An Acad Bras Cienc (2021) 93(3): e20190731 DOI 10.1590/0001-3765202120190731
Anais da Academia Brasileira de Ciências | *Annals of the Brazilian Academy of Sciences*
Printed ISSN 0001-3765 I Online ISSN 1678-2690
www.scielo.br/aabc | www.fb.com/aabcjournal

ANIMAL SCIENCE

High-concentrate diets with fibrous by-products for feedlot Nellore heifers

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Abstract: The objective of this study was to evaluate high-concentrate diets and two energy sources on intake, performance and meat quality parameters of feedlot Nellore heifers. Twenty-eight heifers (200 ± 22.5 kg BW) were randomly assigned to four treatments in a 2×2 factorial arrangement: two concentrate levels (70 and 80%) and two energy sources (corn and corn germ meal). At the end of day 112, heifers were slaughtered. There was no interaction (*P*>0.05) of concentrate levels and energy sources for dry matter intake, unlike crude protein (CP) and neutral detergent fiber (NDF) intakes. The concentrate level of 80% and corn, allowed the highest CP (1.17 kg/day) and NDF (4.05 kg/day) intakes. Final BW (*P*<0.05) and daily gain (*P*<0.01) were influenced just by energy source. The carcass composition represented by muscle and fat was affected by concentrate level (*P*<0.05). Treatments affected (*P*<0.01) carcass fat deposition, global preference and texture of *Longissimus* muscle (*P*<0.05). It was concluded that high proportions of concentrate containing corn as energy source provided the best performance in heifers, and that the total replacement of corn with corn germ meal in high-concentrate diets is not recommended for performance Nellore heifers, but provided good sensory quality to the meat.

Key words: energy sources, fiber, intake, performance, starch.

INTRODUCTION

High-concentrate diets fed to beef cattle are commonly based on cereal grains and are able to improve weight gain and carcass quality, allowing faster fat deposition. These diets, commonly starch-rich, are characterized by faster degradation, providing more energy, especially the net energy for gain. However, in Brazil approximately 87% of the primary grain source of feedstuff diets is the corn, which increases the possibility of causing metabolic disorders, since the inclusion is over 50% in dry matter (Oliveira & Millen 2014).

Corn, when included in high-concentrate diets provides energy to easily achieve animal requirements. However, diets with large amounts of starch, produce acids that decrease rumen pH, negatively influencing intake, microbial metabolism, nutrient degradation and performance parameters (Paulino et al. 2008, Plaizier et al. 2009, Dijkstra et al. 2012, Carvalho et al. 2016).

Energetic by-products, which contain lower amounts of starch and contain more fiber than corn, could be utilized due to its high fermentable capacity to promote rumination, without causing such metabolic disorders, and decreases in animal performance, when using high-concentrate finishing diets. The use of by-products, could help through stimulating rumination and buffering the rumen environment, might replace totally or partially the corn, or simply compose the formulation as a second energy source or protein ingredient.

These by-products potentially fiber-rich has different effectiveness, and although contains the same fiber content, their utilization in the formulations could result in different intake behaviors and performance (Galyean & Defoor 2003).

The processing of corn separates germ, pericarp fiber, endosperm fiber, and oil, which are some byproducts used in animal feeds. The corn germ meal is obtained after oil extraction from the germ, followed by starch standardization to contain less than 40%. This step corresponds to the addition of pericarp fiber, resulting in large differences between the composition of corn and its by-product. Also, technology treatment changes the molecular structure of the starch, which can modify the extent and rate of degradation, resulting in differences in volatile fat acids profile, and ultimately in performance and carcass quality (Chai et al. 2004, Hindle et al. 2005, Ponce et al. 2013, Zhu et al. 2016, Gómez et al. 2016, Maia Filho et al. 2016). The carcass, and more specifically the *Longissimus* muscle, responds to variations in diet. Moran et al. (2019) observed in bulls reared under different feeding systems that the supply of concentrates increased intramuscular fat and decreased omega-3 FA concentration. Bulls fed on concentrates had lighter meat colour compared with grazing bulls.

The associative effect caused by the inclusion of fibrous by-products, could result in similar performance parameters, as these feedstuffs could improve significantly the rumen environment (Mendes et al. 2005). Therefore, the objective of this study was to evaluate high-concentrate diets with two energy sources (corn cracked grain or corn germ meal) on intake, performance and meat quality parameters of feedlot Nellore heifers.

