R. Bras. Zootec., 53:e20220075, 2024
https://doi.org/10.37496/rbz5320220075

Biometeorology and animal welfare
Full-length research article

Revista Brasileira de Zootecnia

Brazilian Journal of Animal Science
e-ISSN 1806-9290
www.rbz.org.br

Shading success: Optimizing climatic conditions and performance of feedlot Nellore cattle in the semi-arid belt

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Received: June 23, 2022
Accepted: February 28, 2024

How to cite: Oliveira, E. M.; Carvalho, C. C. S.; Monção, F. P.; Ferreira, H. C.; Rocha Júnior, V. R.; Costa, M. D.; Ruas, J. R. M. and Rocha, H. C. M. 2024. Shading success: Optimizing climatic conditions and performance of feedlot Nellore cattle in the semi-arid belt. Revista Brasileira de Zootecnia 53:e20220075.
https://doi.org/10.37496/rbz5320220075

Editor:
Mateus Pies Gionbelli

ABSTRACT - The objective of this study was to evaluate, through principal component analysis, the effect of different feedlot structures on climatic conditions, nutrient intake, and performance of Nellore bulls during the feeding period in the semi-arid region. Data from 225 non-castrated Nellore bulls with initial mean body weight (BW) of 294 ± 19 kg and age of 24 months were used. This was done in a completely randomized design with three feedlot structures (no shading, natural shade, and artificial shade with 50% light interception), resulting in 75 repetitions (each animal serving as an experimental unit). The feeding period for the animals in the feedlot was 107 days. The first two components explained 99.65 (no shade), 97.32 (artificial shade), and 99.89 (natural shade) of total data variation. The variables, namely the black globe temperature index (0.88), radiant heat load (0.96, 0.99, 0.76), black globe temperature (0.96), and hot carcass weight (0.64) exerted the greatest influence on the feedlot structures. Climatic and intake variables were identified as having the most significant impact on feedlot structures. Artificial shade with 50% light interception shade cloth positively contributes to the hot carcass weight of feedlot Nellore cattle.

Keywords: ambience, *Bos indicus*, intensive system, productive performance, semi-arid

1. Introduction

Brazil is the largest producer and exporter of beef in the world. Of the total productive areas in Brazil, 18% are dedicated to beef cattle farming. In this system, the fattening time is longer, which is why the use of the intensive system is increasing, and in 2021 and 2022, 7.62 million heads of cattle were confined (ABIEC, 2023).

Due to the shorter finishing time associated with the rusticity of the Nellore breed, which makes up 80% of national herd, the feedlot facilities are mostly without roofs. However, the high demand for meat products has demanded that producers intensify and improve production processes, especially in meeting the precepts of animal welfare. While known for their tolerance to hot environments, Zebu animals undergo metabolic and physiological modifications to withstand adverse temperatures (Meneses et al., 2021, 2023). These modifications impact ruminal (Sales et al., 2021) and productive parameters (Ferraz et al., 2020; Meneses et al., 2021). Brown-Brandl (2018) highlighted that losses in animal performance can occur due to the lack of thermal comfort in feedlots. In this sense, the adequacy in feedlot facilities, such as the use of natural or artificial shade is necessary to improve the welfare and productive performance of animals (Grandin, 2016; Hagenmaier et al., 2016; Brown-Brandl, 2018), mainly in regions with high incidence of solar radiation, such as those registered in the semi-arid region.

In Brazil, several studies have been published on the positive effect of shade on the productive performance of beef cattle (Sullivan et al., 2011; Taveira et al., 2012; Dian et al., 2020). However, they are still scarce, and the results of research are controversial regarding the types of shading of the feedlot stall for beef cattle in the days on feed on the thermal comfort and performance of the animals. Baêta and Souza (2010) stated that the best shading system is natural, due to the microclimate provided by the shade of trees. Rovira and Velazco (2010) and Ferro et al. (2016) highlighted the polyethylene shade as an efficient material to improve the climatic conditions of the stall with lower cost and shorter time, compared with more sophisticated structures, such as tiles and other materials. It is considered that natural or artificial shading of the pens will improve the thermal comfort and performance of animals compared with pens without shade.

