfil and Loerch, 2005; Owens, 2005; Kang et al., 2021).

Conversely, SH use led to a 9.58% TDN reduction in diets. This is due to the low NFC content of SH, which includes vital gluconeogenic precursors and represents the highest energy fraction of ruminant diets (Van Soest, 1994). However, increased DMI led to equivalent TDNI results, a pivotal factor for the consistent weight gain observed. Animals gain weight when tissue nutrient availability is sufficient, which was achieved in diets evaluated in the present study. Similar weight gain has been found in different animal categories (Gorocica-Buenfil and Loerch, 2005; Marques et al., 2016; Poczynek et al., 2020), attributed to uniform energy intake across the animals.

However, the increased DMI negatively influenced DME, necessitating greater feed intake to maintain the same weight gain as that achieved with the diets with no SH. This underscores the need to consider economic viability when using feeds like SH. According to Ezequiel et al. (2006), assessing byproduct availability and market value in the region is crucial alongside its weight gain potential.

Taking the feeding-associated costs into account, the differences in prices resulting from the use of SH or WC were insufficient to significantly alter feeding costs. Whole corn was priced at USD 0.20/kg, GC at USD 0.22/kg, and SH at USD 0.16/kg. A lower cost per kilogram of WC and SH relative to GC is necessary to effectively lower the cost of daily feeding. Nevertheless, despite the limited effect of SH on CFD, its use reduced the cost per kilogram of gain. This change could potentially augment the profit margin (Zambom et al., 2013), as it introduces a distinctive factor that enhances the economic efficiency of this animal production.

Regarding blood indicators, while no impact on glucose levels was evident, glucose values exceeded standard levels for the animal category. According to Fagliari et al. (1998), Holstein male bulls aged 180 to 360 days should have glucose levels ranging from 53.76 to 75.24 mg/dL. In this study, the mean results reached 103 mg/dL, surpassing the maximum standard stated by these authors by 37%. This glucose elevation relative to the findings of Fagliari et al. (1998) stems from the 100% concentrate diet offered to the experimental animals, in contrast to the study by Fagliari et al. (1998), in which animals were given *Brachiaria decumbens* grass and mineral supplementation.

López and Stumpf Junior (2000) affirmed that diets rich in non-structural carbohydrates, such as those examined in this study, lead to elevated serum glucose concentrations primarily due to hepatic synthesis from propionic acid (Journet et al., 1995; Martineau et al., 2007), accounting for around 65% of circulating glucose in ruminants (Herdt, 2000).

Although SH exhibited an effect on total cholesterol levels, both these results and triglyceride levels remained within the normal range for the animals studied (46.32–79.73 mg/dL and 23.36–34.5 mg/dL, respectively; Pogliani and Birgel Junior, 2007). Similarly, the plasma concentrations of total protein, albumin, and urea fell within the established range for cattle (Fagliari et al., 1998; Meyer and Marvey, 1998). This indicates that protein supply through animal feeding satisfied their requirements without excesses, given that ruminal ammonia production highly correlates with plasma urea concentration (Kennedy and Milligan, 1980).

The AST and ALP levels exceeded normal values for the animal category (26.8– 48.6 U/L AST and 77.41–129.31 U/L ALP; Fagliari et al., 1998), suggesting potential hepatocyte membrane rupture. This condition increases membrane permeability and leads to altered hepatic activity (Kaneko et al., 1997; Thrall et al., 2012) which boosts the production of both enzymes (Stojevic et al., 2005), integral in ion exchange across the membrane; therefore, elevated concentrations denote metabolic disruption in the animal (Franzese et al., 1997).

The increased hepatic cell activity results from the diet provided to these animals, as high-energy diets demand intensive hepatic function. Similarly, the creatinine concentration, regardless of diet, resulted in elevated serum levels, despite differing between treatments (standard 1.14–1.7 mg/dL; Fagliari et al., 1998). These results illustrate a high glomerular filtration rate due to impaired renal function (Finco, 1989; Thrall et al., 2012). Comparable findings arise when animals encounter scenarios imposing significant metabolic challenges (Ramaiah, 2007; Mohamed, 2014), as in this study, in which animals were fed 100% concentrate diets throughout their lives.

5. Conclusions

Whole corn is a suitable dietary option for dairy calves, as it yields results similar to ground grain diets in terms of performance, blood indicators, diet digestibility, and associated feed costs. Incorporating soybean hulls into concentrate feed diets presents an attractive alternative for energy sources, enhancing diet digestibility and curtailing production expenses. This practice holds the potential to enhance overall system profitability.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: Santana, A. E. M.; Bozorg, V. L. A. and Neiva, J. N. M. **Data curation:** Santana, A. E. M.; Feitosa, T. R. M. and Freitas, I. B. **Formal analysis:** Sousa, L. F. **Funding acquisition:** Restle, J. and Neiva, J. N. M. **Investigation:** Santana, A. E. M.; Feitosa, T. R. M. and Freitas, I. B. **Methodology:** Santana, A. E. M.; Bozorg, V. L. A. and Neiva, J. N. M. **Project administration:** Santana, A. E. M.; Bozorg, V. L. A. and Neiva, J. N. M. **Resources:** Restle, J.; Miotto, F. R. C. and Neiva, J. N. M. **Supervision:** Santana, A. E. M.; Bozorg, V. L. A. and Neiva, J. N. M. **Validation:** Sousa, L. F. **Visualization:** Santana, A. E. M. **Writing – original draft:** Santana, A. E. M. **Writing – review & editing:** Bozorg, V. L. A.; Restle, J.; Miotto, F. R. C. and Neiva, J. N. M.

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