MATERIALS AND METHODS

The current experiment was carried out at College of Agricultural and Veterinary Sciences, São Paulo State University "Júlio de Mesquita Filho", located in Jaboticabal, SP, Brazil.

Animals, diets and management

Twenty-eight Nellore heifers (200 ± 22.5 kg BW), approximately 14 months old, were randomly assigned to four treatments in a 2×2 factorial arrangement. Cattle were gradually adapted to the finishing diet, during a 40 days period. The animals were confined in individual pens (14 m^2), partially covered, and with individual bunks and waterers, following the guidelines for protection of animals used for experimental and other purposes of the European Economic Community (EC Directive 86/609/EEC).

The four diets were formulated to provide 1.13 kg of daily gain, according to NRC (2000), and consisted of two concentrate levels (70 and 80%, dry matter basis), and two energy sources (corn cracked grain and corn germ meal). Corn silage was used, as roughage and the concentrates were composed of corn grain cracked or corn germ meal, soybean hulls, and sunflower meal. The composition of the experimental diets is presented in Table I.

The heifers were fed twice daily at 0800 and 1600 h a total mixed ration. The quantities offered were adjusted allowing up to 10% of weigh-backs. Every day, before feeding, diet refusal of each bunk were removed and weighted for daily control. To estimate intake, the individual

Table I. Ingredient and chemical composition of the diets experimental (% DM).

Item	70% Concentrate		80% Concentrate	
	CGC[1]	CGM[2]	CGC[1]	CGM[2]
Ingredients				
Corn silage	30.00	30.00	20.00	20.00
Corn grain cracked	22.06	-	26.06	-
Corn germ meal	-	26.55	-	33.89
Soybean hulls	22.10	18.75	30.09	23.47
Sunflower meal	25.06	23.92	23.07	21.86
Mineral/Vitamin premix[3]	0.78	0.78	0.78	0.78
Chemical composition				
CP	13.92	13.76	13.91	13.72
NDF	57.65	62.06	58.16	62.29
ADF	35.09	33.53	35.71	32.70
Starch	25.25	8.16	26.78	6.43

[1]CGC: Corn grain cracked; [2]CGM: Corn germ meal; [3]The premix contained (per kg): 40 g P, 80 g Ca, 195 g Na, 300 g Cl, 5 g Mg, 26 g S, 2000 mg Zn, 1000 mg Cu, 500 mg Mn, 100 mg Co, 100 mg I, 400 mg F, 5 mg Se.

refusal was collected daily, weighed, stored, composited for every week, and then, after dry matter evaluation, it was determined by the difference between offered and refused feed.

The animals remained in feedlot for 112 days, being weighed every 28 days. Average daily gain (ADG) was obtained from the difference between the weight at the beginning and the end of the trial, always after a 14-h solid fast, divided by days on feed.

Chemical analysis

Samples of corn silage and weigh-backs were pre-dried at 55°C for 72 hours. Then, all samples were ground in a knife mill with sieve of 1 mm for further chemical analysis.

The analyzes were performed according to methods described by AOAC (1990) for determination of dry matter (method 930.15), ash (method 942.05), crude protein (method 984.13) and ether extract (method 920.39). To analyze the neutral detergent fiber (NDF), the samples were treated with thermo-stable alpha amylase without using sodium sulfite (Van Soest et al. 1991).

Slaughter and carcass characteristics

At the end of the experiment (112 days), all heifers were slaughtered after the 16-h fast by cerebral concussion, followed by the jugular and carotid venesection, according to the normative instruction n.3 of 01/13/2000 (Technical Regulation of Methods for Humane

Slaughtering of Livestock). After slaughtering, the gastrointestinal tract of each animal was emptied and, along with the other organs, was washed, weighed, and added to the remaining body parts (carcass, head, skin, tail, legs, and blood) to determine the empty body weight (EBW).

Each carcass was split into two identical longitudinal halves and weighed to determine carcass gain and yields in relation to body weight (CYBW) and the empty body weight (CYEBW). All carcasses were weighed again after a 24-h chill period at 4°C. In the right half carcass, commercial cut yields were measured, separating the anterior and posterior quarters by cutting between the fifth and sixth ribs. The forequarter consisted of the chuck, shoulder and flank, and the hindquarter consisted of top sirloin and rump.

