Effect of shading strategies on intake, digestibility, respiratory rate, feeding behaviour, and performance of feedlot-finished Nellore bulls in the semi-arid region of Brazil

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ABSTRACT
The objective of this study was to evaluate the effects of different shading strategies on the intake and digestibility of nutrients, nutrient use efficiency, feeding behaviour, respiratory rate, and performance of feedlot-finished Nellore bulls in the semi-arid region of Brazil. Two hundred and twenty-five intact Nellore cattle with average body weight (BW) of 294 ± 19 kg and 24 months of age were allotted to a completely randomised design with three shading strategies (full sun, artificial shade, and natural shade). There was a significant effect of shading strategies on air temperature ($p = .02$), black globe temperature ($p < .01$), and radiant heat load ($p < .01$), which were 3.63%, 44.07%, and 4.10% higher in the full sun pen than in natural shade pen, respectively. The dry matter intake of animals kept in the natural shade pen was 14.76% higher than that of animals in the full sun pen (mean of 7.39 kg DM/day). The longest feeding time ($p = .02$) was observed in animals kept in the artificial shade pen. Bulls kept in the natural shade pen had the highest ($p = .05$) final body weight and average daily gain ($p = .02$). There was no effect of treatments on feed efficiency, averaging 0.184 kg/kg of DM. There was a trend ($p = .09$) towards higher hot carcase weight for animals kept in the natural shade pen. Natural shade is recommended for feedlot-finished Nellore cattle in the semi-arid region of Brazil.

HIGHLIGHTS
- Natural shade in feedlot pens improves the thermal comfort of animals in the semi-arid region
- The dry matter intake was higher in bulls kept in the pen with natural shade than in animals kept in the full sun pen
- Animal performance was improved in shaded pens

Introduction
The use of intensive production systems for finishing beef cattle in Brazil has increased sharply in recent years (Vellini et al. 2020). Approximately 11.7% of the 44.5 million cattle slaughtered in Brazil annually are finished in feedlots (Abiec 2019). The number of feedlot-finished animals tends to increase due to the consumers’ demand for better-quality meat and the prices of inputs used in feedlot diets.

During the finishing phase, which lasts from 80 to 120 days in Brazil, cattle are fed diets containing high energy density in order to maximise carcase and backfat gains. Given the short finishing time and the well-known climate adaptation of Zebu animals (Bos Taurus indicus) that comprises approximately 80% of the animals slaughtered in Brazil, few feedlot facilities are equipped with natural and/or artificial shade. Besides the beneficial effects on nutrition and animal health, the thermal comfort provided by shading contributes to improving animal performance and welfare (Rovira and Velazco 2010; Ferro et al. 2016; Brown-Brandl 2018). According to Sullivan et al. (2011), stressful conditions trigger adaptive mechanisms that modify the physiological, metabolic, and behavioural...
parameters of animals and may result in low performance. Thus, using tools that alleviate thermal conditions during the finishing phase is essential to slaughter young, heavy, and well-finished cattle. The use of trees or a shade cloth made of polyethylene in feedlot pens can be strategic in the finishing phase (Chiquitelli Neto et al. 2015). However, few studies have evaluated the effects of shade during the finishing phase on cattle performance (Rovira and Velazco 2010; Ferro et al. 2016), mainly in the semi-arid region. Therefore, there are gaps in knowledge regarding the effects of shade (natural and/or artificial) in feedlot pens on nutrient intake, feeding behaviour and performance of Nellore cattle. This study hypothesises that modifying the traditionally used feedlot facility in Brazil by providing artificial or natural shade will provide better thermal comfort to the animals and improve feed efficiency and cattle performance.

Based on the above, the objective of this study was to evaluate the effects of different shading strategies (natural, artificial, full sun) in feedlot pens on intake and digestibility of nutrients, nutrient use efficiency, feeding behaviour, respiratory rate, and performance of Nellore bulls during the finishing phase in a semi-arid region.

### Materials and methods

#### Location

The study was carried out in the municipality of Itacarambi, Minas Gerais, Brazil (geographic coordinates: 15°01'02.3"S latitude, 44°03'48.3"W longitude) from July to November 2019.