To evaluate and select the factors interfering with animal performance, multivariate statistical analysis has been a recommended tool, especially principal component analysis (PCA). Muniz et al. (2014) stated that this technique helps in the development of beef cattle breeding programs, and it is necessary to know the importance and contribution of each of the variables involved. Thus, they use the principal component technique to investigate the structure of covariances and dependency relationships between the characteristics studied.

Therefore, the objective was to evaluate, through PCA, the effect of different feedlot structures on climatic conditions, nutrient intake, and performance of Nellore males in the days on feed.

2. Material and Methods

All procedures involving animals were approved by the Institutional Ethics Committee for Animal Research (protocol number 185/2019). This study was developed based on performance data initially presented by Ferreira et al. (2021). The study was carried out in Itacarambi, Minas Gerais, Brazil (15°01’2.3” S latitude, 44°03’48.3” W longitude).

Two hundred and fifty Nellore cattle (intact, with an initial mean body weight (BW) of 294 ± 19 kg and an age of 24 months) were used. Lots were made up of Nellore animals acquired in several regional farms and reared in feedlot for 90 days. At the beginning of the days on feed, animals were individually weighed on a digital scale (Valfran®, III class, Votuporanga, São Paulo, Brazil), identified by an earring, and dewormed with 15% albendazole sulfoxide (Agebendazol®, União Química, Embu Guaçu, São Paulo, Brazil).

Three groups of seventy-five animals were distributed in two pen management strategies: natural shading (n = 75) with trees and artificial shading (n = 75) using shade cloth and the control group (no shade; n = 75), in pens with 1,200 m^2. The three pens were positioned in the east-west direction. In the control group, the animals were exposed to direct solar radiation (Figure 1).

In the natural shading, mesquite (*Prosopis juliflora* (Sw) DC) and Leucaena (*Leucaena leucocephala*) trees were planted linearly, every 5 m, in the unilateral region of the pen, allowing shading, corresponding to 40% of the total area (Figure 2). In the artificial shading system, a shade cloth made with polyethylene threads and a light interception of 50% was used. The shade cloth was 12 m wide and 30 m long, installed 10 m from the feeding trough in the east-west direction, at the center of the stall (Figure 3). The shade was set up in 30% of the total area of the pen, with 4.8 m^2 per animal (adapted from Ferro et al., 2016).

The diet was offered daily, allowing 5% leftovers of the amount of dry matter (DM) supplied. The diet was the same in all treatments and throughout the experimental period, maintaining the forage:concentrate ratio of 42:58 in the total DM of the diet, and it was offered to the animals five times a day, at 07:30, 11:00, 13:00, 15:00, and 17:00 h in a complete diet system (total mixed ration), using a total mixing wagon with a capacity of 6.1 m^3 (Rotormix express 3120, electronic on-board scale, Kuhn do Brasil, Passo Fundo, Rio Grande do Sul, Brazil).

Figure 1 - Pen with no shading.

Figure 2 - Pen in the natural shading.

The forage base of the diets was corn silage (*Zea mays*), which was weighed daily and mixed with rehydrated corn grain silage and concentrate mineral mixture. Animals were kept in collective pens of 1,200 m^2, equipped with troughs (30 linear meters) and drinkers (600-L capacity). The days on feed of the animals in feedlot lasted 107 days.

Figure 3 - Pen in the artificial shading system.

Samples of ingredients, diets, refusals, and feces were analyzed for DM (method 967.03), ash (method 942.05), and crude protein (CP; method 981.10). Neutral detergent fiber content corrected for ash and protein (NDF) was analyzed using thermostable alpha-amylase without sodium sulfite (Mertens, 2002; Licitra et al., 1996). Total digestible nutrients (TDN) were estimated using the formula proposed by the National Research Council (NRC, 2016). Indigestible neutral detergent fiber (iNDF) was analyzed by incubating the diet, refusals, and fecal samples in non-woven bags (100 and 50 mm; Aurora Têxtil, Leopoldina, Minas Gerais, Brazil) into the rumen for 288 h (Detmann et al., 2012; method INCT-CA F-008/1). Four eight-year-old rumen-cannulated adult crossbred cattle (Holstein × Zebu) weighing 480 ± 30 kg were used for the *in situ* incubation.