In the left half carcass, at the 12^{th} rib were evaluated the fat thickness (BF) and *Longissimus* muscle area (LM). In this half carcass, for assessment of the physical carcass composition, a cross section including the 9 to 11^{th} ribs was sampled, according to Hankins and Howe (1946), which consists in weighing and manually separation into bone, muscle and fat to obtain the percentage of each component.

Longissimus muscle analysis

A boneless *Longissimus* section, 10 cm thick, was sampled from the posterior end of the wholesale rib of the right half carcass. Three *Longissimus* steaks samples, 2.54 cm thick, were individually vacuum packaged and frozen at –20°C.

Steaks were thawed at 4°C for a period of 24 h and oven broiled in an electric oven pre-heated to 175°C. Internal steak temperature was monitored with 20-gauge copper–constantan thermocouples placed in the approximate geometric center of each steak and attached to a digital monitor. When the internal steak temperature reached 35°C, the steak was flipped and allowed to reach an internal temperature of 70°C. After cooling, samples were cut into cubes and offered to 40 untrained panelists, which tasted samples in booths with individual reserved sections. In this panel it was evaluated the overall preference (liking), flavor (sensation), and texture (tenderness), following a 9-point hedonic scale (Wichchukit & O'Mahony 2014). Scores ranged from 1 (highest disapproval) to 9 (highest approval).

Statistical analysis

All data obtained from the experiment were analyzed as a completely randomized design with a 2×2 factorial arrangement of treatments, using the General Linear Model (GLM) procedure of the Statistical Analysis System Institute. The statistical model included terms for animal, concentrate level, energy source and the concentrate level and energy source interactions. Treatment means were compared by Tukey test ($P \leq 0.05$).

RESULTS

There was interaction ($P<0.05$) between the concentrate level (CL) and energy source for the intakes of CP and NDF, and for the meat texture and preference (Table II). The effects of other variables will be discussed independently.

Intake and performance

Dry matter intake was not affected ($P>0.05$) by either concentrate levels or energy source, but for CP and NDF intakes, there was an interaction (Table II). DMI was similar, but differences in CP and NDF intakes contributed to affect the ADG ($P<0.01$) which was 33.54% greater for Nellore heifers fed corn-based diets, although it did not affect ($P>0.05$) feed efficiency. The ADF intake

Table II. **Intakes (kg/day), average daily gain – ADG (kg/day), and feed conversion - FC of Nellore heifers fed two concentrate levels and energy sources.**

Item	70% Concentrate		80% Concentrate		*P value[3]			CV%
	CGC[1]	CGM[2]	CGC	CGM	CL	ES	CL × ES	
DMI	6.31	6.49	7.19	6.51	ns	ns	ns	16.64
DMI, g/kgBW$^{0.75}$	94.63	103.17	110.10	104.34	ns	ns	ns	17.15
CPI	0.99^{Ba}	1.08^{Aa}	1.17^{Aa}	0.84^{Ab}	ns	**	**	16.30
NDFI	3.31^{Ba}	3.27^{Aa}	4.05^{Aa}	3.46^{Ab}	ns	*	*	16.26
ADFI	2.44^{B}	2.59^{B}	3.22^{A}	2.82^{A}	*	ns	ns	16.30
ADG	1.08^{a}	0.88^{b}	1.07^{a}	0.73^{b}	ns	**	ns	28.74
FC	5.84	7.37	6.72	8.92	ns	ns	ns	30.11

[1]CGC: Corn grain cracked. [2]CGM: Corn germ meal. [3]Level significance of the effect of concentrate level (CL), energy source (ES), concentrate level x energy source (CL × ES). *Significant effect *P*<0.05, **Significant effect *P*<0.01, ns: Not significant *P*>0.05. Capital letters correspond to the effect of concentrate levels and lowercase letters, within the same level of concentrate, correspond to the energy source effect.

was also influenced (P<0.05) by concentrate level (Table II).

Carcass characteristics

There were differences due to the energy source (P<0.05) in final BW and EBW (Empty body weight), which was reflected in ADG, with the best results obtained for corn-based diets (Table III). Concentrate level and energy source affected (P<0.01) carcass internal fat deposition (perirenal, pelvic and inguinal). The empty gastrointestinal weight was influenced (P<0.05) just by the concentrate level. Other carcass characteristics were not affected by concentrate level or energy source (Table III).

