

Substitution of corn grain with white oat grain in non-forage diets for feedlot beef cattle

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ABSTRACT - This study evaluated the substitution of corn grain with white oat grain in finishing yearling bulls (initial weight of 259.4±31.7 kg and 18.0±0.2 months of age). The experimental design was completely randomized. The substitution levels of corn grain for white oat grain were 0, 25, 50, 75, and 100%. Diets comprised 85% of grains + 15% of a protein-vitamin-mineral pelleted supplement. The adaptation program consisted of *ad libitum* feeding of five diets over the adaptation period of 14 days, with the concentration level increasing from 60 to 100% of the diet on a dry matter basis. Daily weight gain and carcass gain presented a quadratic behavior with the inclusion of white oat grain. As a result of the differences in average daily gain, the feedlot period varied among groups until the target slaughter weight was reached. Dry matter intake, nutrient intake, feed efficiency, and Kleiber ratio presented a quadratic behavior. Ingestive behavior and rumination patterns were modified by the levels of white oat grain, with longer rumination time observed with the combination of grains. A similar response was observed for the number of regurgitated and chewed bolus. Conversely, the number of chews per bolus and the chewing time per bolus increased linearly with the replacement of corn with white oat grain. Residual intake and body weight gain and the participation of heart, lung, and kidney, heart, and pelvic fat g kg⁻¹ of empty body weight decreases linearly with the inclusion of white oat grain. The partial substitution of corn grain with white oat grain improves the productive performance and rumination patterns yearling bulls in feedlots receiving non-forage diets.

Keywords: beef cattle, feed intake, ingestive behavior, Kleiber ratio, starch

1. Introduction

Beef production systems worldwide undergo paradoxical processes to reconcile the problematic interfaces of productive increase with the more efficient use of natural resources. In this context, the adoption of feedlot systems is important for sustainable intensification, especially those that do not require the use of forage. This approach has advantages such as ease of implementation and operation,

but mainly because it does not use production factors related to the cultivation, storage, and supply of forage (Dias et al., 2016).

Given the significant role of Brazil in the global beef market, the use of high-grain feedlot technology is seen as a promising alternative and can be used as a productive model for different realities (Lemos et al., 2016; Marques et al., 2016; Cattalam et al., 2018). This technique was brought and adapted from the USA, based on an abundant supply of corn grain. However, acquiring corn in certain regions of Brazil can be significantly expensive, affecting the cost of the beef cattle diet. Thus, studying alternative feed for substitution, partially or totally, without jeopardizing livestock development becomes an important challenge when searching for sustainable production systems.

Specifically, regions with a subtropical climate have favorable prospects for cultivating winter cereals, which, among other purposes, may have their grains destined for animal feed. Among these cereals is white oat grain, which has been showing promising results when used as an ingredient for cattle feed (Cattalam et al., 2018; Argenta et al., 2019). It may be a viable option in diets without forage, mainly because it has a higher neutral detergent fiber content than corn (Argenta et al., 2019). Diets with low levels of fiber become challenging due to metabolic disorders resulting from the greater production of acids in the rumen, acidifying its environment when these substances are not efficiently absorbed by the ruminal epithelium (Bevans et al., 2005; Nagaraja and Titgemeyer, 2007).

Thus, our hypothesis will test whether the inclusion of white oat grain in diets without forage, which is generally based on corn, can improve ingestive behavior, animal performance, and carcass quality. Thereby, we will investigate increasing levels of corn grain substitution with white oat grain in a non-forage diet with feedlot cattle.

2. Material and Methods

The experiment was conducted on an experimental farm in Santa Maria, RS, Brazil (29°43'39" S latitude and 53°43'51" W longitude). Animal research was conducted according to the institutional committee on animal use (case number 8876170417).

2.1 Animals, treatments, and experimental design

Forty-five young Charolais × Nellore bulls with an average initial body weight of 259.4±31.6 kg and an average initial age of 18.0±0.2 months were used in the experiment. The experimental design was completely randomized, totaling five treatments with nine experimental units (animals) per treatment. The animals were distributed in the dietary treatments according to the replacement levels of corn grain (*Zea mays* L.) with white oats grain (*Avena sativa* L.) at 0, 25, 50, 75, and 100%.