#### Treatments, animal history, management, and diet

Two hundred and twenty-five intact Nellore cattle with average body weight (BW) of 294 ± 19 kg and 24 months of age were used. Seventy-five animals were allotted to one of three shading strategies in the feedlot pen: full sun, artificial shade, and natural shade with trees. The animals were kept in a single pen according to each treatment group. The pen with natural shade had a single row of trees of the species *Prosopis juliflora* (Sw) DC and *Leucaena leucocephala*, spaced 5 m apart, along the side of the pen, producing 400 m² of shade (30 m × 40 m; 1,200 m²). The pen with artificial shade had a shade cloth made of polyethylene with 50% shade block, which covered 30% of the total area of the pen (adapted from Ferro et al. 2016). The groups of animals were formed by Nellore bulls purchased from different farms in the region and were kept in the feedlot during the growing phase for 90 days. At the beginning of the finishing phase, the animals were weighed (digital scale; Valfran® III class model, Votuporanga, São Paulo, Brazil), individually tagged with ear tags and drenched with 15% albendazole sulfoxide (Agebendazol®, União Química, Embu Guaçu, São Paulo, Brazil).

The diet was offered daily, allowing 5% of refusals (on a DM basis). The diet was the same for all treatments during the experimental period, maintaining a forage: concentrate ratio of 42:58 in the total dry matter. The diet was fed (20% of daily intake) to the animals five times a day at 7:30 a.m., 11:00 a.m., 1:00 p.m., 3:00 p.m., and 5:00 p.m. as a total mixed ration (TMR). The TMR was prepared using a mixing wagon equipped with feed troughs (30 linear metres) and waterers (600 litres capacity). The experimental period lasted for 107 days, divided into 70 days for adaptation to diets and handling and 37 for data collection.
Sample of ingredients, diets, refusals, and faeces were analysed for dry matter (DM; method 967.03), ash (method 942.05), crude protein (CP; method 981.10), and ether extract (EE; method 920.39) as recommended by AOAC (1990) (Tables 1 and 2). The neutral detergent fibre content corrected for ash and protein (using thermostable alpha-amylase without sodium sulfite) (NDF; Mertens 2002; Licitra et al. 1996) and acid detergent fibre (ADF) contents were determined as described by Van Soest et al. (1991). Lignin was determined by treating the fibre residue in acid detergent fibre (iNDF) was analysed by incubating the diet, (NDF; Mertens 2002; Licitra et al. 1996) and acid detergent fibre (ADF) contents were determined as described by Van Soest et al. (1991). Lignin was determined by treating the fibre residue in acid detergent with 72% sulphuric acid. The content of non-fibrous carbohydrates (NFC) was calculated as percentage of dry matter (DM) (Detmann et al. 2012; Orskov and McDonald 1979). The indigestible neutral detergent fibre (iNDF) was analysed by incubating the diet, refusals, and faecal samples in non-woven bags (NWS, weight 100), measuring 12 × 7 cm, with porosity of approximately 50 µm, according to Casali et al. (2009), with quantity of samples following a ratio of 20 mg DM/cm² of surface area of the bag (Nocek 1988).

Samples of corn silage and silage of rehydrated corn grain and diet were evaluated, all used during the experiment for nutritional characterisation. The samples were deposited in the ventral sac region of the rumen for 0, 3, 6, 12, 24, 48, 72, 96, 120 and 144 h. The bags were placed in reverse order, starting with 144 h. The samples referring to time 0 h were washed in running water (20 °C) along with the other samples, aiming at stopping the ruminal fermentation. Subsequently, the samples were placed in forced ventilation oven at 55 °C for 72 h and cooled in a desiccator and weighed. The remaining residues in the NWS bags, collected in the rumen, were analysed for DM content. The percentage of degradation was calculated by the proportion of feed remaining in the bags after ruminal incubation. The data obtained were adjusted for a non-linear regression by the Gauss–Newton method (Neter et al. 1985), using the SAS software (SAS Institute, Cary, NC, USA), according to the equation proposed by Orskov and McDonald (1979): \( Y = a + b \left(1 - e^{-ct}\right) \), where: \( Y \) = accumulated degradation of the analysed nutritional component, after time \( t \); \( a \) = intercept of degradation curve when \( t = 0 \), which corresponds to the water-soluble fraction of the analysed nutritional component; \( b \) = potential for degradation of the water-insoluble fraction of the analysed nutritional component; \( a + b \) = potential degradation of the nutritional component analysed when time is not a limiting factor; \( c \) = rate of degradation by fermentative action of \( b \); \( t \) = incubation time (Table 3). Once calculated, the coefficients \( a \), \( b \) and \( c \) were applied to the equation proposed by Orskov and McDonald (1979): \( ED = a + (b \times c / c + k) \), where: \( ED \) = effective ruminal degradation of