The carcass physical composition, mainly represented by muscle and fat, was affected (P<0.05) by the concentrate level (Table IV). The commercial cuts yields, forequarter and hindquarter, did not differ with the concentrate level and energy source.

Longissimus quality characteristic

The flavor was not influenced by concentrate level and energy source (P>0.05), but there were interactions of these two factors for the parameters global preference and texture (P<0.05), being the energy source the most important cause of variation (Table V).

DISCUSSION

Intake and performance

The lack of effects of concentrate level and energy source on DMI could be attributed to the ingredients characteristics, whose substrate availability and degradation was not limiting, except for the sunflower meal, which has low fiber degradation. The fiber contributions

Table III. Feedlot performance, carcass and non-carcass traits of Nellore heifers fed two concentrate levels and energy sources.

Item[1]	70% Concentrate		80% Concentrate		*P* value[4]			CV%
	CGC[2]	CGM[3]	CGC	CGM	CL	ES	CL × ES	
Initial BW	208.48	200.14	203.14	203.57	ns	ns	ns	7.84
Final BW	329.57[a]	298.71[b]	322.71[a]	285.42[b]	ns	*	ns	12.54
EBW	313.09[a]	276.94[b]	305.78[a]	276.58[b]	ns	*	ns	14.64
HCW	182.35	164.78	177.28	164.64	ns	ns	ns	11.47
CYBW	55.32	55.12	54.93	56.00	ns	ns	ns	4.29
CYEBW	58.24	59.50	57.97	59.52	ns	ns	ns	10.18
BF	6.56	5.78	5.91	6.13	ns	ns	ns	43.38
LM	47.33	45.25	47.70	46.87	ns	ns	ns	12.85
PPIF	4.41[Ba]	3.59[Aa]	5.36[Aa]	3.73[Ab]	**	**	ns	30.33
EGIW	22.18[B]	23.58[B]	26.88[A]	27.45[A]	*	ns	ns	27.16

[1]Initial BW: Initial body weight (kg), Final BW: Final body weight (kg), EBW: Empty body weight (kg), HCW: Hot carcass weight (kg), CYBW: Carcass yield in relation to body weight (%), CYEBW: Carcass yield in relation to empty body weight (%), BF: 12th rib fat thickness (mm), LM: *Longissimus* muscle area (cm²), PPIF: Perineal, pelvic and inguinal fat (kg) and EGIW: Empty gastrointestinal weight (kg). [2]CGC: Corn grain cracked. [3]CGM: Corn germ meal. [4]Level significance of the effect of concentrate level (CL), energy source (ES), concentrate level × energy source (CL × ES). *Significant effect *P*<0.05, **Significant effect *P*<0.01, ns: Not significant *P*>0.05. Capital letters correspond to the effect of concentrate levels and lowercase letters, within the same level of concentrate, correspond to the energy source effect.

from forage and byproducts did not damage rumen stability, which constitute an important characteristic in high-concentrate diets.

Galyean & Deffor (2003) showed that diets containing 30% roughage have approximately 70% of intake variations explained by this source, but when assessing the amount of fiber, the effect rises to at least 92%. This demonstrates that the nutritional quality of this component is more important than the quantities. Thus, increasing amounts of fiber in high-concentrate diets, with special attention to byproducts, characterized by non-forage fiber, can reflect positively on the DMI, but not necessarily on performance.

Zebeli et al. (2008) showed that when increase peNDF up to 310 g/kg of dietary DM, the pH value increases, and probably in this study, the peNDF was above of this value. Then, byproducts containing high levels of NDF in high-concentrate diets can be strategically decisive when the use of grains in finishing heifers diets are needed, without causing metabolic disorders or compromising performance.

The DMI intake prediction for Nellore Brazilian cattle at 250 kg, to obtain 1 kg/day is 6.05 kg/day with approximately 80% TDN (Valadares Filho et al. 2006, Souza et al. 2012). According to the results, high-concentrate diets rich in non-forage fiber, do not decrease DMI and daily gain, but just if the energy intake requirements are achieved. It was observed that estimating the energy requirements of Brazilian Nellore heifers from observed daily gain (Souza et al. 2012), regardless the concentrate level, corn inclusion provided the required TDN (811.7 g/kg DM) to explain gains. Replacing corn by

Table IV. Carcass physical composition (%) and cushion thickness (cm) of Nellore heifers fed two concentrate levels and energy sources.