The thermal environment was analyzed for 37 consecutive days using RHT10 dataloggers set to collect information on air temperature (°C), relative humidity (%), dew point temperature (Dpt; °C), and black globe temperature (BGT; °C) in the full sun, artificial shade, and a natural shade (trees) pens every 30 min. The dataloggers were installed at 1.70 m above the ground level. The data were used to calculate the black globe temperature and humidity index (BGHI) according to Buffington et al. (1981) following the model:

$$BGHI = Dpt + 0.36 \times Bgt + 41.5$$

Wind speed and the radiant heat load (RHL; $W.m^{-2}$) were measured using a portable digital anemometer (Esmay, 1982), every 30 min, and the values were recorded on spreadsheets. The RHL characterizes the amount of radiant energy emitted in a given environment.

$$RHL = \sigma(MRT)^4$$

wherein σ = Stefan–Boltzmann constant (5.67×10^{-8} $W.m^{-2}$ K^{-4}).

The animals were weighed using an electronic scale at the beginning and end of the experiment after fasting from liquids and solids for 16 h. Animal performance was assessed by average daily weight gain (ADG; kg/day), which was calculated as the difference between the initial body weight (IBW; 15 July, 2019) and final body weight (FBW; 30 October, 2019) divided by the number of days in the feedlot (107 days). Feed efficiency was estimated as the ratio of ADG by DMI. The observed ADG values can be verified in Ferreira et al. (2021).

The animals were slaughtered in a commercial slaughterhouse (140 km away from the farm) after reaching a minimum body weight (BW) of 400 kg. After the slaughter process, the half-carcasses were weighed to obtain hot carcass weight, which was used to estimate carcass transfer. The initial carcass transfer was considered to be 50%, according to Sampaio et al. (2017). Carcass transfer, expressed as a proportion of the ADG, was calculated by the adapted equation from Sampaio et al. (2017):

$$Carcass\ transfer = \frac{Final\ hot\ carcass\ weight - Initial\ hot\ carcass\ weight}{Final\ body\ weight - Initial\ body\ weight} \times 100$$

Principal component analysis was performed to better understand the nature of the relationship between the variables studied and the independent variables. For this analysis, 10 studied characteristics were considered: BGHI, RHL, BGT, DM intake (DMI), CP intake (CPI), iNDF, TDN, IBW, and FBW, hot carcass weight, and hot carcass yield. Based on the correlation matrix between the characteristics, data were subjected to PCA, in which the variables were standardized to have a mean of 0 and a variance of 1. The correlation matrix was used instead of a covariance matrix (Johnson and Wichern, 2007).

Kaiser's method (1960) was used to retain the principal components that best explain the variability in the data set for the other analyses and interpretations. In this method, eigenvalues equal to or greater than 1 were considered, since the original variables also have a variance equal to 1, after being standardized. To compare the variables, new standardized variables were created from the original ones, as follows:

$$Vp = \frac{(V - x)}{\sigma}$$

wherein Vp = new weighted variable, V = observed variable, x = mean of the observations of the original variable, and σ = standard deviation of the observed variable.

In PCA, each principal component (Y_i) corresponds to a linear combination of the 10 standardized variables (X_j), and these combinations are not correlated with each other:

$$Y_i = a_{i1}X_1 + a_{i2}X_2 + \ldots + a_{ip}X_p = \sum_{j=1}^{p} a_{ij}X_j$$

wherein a_{ij} are the eigenvectors, with i = 1, 2, p and

$$\sum_{j=1}^{p} a_{ij}^2 = 1$$

The first principal component, Y_1, has the maximum variance among all linear combinations of X. The second principal component is uncorrelated with the first and has the second highest variance, and so on. For each principal component Y_i, there is *p* eigenvalue (λ) ordered in such a way that:

$$\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_p$$

The relative importance of a principal component was evaluated from the percentage of total variance explained by it, that is, the percentage of its eigenvalue in relation to the total eigenvalues of all components, given by:

$$Y_i = \frac{Var\ (Y_i)}{\sum_{i=1}^{p} Var(Y_i)} \times 100 = \frac{\lambda_i}{\sum_{i=1}^{p} \lambda_i} \times 100$$

The interpretation of each of the principal components selected was performed according to the variables with the highest weighting coefficients (eigenvectors), in absolute value. In the literature, there is no specific value that determines when a weighting coefficient is important, so these values were interpreted according to the relationship between the characteristics within each component.