**Table 2. Composition of ingredients used in the animals’ diet during the experiment.**

| Item                        | Corn silage | Silage of rehydrated corn grain | Ground corn | Soybean meal | Protein mineral mix |
|-----------------------------|------------|---------------------------------|-------------|--------------|-------------------|
| Dry matter                  | 34.51      | 67.19                           | 88.84       | 90.01        | 92.37             |
| Ash                         | 4.97       | 0.81                            | 1.68        | 6.92         | 45.00             |
| Crude protein               | 7.22       | 7.78                            | 9.72        | 50.08        | 55.09             |
| Ether extract               | 3.30       | 3.71                            | 3.76        | 2.69         | 1.88              |
| Neutral detergent fibre     | 46.74      | 8.57                            | 15.82       | 19.21        | 7.91              |
| NDFap                       | 44.03      | 7.42                            | 14.21       | 11.04        | 7.11              |
| Acid detergent fibre        | 32.21      | 3.18                            | 3.84        | 8.63         | 1.92              |
| Lignin                      | 12.92      | 1.25                            | 1.37        | 1.73         | 1.69              |
| Total carbohydrates         | 80.51      | 84.71                           | 84.58       | 41.29        | 42.29             |
| Non-fibrous carbohydrates   | 33.77      | 76.14                           | 69.92       | 26.82        | 34.96             |
| Total digestible nutrients  | 64.73      | 84.79                           | 81.34       | 73.00        | 68.50             |
| Indigestible neutral detergent fibre | 18.19 | 3.66                             | 3.73        | 1.91         | 1.86              |

NDFap: neutral detergent fibre corrected for ash and protein.

**Chemical composition, intake, and digestibility of nutrients**

For the evaluation of ruminal kinetics, four adult crossbred cattle (Holstein × Zebu) were used, randomly, weighing 480 ± 30 kg. The animals received 6.0 kg of concentrate, divided into two meals, morning and afternoon, in addition to the supply of roughage based on sorghum silage. The in situ degradability technique was used using non-woven synthetic fibre bags (NWS, weight 100), measuring 12 × 7 cm, with porosity of approximately 50 µm, according to Casali et al. (2009), with quantity of samples following a ratio of 20 mg DM/cm² of surface area of the bag (Nocek 1988).
the analysed nutritional component; \( k \) = passage rate digesta. The passage rate digesta were assumed to be estimated at 2, 5 and 8% per hour, as suggested by the AFRC (1993).

### Assessment of the thermal environment

The thermal environment was analysed for 37 consecutive days using RHT10 dataloggers set to collect information on air temperature (°C), relative humidity (%), dew point temperature (°C), and black globe temperature (°C) in the full sun, artificial shade and natural shade (trees) pens every 30 min. The data loggers 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) according to the following model:

\[
\text{BGHI} = \text{Dpt} + 0.36 \times \text{Bgt} + 41.5 \quad (1)
\]

where

- \( \text{Dpt} \) = Dew point temperature (°C)
- \( \text{Bgt} \) = Black globe temperature (°C)

Wind speed and the radiant heat load (RHL) were measured using a portable digital anemometer (Esmay 1982). The RHL characterises the amount of radiant energy emitted in a given environment.