Item	70% Concentrate		80% Concentrate		*P* value3			CV%
	CGC[1]	CGM[2]	CGC	CGM	CL	ES	CL × ES	
Muscle	44.84^{B}	46.77^{B}	49.02^{A}	48.19^{A}	*	ns	ns	12.69
Fat	30.88^{B}	28.83^{B}	32.01^{A}	32.12^{A}	*	ns	ns	17.82
Bones	23.96^{A}	23.46^{A}	19.11^{B}	20.07^{B}	*	ns	ns	12.83
Muscle + Fat	75.72	75.60	81.03	80.31	ns	ns	ns	5.62
Forequater	48.49	47.77	48.16	46.94	ns	ns	ns	4.32
Hindquater	51.51	52.23	51.84	53.06	ns	ns	ns	4.30
Cushion hickness	25.14	24.85	24.52	24.85	ns	ns	ns	9.35

[1]CGC: Corn grain cracked. [2]CGM: Corn germ meal. [3]Level significance of the effect of concentrate level (CL), energy source (ES), concentrate level × energy source (CL × ES). *Significant effect *P*<0.05, **Significant effect, ns: Not significant *P*>0.05. Capital letters correspond to the effect of concentrate levels and lowercase letters, within the same level of concentrate, correspond to the energy source effect.

corn germ changed drastically weight gains, especially in 80% concentrate diet, because TDN decreased to 550.70 g/kg DM, corresponding to a drop of 46.50%. Then, despite the lack of any effect on DMI, corn germ diets provided lower energy intake, explaining the lower gains.

Diets were formulated with soybean hulls, a recognized high-fermentable ingredient that provides energy (Mendes et al. 2010, Liu & Li 2017). The ratio between energy sources and soybean hulls was about 1:1 in diets with corn, while the ones with corn germ meal presented 1.4 times more than soybean hulls. The lower amounts of starch provided by corn germ meal and the lower contributions of soybean hulls probably affected the energy intakes resulting in less weight gains. Russell et al. (2016) corroborate with current study by replace starch for fiber concentrate, decreasing the average daily gain in steers and heifers cattle.

Regarding to the NDF intake, a possible explanation for the interaction (*P*<0.05) between the concentrate level and energy source could be based by the importance of quantity and quality of fiber and its relationship with starch. The soybean hulls (30.1%) at diet containing 80% concentrate and corn was approximately 28% higher than the similar diet containing corn germ meal (23.5%), which reflected on the NDF intake (*P*<0.05). A recurrent concern about increases in concentrate is the NDF intake, because it tends to decrease due to the reduction of roughage. This fact was not observed in this study, which naturally was compensated with the use of high-fiber byproducts, especially soybean hulls.

Fiber and starch in this study are important because influenced the energy intake and probably the profile of nutrients available for absorption in the rumen (Dijkstra et al. 2012), however, this was not reflected on the subcutaneous fat. In the diets containing 70 or 80% concentrate, the ratio of starch and NDF was about 0.9:1, while in the diet containing corn germ meal this ratio was 0.65:1. These differences

Table V. ***Longissimus*** **muscle sensory characteristics of Nellore heifers fed two concentrate levels and energy sources.**

Item	70% Concentrate		80% Concentrate		*P* value[3]			CV%
	CGC[1]	CGM[2]	CGC	CGM	CL	ES	CL × ES	
Preference	6.57^{Bb}	6.37^{Bb}	6.70^{Bb}	7.27^{Aa}	ns	*	*	18.65
Flavor	6.77	6.73	6.83	7.30	ns	ns	ns	17.81
Texture	6.50^{Bb}	6.20^{Bb}	6.70^{Bb}	7.13^{Aa}	ns	*	*	19.09

[1]CGC: Corn grain cracked. [2]CGM: Corn germ meal. [3]Level significance of the effect of concentrate level (CL), energy source (ES), concentrate level × energy source (CL × ES). *Significant effect *P*<0.05, **Significant effect, ns: Not significant *P*>0.05. Capital letters correspond to the effect of concentrate levels and lowercase letters, within the same level of concentrate, correspond to the energy source effect.

reinforce the idea that replacing corn by corn germ meal, decreases energy intake, even when using soybean hulls. Despite the lack of effect (*P*>0.05) in the DMI, it seems reasonable to hypothesize that close relations between starch and NDF would be advisable, since only the energy source influenced dietary fiber intake (*P*< 0.01).