2.2 Feeding and management description

At the beginning of the study, all yearling bulls were dewormed with a product based on Levamisole phosphate (Ripercol® L-150F, Zoetis, Campinas, São Paulo, Brazil) in a dosage of 4.5 mg/kg body weight (BW). Cattle were allocated individually in paved and semi-covered stalls, provided with water troughs with *ad libitum* supply and feeding troughs. Experimental diets were composed of 85% of grain (corn and/or white oats), plus calcitic limestone and urea + 15% of protein-vitamin-mineral pelleted supplement (Granobel®, Agrobella, Frederico Westphalen, Rio Grande do Sul, Brazil). Experimental diets were formulated to be isonitrogenous and to provide a dry matter intake (DMI) of 2.2% of BW according to the Beef Cattle Nutrient Requirements Model (NASEM, 2016) (Table 1).

The step-up adaptation program consisted of *ad libitum* intake with increasing levels of concentrate ingredients until reaching the concentrate level for the finishing diet (100%). The adaptation period lasted 14 days, during which five adaptation diets containing 60, 70, 80, 90, and 100% concentrate levels were offered for two, two, three, three, and four days, respectively. The source of forage used

was corn silage, and the concentrate had the same formulation as the experimental period for each treatment. The prior study reported that Nellore yearling bulls should be adapted for 14 days because it improved feedlot performance and presented greater development of rumen epithelium without increasing rumenitis scores (Estevam et al., 2020).

The yearling bulls were fed with no restriction twice a day, at 08:00 and 14:00 h. Before the first daily diet supply, the leftovers from the previous day were collected and pre-established between 2 and 5% of the feed offered.

Table 1 - Ingredients and chemical composition of experimental diets

Ingredient	Replacement of corn with white oat (%)				
	0	25	50	75	100
Corn grain (%)	82.56	62.47	41.54	21.82	–
White oat grain (%)	–	20.65	41.54	61.93	83.65
Pelleted supplement (%) ¹	15.00	15.00	15.00	15.00	15.00
Calcitic limestone (%)	1.10	0.80	1.20	0.90	1.35
Urea (%)	1.34	1.08	0.72	0.35	–
Chemical composition					
Dry matter (as-fed basis)	86.55	87.20	87.39	88.21	88.36
Crude protein (% of DM)	17.95	17.95	17.95	17.95	17.95
Ether extract (% of DM)	3.29	3.35	3.39	3.45	3.49
Neutral detergent fiber (% of DM)	17.78	18.66	19.48	20.39	21.23
Ash (% of DM)	4.69	4.75	4.79	4.85	4.90
Starch (% of DM)	51.70	50.52	49.02	47.97	46.37
Non-fiber carbohydrates (% of DM)	56.23	55.13	54.13	52.99	51.95
Net energy for maintenance (Mcal kg ⁻¹ DM) ²	1.92	1.83	1.77	1.76	1.71
Net energy for gain (Mcal kg ⁻¹ DM) ²	1.29	1.20	1.15	1.14	1.10
Rumen degradable protein (% CP)	64.62	66.69	68.40	69.97	71.92
Rumen undegradable protein (% CP)	35.38	33.31	31.60	30.03	28.08

¹ Composition of the product expressed in g or mg per kg of the pelleted supplement: crude protein: 360 g; non-protein nitrogen equivalent protein: 150 g; ether extract: 20 g; acid detergent fiber: 160 g; fiber: 100 g. Minerals: 260 g containing Ca (max), 35 g; Ca (min), 25 g; P (min), 10 g; Na (max), 18 g; Co (min), 7 mg; Cu (min), 84 mg; I (min), 7 mg; Mn (min), 140 mg; Se (min), 2.66 mg; Fe (min), 196 mg; Zn (min), 420 mg; vitamins (21,000 IU vitamin A, 4,200 IU vitamin D3, and 35 IU vitamin E/kg), and sodium monensin, 210 mg/kg.

² Based on NASEM (2016) nutrient analysis of each dietary ingredient.

2.3. Sample collection, performance, and biological efficiency

Dry matter intake was calculated daily by weighing the concentrate offered and leftovers before the supply of the following morning and expressed in kg and as a percentage of BW. Samples of ingredients and leftovers were collected weekly. Subsequently, composite samples were made and dried in a forced-air oven at 55 °C for 72 h and then ground in a Wiley mill (Thomas Scientific, Swedesboro, NJ, USA) to pass through a 1-mm sieve. These samples were further analyzed in dry matter (DM, method 942.05), ash (method 942.050), crude protein (CP, method 984.13), and ether extract (method 920.39) (AOAC, 2005). Neutral detergent fiber (aNDF) was determined using α -amylase and without the addition of sodium sulfite by following the procedure of Van Soest et al. (1991). Starch was determined using the AOAC 996.11 technique (AOAC, 1995) modified by Walter et al. (2005).