The experiment was carried out following a completely randomized design with three treatments and 75 replications. Each animal was an experimental unit according to the statistical model:

$$Y_{ij} = \mu + T_i + PI + e_{ij}$$

wherein Y_{ij} = observation referring to treatment i, within repetition j; μ = constant associated with all observations; T_{ij} = effect of treatment i, with i = 1, 2 and 3; PI = IBW as a covariate; and e_{ij} = experimental error associated with all observations (Y_{ij}), independent, which by hypothesis has a normal distribution with mean zero and variance δ^2.

The treatment means when significant by the F test were grouped using the Scott Knott test considering P<0.05. For exploratory data analysis by PCA, PAST® 4.03 software was used (Hammer et al., 2001).

3. Results

Variables RHL and DMI, expressed as a percentage of BW, presented higher weighting coefficients within the PC1 with greater impacts on the explained variance, 63.70%. While in PC2, BGT had the highest weighting coefficient (0.92) (Table 1).

Among the dependent variables, RHL, DMI, and BGT showed the greatest contribution to the explained variance of the results.

Variables BGT and IBW showed a positive correlation for PC2, while the RHL showed a positive correlation for PC1 and a negative for PC2. Final body weight showed a negative correlation for PC1 and PC2 (Figure 4).

Components PC1 and PC2 presented eigenvalues that explained 87.14% of data variance. For these components, eigenvectors were above 1 (Figure 5).

In animals kept in a pen without shade, the first two principal components (PC 1 and PC 2) explained 99.65% of data variance. The highest weighting coefficients (eigenvectors) were observed for RHL (0.96; PC1) and BGT (0.96; PC2). These variables had a greater impact on animal performance (Table 2).

In the natural shading of the pen, RHL explained 99.71% (PC1) of the variation in the results, followed by BGHI (0.88; PC2) that explained 0.18%.

In the PCA for the shading strategy using 50% shade cloth, it was found that RHL (coefficient of 0.76) and hot carcass weight (coefficient of 0.64) explained 97.32% of the variance of the results.

Table 1 - Joint principal component analysis of the shading strategies of the Nelore cattle stall in the feedlot finishing phase

Item	Eigenvector	
	PC1	PC2
Climatic characteristics		
Black globe temperature and humidity index	0.09	0.01
Radiant thermal load	0.94	−0.24
Black globe temperature	0.16	0.92
Intake (% crude protein)		
Dry matter	0.70	−0.01
Crude protein	0.00	0.00
Indigestible neutral detergent fiber	0.00	0.00
Total digestible nutrients	0.00	0.00
Performance (%)		
Initial body weight	−0.05	0.24
Final body weight	−0.12	−0.17
Hot carcass weight	−0.24	−0.25
Cold carcass yield	0.00	−0.01
Explained variance (%)	63.70	23.44