Crude protein intakes in diets with 70% concentrate were similar regardless the energy source, but in diets with 80% concentrate, corn demonstrated to be the most appropriate option (Table II). Mendes et al. (2005) mentioned that lower intakes of CP in diets with corn germ meal could be explained by the particle size of this ingredient, which despite being marketed pelletized, has very small particles, which adhere to the corn silage, increasing the percentage of protein in the refused feed.

Carcass characteristics

Regardless the concentrate proportions, diets with corn promoted greater gains (18 and 31%) and considering the ratio of starch and NDF mentioned earlier, it is clear that the possibility of keeping it close to 1, seems to be quite reasonable in high-concentrate diets.

The EBW is a variable determined by summing all components of the carcass, except the gastrointestinal contents and internal fat. The gastrointestinal tract, content decreases with an increase in the concentrate level, which improves carcass yield and other components of the empty body (Costa et al. 2005). Due, to the small difference between concentrate levels, the EBW was not affected.

The LM has been largely used to evaluate muscle development and carcass characteristics and quality because it could express the diet effect. Concentrate level or energy source did not change this variable probably because heifers of this study were originated from the same contemporaneous group and had the same breed composition. So, genetic, breed, sex and age are the most important factors which can significantly develop LM (Hocquette et al. 2012).

The carcass yield (CY) of female cattle is lower than males, castrated or not. In this study, the values of CY could be explained by the concentrate level, which provides better performance, but it is necessary to analyze the gain composition and the empty gastrointestinal weight. Just the concentrate level influenced the physical composition of the carcass, and the internal fat constituted by perirenal, pelvic and inguinal fat was affected by concentrate level and energy source, with great amounts of fat, especially in heifers fed with corn. So, the greater ADG assigned to heifers fed with corn is due to the higher perirenal, pelvic and inguinal fat deposition and it constitutes a loss of nutrients, mainly energy. It is desirable to obtain more than 3 mm of back fat, and it was observed in the present study (Table III), which is in accordance with the marketing requirements for the Brazilian beef industry (Diniz et al. 2010).

The concentrate level contributed to muscle development, which could be attributed in response of the energy intake, even for heifers fed with 80% concentrate and corn germ meal. However, for the edible portion and the hindquarter, none of the factors could express some effect.

Longissimus quality characteristics

The meat texture and global preference of *Longissimus* muscle were influenced by concentrate level and energy source, with the best results attributed to 80% concentrate and corn germ meal (Table V).

The back fat has an important function, protecting the carcass under cold storage. Thus, thicker layers of fat are more effective as an insulator, minimizing the shortening of muscle fibers caused by a decrease of the temperature on the muscle surface, which brings negative consequences to the tenderness and texture of meat. In this study, the back fat was above 3 mm, regardless the concentrate level or energy source, so, the carcass was protected against low temperature. Heifers fed corn had a greater deposition of internal fat than the ones fed corn germ meal, probably providing more marbling in the *Longissimus* muscle, which improved the preference, without causing flavor changes.

CONCLUSIONS

High proportions of concentrate containing corn as energy source provided the best performance in heifers, without compromising the dry matter intake. While the total replacement of corn by corn germ meal, in high-concentrate diets is not recommended to performance in Nellore heifers, the same presented satisfactory of qualities characteristics carcass, sensory specially, indicating a possible alternative substitute corn, when the diets compensated financially.

Acknowledgments

Authors wish to thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for scholarships, Caramuru, Itumbiara, GO, Brazil for providing part of the feed ingredients, students and staff of the College of Agricultural and Veterinary Sciences of the São Paulo State University for technical support.

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How to cite
VAN CLEEF EHCB, OLIVEIRA PSN, GALATI RL, FERREIRA DS, SANTOS VC, JUNIOR ACH, JÚNIOR SAGP, PARDO RMP & EZEQUIEL JMB. 2021. High-concentrate diets with fibrous by-products for feedlot Nellore heifers. An Acad Bras Cienc 93: e20190731. DOI 10.1590/0001-3765202120190731.

Manuscript received on June 25, 2019;
accepted for publication on October 2, 2019

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