Yearling bulls were individually weighed at the beginning (d0) and at the end of the adaptation period (d14) to calculate the average daily gain (ADG), carcass gain, and biological efficiency after overnight withdrawal of feed and water (approximately 14 h). Subsequently, cattle were individually weighed at 28-day intervals before feed delivery without fasting to monitor their growth until they reached the conditions necessary for slaughter. Carcass daily gain was calculated assuming 50%

of the dressing percentage for initial BW, according to the methodology described by Michels et al. (2018). Biological efficiency was assessed using three parameters: feed efficiency (FE; kg ADG kg⁻¹ DMI), Kleiber ratio (KR), and residual intake and BW gain (RIG). The KR (Kleiber, 1936) was calculated by $KR = \frac{ADG}{Mean\ BW^{0.75}}$, in which Mean BW^{0.75} is the mean metabolic body weight.

Residual feed intake (RFI) and residual weight gain (RWG) were calculated to determine RIG, according to Koch et al. (1963):

$$Y_{ij} = \beta_0 + \beta_1 X_{1ij} + \beta_2 X_{2ij} + \varepsilon_{ij}$$

in which Y_{ij} = DMI (kg d⁻¹) of the j -th replicate, in the i -th inclusion level of white oats; β_0 = intercept or constant of the regression; β_1 and β_2 = regression coefficients; X_{1ij} = ADG (kg d⁻¹); X_{2ij} = BW^{0.75}; and ε_{ij} = residual random error, representing the RFI of observation ij , assumption (0, σ^2). The same equation was used to calculate RWG, which is determined from the regression of ADG as a function of BW^{0.75} and DMI. The RIG was determined to RIG = RWG + (-1 × RFI) (Berry and Crowley, 2012).

2.4. Feeding behavior

The DMI variation was calculated using the methodology proposed by Bevans et al. (2005) as the difference in intake between consecutive days throughout the study. Daily DMI variation data were expressed as a percentage of variation as follows: [(DMI current day – DMI previous day)/DMI previous day × 100]. The DMI variations were calculated for the finishing period, disregarding the days before weighing to eliminate fluctuations resulting from management.

Yearling bulls were subjected to visual observations to evaluate feeding behavior over three periods, with 28-day intervals (days 14, 42, and 70 on the finishing diet), using scan sampling with an interval of 10 min (Mitlöhner et al., 2001) during 24 h consecutively. The monitoring of feeding behavior was always conducted by the same person in each experimental group. Feeding behavior data were recorded for each bull as follows: time spent eating, ruminating, and performing other activities (expressed in hours). Concomitantly with feeding behavior, chewing time per bolus (sec bolus⁻¹), number of regurgitated and chewed bolus (bolus d⁻¹), and number of chewing per bolus (n chewing bolus⁻¹) were observed, representing the activities inherent to rumination (Bürger et al., 2000). A digital timer (Extech™ 365510, Extech Instruments, Boston, Massachusetts, USA) recorded chewing time per bolus.

2.5. Carcass traits, vital organs, and visceral fat

Final body weight (FBW) was obtained at the feedlot before transportation after a 14-hour fasting of solids and liquids. The slaughterhouse was 20 km and 45 min away from the feedlot. Slaughter was performed in a commercial slaughterhouse under state inspection according to the Animal Welfare Guidelines. Based on a previous study, the slaughter criterion was pre-established by estimating the hot carcass weight in the order of 220 to 230 kg (Cattalam et al., 2018). To achieve these criteria, the feedlot period was 80 d for treatments 25 and 75%, 88 d for treatments 0 and 50%, and 123 d for treatment 100%.

Hot carcass weight (HCW) was obtained after pelvic fat removal. The carcass of each animal was divided into two half-carcasses and weighed to determine the HCW. Dressing percentage was calculated by dividing HCW by the FBW. Carcasses were then chilled in a cold room at 0 °C for 24 h. After weighing, the right half-carcass was sectioned between the 12th and 13th ribs and the longissimus muscle was used to measure the loin-eye area and subcutaneous fat thickness. A digital caliper was used to determine subcutaneous fat thickness, and loin-eye area was traced on vegetable paper and measured later with a graphics tablet. During slaughter, all parts of carcasses were separated and individually weighed; these comprised a set of peripheral components, vital organs, empty digestive tract, and blood. The visceral fat of each organ was removed, and the organ was weighed. The empty body weight (EBW) was obtained by summing the HCW, blood, and all sets of components.