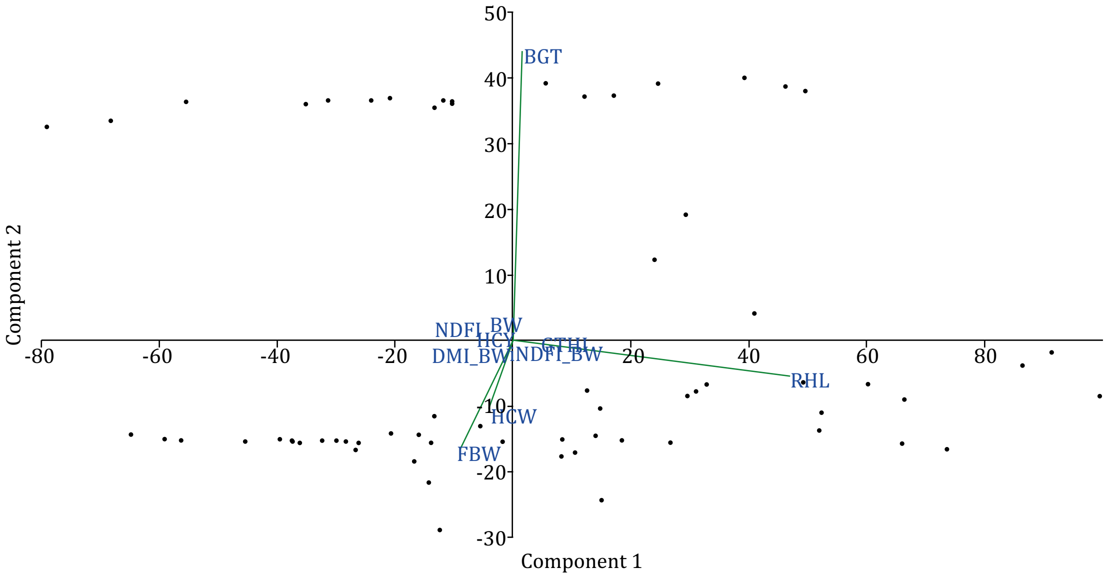

Figure 4 - Schematic representation of the main components of the shading strategies of the Nelore cattle stall in the feedlot finishing phase.

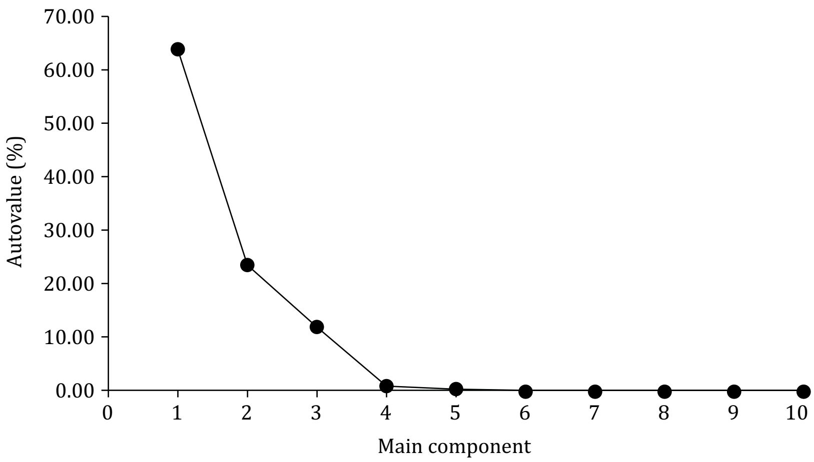

Figure 5 - Scree Plot of the eigenvalues corresponding to each of the 10 main components.

4. Discussion

The PC1 had the greatest contribution, with 63.70% data variability, while PC2 had the least influence (23%) (Table 1). The variables of PC1 with the highest weighting coefficients (eigenvectors) were RHL (0.94%) and DMI (0.70%), while for PC2, BGT had the highest weighting coefficient (92%). Therefore, based on these components, it appears that the climatic and intake characteristics were the most influenced by the feedlot structures.

Under heat stress conditions, one of the main changes in the physiological adaptation mechanism of beef cattle is the decline in DMI (Meneses et al., 2021). This reduction occurs by the inhibitory action on the appetite center, by the increase in respiratory rate, and the activity of the gastrointestinal tract. This results in a decrease in the rate of feed passage and accelerates the inhibition of intake by filling the rumen (Meneses et al., 2021). This alteration is one of the mechanisms that allow the animal to regulate its body temperature, within a temperature range compatible with its metabolic activity (NRC, 2000) and occurs in many other species (Kim et al., 2023; Ross et al., 2015).

Table 2 - Analysis of individual principal components of pen shading strategies of Nellore cattle in the feedlot finishing phase

Item	No shading		Natural		50% shading	
	PC1	PC2	PC1	PC2	PC1	PC2
Climatic characteristics						
Black globe temperature and humidity index	0.08	0.01	0.11	0.88	0.00	0.02
Radiant thermal load	0.96	0.27	0.99	−0.16	−0.65	0.76
Black globe temperature	−0.27	0.96	0.13	0.44	−0.01	0.01
Intake (% crude protein)						
Dry matter	0.00	0.00	0.00	−0.07	0.00	0.00
Crude protein	0.00	0.00	0.00	0.01	0.00	0.00
Indigestible neutral detergent fiber	0.00	0.00	0.00	0.01	0.00	0.00
Total digestible nutrients	0.00	0.00	0.00	0.07	0.00	0.00
Performance (%)						
Initial body weight	−0.05	0.24	−0.05	0.24	−0.05	0.24
Final body weight	0.00	0.01	0.00	0.00	0.40	0.37
Hot carcass weight	0.00	0.00	0.00	0.00	0.64	0.54
Cold carcass yield	0.00	0.00	0.00	0.00	0.01	0.02
Explained variance (%)	81.22	18.43	99.71	0.18	68.68	28.64

Analyzing the two selected components, the characteristics classified in order of importance, with the highest values of weighting coefficients, were RHL, BGT, and DMI. The intake (CP, iNDF, TDN) (PC1) and performance (carcass yield) (PC2) variables did not impact the analysis due to the low weighting coefficient. This is corroborated by Aranha et al. (2019), who detected no differences in animal performance kept in integrated crop-livestock-forestry systems (ILPF) when compared with those kept in full sun. However, they observed an improvement in thermal comfort provided to the animals in the ILPF system.