2.6. Statistical analysis

Tests for normality and heterogeneity of treatment variances were performed before analyzing the data. Studentized residuals were plotted against the predicted values using the plot procedure to analyze data for outliers. Subsequently, data were subjected to analysis of variance by the F test. Statistical differences were declared at $P < 0.05$, and trends were discussed at $P \leq 0.08$. Additionally, polynomial regression studies were performed using the following mathematical model:

$$Y_{ijk} = \beta_0 + \beta_1 X_i + \beta_2 X_i^2 + \beta_3 X_i^3 + \alpha_{ijk} + \varepsilon_{ijk},$$

in which Y_{ijk} = represents the dependent variables; β_0 = the intercept or constant of the regression; β_{123} = linear, quadratic, and cubic regression coefficients; X_i = level of substitution of corn grain with white oat grain; α_{ijk} = regression deviations; ε_{ijk} = random error associated with observation Y_{ijk} . All statistical analyses were performed using the SAS package (Statistical Analysis System, University Edition 3.5).

3. Results

3.1. Feedlot performance and biological efficiency

The ADG during adaptation did not differ among diets (Table 2). However, in the experimental period, substituting oat grain with corn grain had a quadratic effect on ADG between 28 and 56 days ($P = 0.022$), between 56 and 80 days ($P = 0.011$), and for the total feedlot period ($P = 0.013$). Carcass gain also exhibited a quadratic behavior ($P = 0.034$).

The substitution of corn grain with white oat grain in the diet of feedlot yearling bulls resulted in quadratic behavior in the DMI in kg d^{-1} ($P = 0.027$) and % of BW ($P = 0.027$) (Table 3). There was also a quadratic behavior for the intake of CP ($P = 0.015$), NDF ($P < 0.001$), and starch in % of BW ($P = 0.009$).

The biological efficiency of the yearling bulls was investigated by three variables, in which FE ($P < 0.001$) and KR ($P = 0.001$) showed quadratic behavior, while RIG reduced linearly with the inclusion of white oat grain in substitution to corn in the diet ($P = 0.001$). The FBW did not differ among diets once the moment of slaughtering was previously predetermined.

Table 2 - Feedlot performance of yearling bulls without receiving forage with substitution of corn grain with white oat grain

Item	Substitution level of corn with white oat (%)					SEM	P-value		
	0	25	50	75	100		L	Q	C
Adaptation period (d)	14	14	14	14	14	-	-	-	-
Experimental period (d)	88	80	88	80	123	-	-	-	-
IBW adaptation period (kg)	259.94	259.72	261.07	259.22	259.33	4.72	0.386	0.681	0.859
ADG adaptation period (kg d^{-1})	1.12	0.74	0.81	0.74	0.67	0.08	0.187	0.335	0.426
Initial BW (kg)	282.04	269.71	274.82	269.34	268.43	4.61	0.221	0.450	0.655
Final BW (kg d^{-1})	420.38	421.7	430.31	417.11	434.54	8.43	0.892	0.865	0.917
ADG 0–28 d (kg d^{-1})	1.52	1.84	1.67	1.65	1.20	0.05	0.290	0.118	0.320
ADG 28–56 d (kg d^{-1}) ¹	1.53	2.06	1.75	1.65	1.37	0.06	0.167	0.022	0.089
ADG 56–80 d (kg d^{-1}) ²	1.87	2.13	1.95	1.97	1.48	0.05	0.217	0.011	0.099
Total ADG (kg d^{-1}) ³	1.63	2.01	1.79	1.76	1.45	0.06	0.178	0.013	0.039
Carcass gain (kg d^{-1}) ⁴	1.14	1.25	1.26	1.17	0.97	0.06	0.165	0.034	0.081

ADG - average daily gain; SEM - standard error of the mean; L - linear effect; Q - quadratic effect; C - cubic effect.

¹ $y = 1.71 + 0.0121x - 0.00012x^2$ ($R^2 = 0.20$).

² $y = 1.91 + 0.0116x - 0.00018x^2$ ($R^2 = 0.28$).

³ $y = 1.68 + 0.0112x - 0.00014x^2$ ($R^2 = 0.20$).

⁴ $y = 1.14 + 0.628x - 0.8032x^2$ ($R^2 = 0.26$).

Table 3 - Intake and biological efficiency of yearling bulls without receiving forage with substitution of corn grain with white oat grain

Item	Substitution level of corn with white oat (%)					SEM	P-value		
	0	25	50	75	100		L	Q	C
Feedlot performance									
Intake									
Dry matter intake (DMI; kg d ⁻¹) ¹	6.36	6.80	7.19	7.20	6.38	0.16	0.276	0.027	0.189
Dry matter intake (% of BW) ²	1.89	1.99	2.10	2.13	1.94	0.04	0.403	0.027	0.124
Crude protein (% of BW) ³	0.33	0.35	0.37	0.37	0.34	0.01	0.409	0.015	0.119
Neutral detergent fiber (% of BW) ⁴	0.30	0.35	0.39	0.44	0.37	0.01	<0.001	<0.001	0.010
Starch (% of BW) ⁵	0.91	0.97	0.99	1.03	0.88	0.02	0.597	0.009	0.049
Biological efficiency									
Feed efficiency (kg ADG kg ⁻¹ DMI) ⁶	0.24	0.26	0.22	0.23	0.19	0.00	0.030	<0.001	0.008
Kleiber ratio (g kg BW ^{0.75} d ⁻¹) ⁷	20.24	23.48	22.08	23.08	16.48	0.67	0.104	0.001	0.018
Residual intake and BW gain ⁸	0.59	0.45	-0.28	-0.18	-0.57	**	0.001	0.003	0.012

BW - body weight; DMI - dry matter intake; ADG - average daily gain; SEM - standard error of the mean; L - linear effect; Q - quadratic effect; C - cubic effect.

** Dimensionless.

¹ $y = 6.32 + 0.0426x - 0.00040x^2$ ($R^2 = 0.22$).

² $y = 1.86 + 0.0099x - 0.000086x^2$ ($R^2 = 0.21$).

³ $y = 1.12 + 0.0066x - 0.000058x^2$ ($R^2 = 0.51$).

⁴ $y = 1.05 + 0.0110x - 0.000075x^2$ ($R^2 = 0.51$).

⁵ $y = 0.92 + 0.0043x - 0.000046x^2$ ($R^2 = 0.28$).

⁶ $y = 0.24 + 0.00035x - 0.0000087x^2$ ($R^2 = 0.55$).

⁷ $y = 20.93 + 0.1414x - 0.00168x^2$ ($R^2 = 0.30$).

⁸ $y = 0.59 - 0.012x$ ($R^2 = 0.34$).

3.2. Feeding behavior

There was a linear reduction trend in DMI variation with the inclusion of oat grain in the diet ($P = 0.073$). The daily eating time did not vary among treatments ($P > 0.05$). There was a quadratic effect of the level of corn substitution with white oat grain, which showed a maximum point. The time spent on other activities, including idling, also had a quadratic effect, but with a minimum point (Table 4).

The number of regurgitated and chewed bolus per day showed a quadratic behavior in ruminative activities ($P = 0.001$). However, the number of chewing and the chewing time per bolus increased linearly with the substitution of corn grain with white oat grain in diets without forage for yearling bulls in feedlot ($P < 0.001$).

Table 4 - Behavioral variables of feedlot yearling bulls without receiving forage with substitution of corn grain with white oat grain

Item	Substitution level of corn with white oat (%)					SEM	P-value		
	0	25	50	75	100		L	Q	C
Feeding behavior									
DMI variation (%)	10.77	7.58	9.19	9.01	7.53	0.22	0.073	0.136	0.157
Time spent eating (h d ⁻¹)	2.57	2.57	2.72	2.59	2.22	0.06	0.191	0.112	0.182
Time spent ruminating (h d ⁻¹) ¹	1.86	3.50	4.23	5.56	4.93	0.25	<0.001	<0.001	0.291
Time spent performing other activities (h d ⁻¹) ²	19.57	17.93	17.05	15.85	16.84	0.24	<0.001	<0.001	0.170
Rumination activities									
NRCB (bolus d ⁻¹) ³	168	260	245	269	145	12.82	0.796	0.001	0.090
NCB (no. of chewing bolus ⁻¹) ⁴	42	58	63	63	69	1.76	<0.001	0.197	0.110
Chewing time per bolus (sec bolus ⁻¹) ⁵	44.89	62.75	66.35	64.29	70.07	1.63	<0.001	0.097	0.049

DMI - dry matter intake; NRCB - number of regurgitated and chewed bolus; NCB - number of chewing per bolus; SEM - standard error of the mean; L - linear effect; Q - quadratic effect; C - cubic effect.

¹ $y = 1.81 + 0.0830x - 0.00053x^2$ ($R^2 = 0.65$).

² $y = 19.59 - 0.0785x + 0.00048x^2$ ($R^2 = 0.68$).

³ $y = 169.44 + 3.76x - 0.0380x^2$ ($R^2 = 0.49$).