Black globe temperature had the highest correlation (Figure 4), contributing substantially to PC2, resulting in greater variability of this characteristic when compared with the other variables. For PC1, RHL had the highest correlation among the characteristics studied.

These results indicate that the climatic characteristics had a greater influence on the different shading strategies of the feedlot stalls. Cattell (1996) proposed the *Scree Plot* test, which identifies the factors of a scale (Figure 5). What determines the importance of each principal component in this plot is the inflection point of the curve. The principal component with the highest eigenvalue contributes most to explaining the variability in the dataset. The more the component is added, the smaller the difference between the eigenvalues, especially after the inflection point (Silva et al., 2015b). In this study, the inflection point was recorded up to the second component, where there was an explanation of 87.14% data variability.

According to Silva et al. (2015a), eigenvalues have the power to explain the total variation of the original (observed) variables, and these are the variance of the principal components, in this case, the variance is equal to 10. Silva et al. (2015b) pointed out that this total variation depends on the number, type, and way in which these variables are included and correlated in the analysis.

The analysis generated 10 principal components. According to Kaiser (1960), in all shading strategies, the first two components were selected because they had a variance (eigenvalue) greater than 1.00 and explained 99.65% (no shade), 97.32% (artificial shade), and 99.65% and 99.89% (natural shade) of the total variation present in the dataset.

Variables with the greatest influence on the feedlot structures were BGHI (0.88), RHL (0.96; 0.99; 0.76), and BGT (0.96) for the two principal components and shading strategies, respectively, except for the shade cloth in which the variables with the greatest influence (PC1) for natural shade was RHL (−0.65), which showed moderate negative correlation, and hot carcass weight (0.64) (Table 2).

According to Pinheiro et al. (2015), direct solar radiation is one of the components that most contribute to the heat load in cattle, causing changes in its physiological mechanism, such as increased body temperature, respiratory rate, and heart rate. Storti et al. (2019) analyzed heat stress indices in young Nellore raised in a tropical environment and mentioned that high RHL contributes to reduced welfare, so they suggested natural or artificial shading for both animals raised on pasture and in feedlot. Reducing heat stress by implementing adaptation measures will reduce economic losses in these systems (Schauberger et al., 2021).

5. Conclusions

The climatic and intake variables rank with the greatest impact from the feedlot structures. Artificial shading with 50% light interception shade cloth contributes positively to the hot carcass weight of feedlot Nellore cattle.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Conceptualization: Oliveira, E. M.; Monção, F. P.; Costa, M. D. and Ruas, J. R. M. **Data curation:** Oliveira, E. M.; Carvalho, C. C. S. and Monção, F. P. **Formal analysis:** Monção, F. P.; Rocha Júnior, V. R.; Costa, M. D. and Ruas, J. R. M. **Funding acquisition:** Carvalho, C. C. S. and Rocha Júnior, V. R. **Investigation:** Oliveira, E. M. **Methodology:** Oliveira, E. M.; Monção, F. P.; Ferreira, H. C.; Rocha Júnior, V. R. and Rocha, H. C. M. **Project administration:** Carvalho, C. C. S. **Resources:** Carvalho, C. C. S. **Validation:** Carvalho, C. C. S. and Monção, F. P. **Visualization:** Carvalho, C. C. S. **Writing – original draft:** Oliveira, E. M. and Carvalho, C. C. S. **Writing – review & editing:** Oliveira, E. M.; Carvalho, C. C. S.; Monção, F. P.; Costa, M. D. and Ruas, J. R. M.

Acknowledgments

The authors would like to thank the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG; TO – 37300351/2021), Universidade Estadual de Montes Claros (Unimontes), and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for assistance with scholarships/research.

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