⁴ $y = 48.36 + 0.2232x$ ($R^2 = 0.56$).

⁵ $y = 52.46 + 0.2001x$ ($R^2 = 0.52$).

3.3. Vital organs and carcass traits

Heart ($P < 0.001$), lungs ($P = 0.027$), and kidney, heart, and pelvic fat (KPH fat) ($P = 0.043$) showed a linear decrease with the inclusion of white oats in the diet (Table 5).

Diets did not influence the liver and kidney, although the liver presented a tendency to linear reduction ($P = 0.051$). Carcass traits were not influenced by the substitution levels of corn grain with white oat grain in relation to the slaughter weight, except for the dressing percentage, which showed a quadratic behavior ($P = 0.020$).

Table 5 - Carcass traits, vital organs, and internal fats of feedlot yearling bulls without receiving forage with substitution of corn grain with white oat grain

Item	Substitution level of corn with white oat (%)					SEM	P-value		
	0	25	50	75	100		L	Q	C
Empty body weight (kg)	375.46	368.72	373.37	352.54	380.02	7.31	0.891	0.761	0.789
Hot carcass weight (kg)	243.38	240.99	244.70	232.34	253.12	5.29	0.835	0.727	0.707
Dressing percentage (% of SW) ¹	58.24	57.10	56.83	55.70	58.16	0.34	0.331	0.020	0.249
Dressing percentage (% of EBW)	64.77	65.20	65.47	64.94	66.50	0.35	0.074	0.117	0.102
Rib eye area (cm ²)	65.69	61.70	70.13	61.53	70.50	1.93	0.492	0.655	0.807
Subcutaneous fat thickness (mm)	4.24	4.23	3.93	3.09	4.02	0.21	0.254	0.358	0.118
Liver (g kg ⁻¹ of EBW)	14.33	14.40	13.93	13.72	12.65	0.29	0.051	0.108	0.219
Heart (g kg ⁻¹ of EBW) ²	3.53	3.48	3.21	3.29	2.89	0.05	<0.001	0.067	0.104
Lungs (g kg ⁻¹ of EBW) ³	14.15	13.42	13.84	13.32	11.73	0.25	0.027	0.053	0.039
Kidney (g kg ⁻¹ of EBW)	2.30	2.26	2.08	2.90	2.05	0.05	0.175	0.402	0.461
KPH fat (g kg ⁻¹ of EBW) ⁴	14.06	14.32	12.44	12.13	11.41	0.31	0.043	0.267	0.331

L - linear effect; Q - quadratic effect; C - cubic effect; SW - slaughter weight; KPH fat - kidney, heart, and pelvic fat; EBW - empty body weight.

¹ $y = 56.72 - 0.0931x + 0.00084x^2$ ($R^2 = 0.18$).

² $y = 3.58 - 0.0062x$ ($R^2 = 0.49$).

³ $y = 13.97 - 0.0137x$ ($R^2 = 0.40$).

⁴ $y = 13.98 - 0.0241x$ ($R^2 = 0.18$).

4. Discussion

4.1. Feedlot performance and biological efficiency

The hypothesis that using white oat grain in combination with corn grain would improve behavioral patterns and biological efficiency was confirmed, with the best results at levels between 25 and 75% of substitution. However, when cattle are slaughtered at similar weights, the hypothesis that there would be changes in carcass characteristics is rejected.

Cattle finished with high energy density diets showed DMI depletion, in which the observed DMI was lower than the predicted (2.2% of BW). This response is characteristic of diets with a high-grain content since propionic acid, produced by the fermentation of starch, is rapidly absorbed and extracted by the liver. Furthermore, in this type of diet, the accumulation of lactic acid in the ruminal environment and the drop in pH can reduce DMI. A similar result was obtained by Carvalho et al. (2016) with DMI values, in which % of BW was significantly lower in diets with 100% (61.8% of starch) concentrate compared with diets with 70% (49.0% of starch) concentrate for young Nellore and Angus bulls. The higher concentration of propionic acid derived from starch fermentation in the rumen stimulates the oxidation of acetyl-CoA and oxidative phosphorylation, decreasing the firing rate of the hepatic vagus and acting on the center of satiety (Allen, 2014).

The complementarity between the fractions of carbohydrates and proteins of the ingredients is attributed to the quadratic effect on DMI, with different rates of ruminal digestion, mainly of the protein component. The CNCPS (Cornell Net Carbohydrate and Protein System) nutritional system presents degradation rates for whole grains of corn and oats with similar values for carbohydrates but discrepant for the protein fraction, which in corn are B1: 120-150%/h, B2: 3-5%/h, and B3: 0.60-0.70%/h; and in oats, they are B1: 300-350%/h, B2: 12-15%/h, and B3: 0.20-0.50%/h (Sniffen et al., 1992). The association of ingredients in cattle feed has shown positive effects concerning rumen balance. Russell et al. (2016) evaluated the substitution of corn grain with soybean hulls. They observed that diets with 80-90% replacement increased ruminal pH, which improved fiber digestibility due to the survival capacity and activity of fibrolytic microorganisms, inducing a higher DMI.

Despite the inclusion of oat grain providing an additional 4.85% in the NDF content at each level studied, the intake showed a quadratic behavior. This result is mainly explained by the higher DMI in diets with both grains, which influenced the NDF for a similar response. The relation between DMI and NDF in a high-energy diet is reported by Marques et al. (2016), who observed a higher intake with an increase in NDF level in diets with more than 79% concentrate. Due to their nutritional profile, grain-based diets are characteristically low in NDF intake, which raises concern among nutritionists.

Although adding white oat grains to the diet reduced the starch level, the variation in the DMI positively influenced the starch intake in % of BW to present a quadratic response. Optimization of duodenal starch digestion for beef cattle fed high concentrate has the potential to increase energy and productive efficiency, especially when combined with higher post-ruminal flows of protein and amino acids (Brake and Swanson, 2018). Sanz-Fernandez et al. (2020) found that the increase in starch supply has an exponential effect on the flow of duodenal starch, indicating that when starch increases in the diet, the proportion of starch digested in the rumen decreases. It is speculated that this phenomenon has occurred because there is a convergence between greater starch intake and greater weight gain and biological efficiency of cattle. The displacement of starch digestion to the duodenum is important in starch-rich diets because it prevents a propionate “overload” in the rumen, which can trigger metabolic syndromes that compromise animal health, welfare, and performance.

Productive performance during adaptation can be considered satisfactory. Adaptation is the most critical phase for the animal in a feedlot system. In this period, protozoa and cultivable bacteria populations change when the forage:concentrate ratio is altered (Brown et al., 2006). The partial substitution of corn with white oats contributed to a higher DMI, significantly impacting daily weight gain. The positive associative effect of the grain mixture on ADG was reported by Larraín et al. (2009), who evaluated the use of corn grain, sorghum grain, and the mix of both in the same proportions for feedlot cattle receiving high-grain diets. The highest DMI increased nutrient intake (starch, protein, and NDF), positively affecting the quadratic ADG adjustment and carcass gain.

The biological efficiency of the yearling bulls was evaluated by three parameters, of which FE and KR had a quadratic effect. Considering DMI, FE presented a maximum point with a 25% inclusion of white oat grain. In contrast, KR, which does not consider DMI, also presented the highest value with a 25% substitution of corn grain with white oats. One of the premises of using a diet with no forage availability to cattle is to improve FE, as the animals present low intake and high weight gains. Maximum weight gain is observed to be adjusted to 25% of white oat grain. However, ADG presented values between 1.76 and 2.01 kg d⁻¹ with the inclusion of white oats in the diet. Therefore, in this interval of substitution of corn grain with white oat grain (25 to 75%), animals tend to present the best productive responses.

In contrast to FE, the investigation of biological efficiency by KR does not imply an assessment of DMI, which is often difficult to collect at a field level. In addition, KR is correlated with the average metabolic body weight that can determine the growth potential relative to physiological maturity. Therefore, feedlot steers fed corn grain partially substituted with white oat grain on a non-forage diet gain more weight daily with the same metabolic weight than those fed these grains separately. Due to the low DMI of animals that received only corn grain as an energy ingredient compared with the mixtures and the higher ADG of the 0% replacement treatment compared with the 100% replacement treatment, there

was a linear decrease in RIG with the inclusion of white oat grain. In this case, the better residual FE resulted from the lower DMI and not the higher ADG values observed in diets with both grains.

4.2. Feeding behavior

The DMI variation is a characteristic used as a parameter for ruminal comfort and health, especially in high-grain diets, and it showed a linear reduction trend with the inclusion of white oat grain in the diet. This tendency probably occurs due to the higher NDF content of this grain. According to Galyean et al. (1992), the daily variation in DMI greater than 10% can negatively impact animal performance, reducing weight gain and increasing feed conversion. However, it should be noted that only the white oat grain-free diet exceeded the reported limit. This measurement is important, as it can indicate subclinical acidosis (Bevans et al., 2005). Therefore, it is noteworthy that even with two daily treatments, the buffering agents in the pelleted supplement were important to supply the lack of physically effective NDF and mitigate the excessive production of fatty acids during rumen fermentation.

The time spent ruminating ranged from 1.86 to 5.56 h d⁻¹, a variation of 67% between the extreme values, with the maximum point estimated for a proportion of 75% of corn grain substitution with white oat grain, an extremely close value to the maximum intake of NDF (0.44% of BW). This higher NDF intake explains the rumination time and the synergism in the degradation rates of grains already mentioned and hypothesized, which improved ruminal homeostasis. The daily rumination times, especially in diets with white oats, were higher than those observed by Carvalho et al. (2016) in diets with 85% corn grain + 15% pelleted supplement. The total substitution of corn grain with other grains with different physical structures and higher NDF contents increased rumination time for cattle (Argenta et al., 2019).

The lower the intake of physically effective NDF, the faster the degradation of carbohydrates in the rumen, especially non-fibrous ones, causing a decrease in the number of regurgitated and chewed bolus per day (Argenta et al., 2019). The increased number of ruminations and longer chewing time for each regurgitated feed bolus indicate that the higher concentrations of NDF and lower concentrations of non-fibrous carbohydrates in white oat grain positively impact cattle's adaptation to diets with low fiber content. Thus, the white oat grain associated with the corn grain is a potential ingredient for use in a non-forage diet, intending to reduce the risks of metabolic disorders, especially acidosis.

4.3. Vital organs and carcass traits

The results for HCW present feedlot owners with a new feed option, an alternative input often purchased at a lower price, with no increase in the termination time to deliver similar carcasses to a corn grain diet to the beef industry when the substitution is made up to 75%. The quadratic response of dressing percentage (% of slaughter weight) is explained by the greater content in the digestive tract content, as it did not differ in relation to EBW. The highest DM and NDF intakes were determinants for this result. A similar response was observed by Cattelan et al. (2018), who identified a lower dressing percentage when substituting 100% corn grain with white oat grain due to the greater digestive tract content but without a difference when adjusted to EBW.

Differences in energy intake may express changes in the relative liver participation. According to Owens et al. (1993), the organ participates more actively in the metabolism of nutrients, triggered by feed intake, energy requirements, and metabolic rate. However, this organ showed only a trend of linear reduction with the inclusion of white oat grain in the diet. Net energy was reduced for maintenance and gain as white oats were added to the diet. For Almeida Júnior et al. (2008), it is expected that cattle fed high energy densities have greater development of internal organs to meet the most intense metabolism, a fact observed in the linear reduction of heart and lung in g kg⁻¹ EBW. Carvalho et al. (2016) observed a trend of liver and heart reduction (in % of BW) in diets without forage in relation to those with 30% forage.

The lower intensity of weight gain in the diet with 100% white oat grain took the yearling bulls a longer time to reach the slaughter condition. Therefore, these animals may have reduced the maintenance requirements of the organs themselves in relation to the others, decreasing the participation of internal fats (KPH fat). This lower numerical value may have contributed to the linear reduction in this set of fats. The sites of fat deposits in the bovine body are followed as a priority route by visceral, intermuscular, subcutaneous, and intramuscular fat (Owens et al., 1993). Therefore, only KPH fat may have been sensitive to minor differences in dietary energy, which is different from subcutaneous fat thickness.

White oat grain, especially with corn grain, is an excellent alternative for inclusion in feedlot cattle diets in regions of the planet where climate and soil conditions allow its cultivation.

5. Conclusions

We recommend partially substituting corn grain with white oat grain for feedlot cattle without forage, as it maximizes animal performance and biological efficiency. The inclusion of white oats in the diet improves the behavioral patterns of cattle, such as a more extended rumination period and better rumination conditions, which is especially important in diets without forage.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: Pereira, L. B.; Machado, D. S. and Alves Filho, D. C. **Data curation:** Pereira, L. B.; Alves Filho, D. C. and Brondani, I. L. **Formal analysis:** Machado, D. S. and Brondani, I. L. **Methodology:** Machado, D. S.; Adams, S. M. and Klein, J. L. **Project administration:** Pereira, L. B. and Machado, D. S. **Supervision:** Alves Filho, D. C. **Writing – original draft:** Pereira, L. B.; Machado, D. S.; Silva, M. B.; Michelin, J. M. and Maidana, F. M. **Writing – review & editing:** Pereira, L. B.; Machado, D. S.; Brondani, I. L.; Adams, S. M.; Klein, J. L. and Volpato, R. S.

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