\[
\text{RHL} = S \times (\text{MRT})^4 \quad (2)
\]

where

- \( \text{RHL} \) = radiant heat load, on W m\(^{-2}\)
- \( S \) = Stefan–Boltzmann constant (5.67 \times 10\(^{-8}\)W m\(^{-2}\)K\(^{-4}\))

The mean radiant temperature (MRT) was obtained according to the equation:

\[
\text{MRT} = 100 \sqrt{2.51x \sqrt{Vx(bgt - dbt)} + \frac{bgt}{100}} \quad (3)
\]

where

- \( \text{MRT} \) = mean radiant temperature, K;
- \( V \) = wind speed, m/s

### Respiratory rate

The respiratory rate was measured in the same five animals per treatment at 5-day intervals during the experimental period, totalling seven collections (each collection was considered as an experimental unit). Respiratory rate was recorded three times throughout the day (9:00 a.m., 1:00 p.m. and 5:00 p.m.) using visual observation of flank movements for 60 s (Brown-Brandl et al. 2006).

### Assessment of feeding behaviour

Feeding behaviour was evaluated for 24 h at 7-day intervals during the experimental period, totalling four evaluation periods (1, 8, 15, and 22 days before slaughter). Five animals (experimental units) per pen were numbered sequentially with red paint, characterised (i.e. cut ear, hornless), and observed at 5-min intervals. The times spent feeding, ruminating, and resting were measured according to the methodology described by Mezzalira et al. (2011). In the same animals, the number of chews per bolus was counted, and the time spent chewing each bolus was determined using a digital timer. The time spent chewing each bolus and the number of chews per bolus were obtained from observations made during the ruminating of three boluses at three different periods of the day (9 a.m. to 11 a.m.; 5 p.m. to 7 p.m. and 9 p.m. to 11 p.m.) according to the methodology described by Burger et al. (2000).

### Animal performance and slaughter

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 the average daily weight gain (ADG; kg/day), which was calculated determined by as the

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### Table 3. Ruminal kinetics of the dry matter of the ingredients and the experimental diet.

| Item                      | Corn silage | Silage of rehydrated corn grain | Diet | SEM |
|---------------------------|-------------|---------------------------------|------|-----|
| Fraction a, %             | 25.74       | 39.22                           | 35.68| 0.41|
| Fraction b, %             | 43.08       | 46.27                           | 43.16| 1.83|
| Degradation rate c, %/h   | 3.35        | 3.34                            | 3.34 | 0.14|
| Colonisation time, h      | 5.08        | 7.06                            | 6.73 | 0.37|
| Potential degradability, %| 68.83       | 85.50                           | 78.84| 1.90|
| Effective degradability, k=2%| 52.58      | 68.00                           | 62.68| 1.35|
| Effective degradability, k=5%| 42.93      | 57.65                           | 52.97| 1.00|
| Effective degradability, k=8%| 38.40      | 52.78                           | 48.39| 0.81|
| Undegradable fraction, %  | 31.16       | 14.50                           | 21.15| 1.90|

SEM: standard error of the mean; \( k \) = passage rate digesta (AFRC 1993).
difference between the initial body weight (15 July 2019) and final body weight (30 October 2019) divided by the number of days in the feedlot (107 days). Feed efficiency was estimated as the ratio of ADG to DMI.

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

\[
\text{Carcase transfer} = \frac{\text{final hot carcass weight} - \text{initial hot carcass weight}}{\text{final BW} - \text{initial BW}} \times 100
\]

**Experimental design and statistical analysis**

Data on intake and digestibility were analysed as a completely randomised design with three treatments and 17 replicates. Performance-related variables were analysed as a completely randomised design with three treatments and 75 replicates. Data were submitted to analysis of variance using the GLM procedure of SAS, version 9.0 (SAS Institute, Cary, NC, USA). The UNIVARIATE procedure was used to detect outliers and to test the normality of the residuals. Nutrient intake, digestibility, feed efficiency, and animal performance were analysed according to the model:

\[
Y_{ij} = \mu + T_i + \text{IBW} + e_{ijk}
\]

where

- \(Y_{ij}\) = observed response of the ‘j’th bull from the ‘i’th treatment;
- \(\mu\) = overall mean;
- \(T_i\) = Effect of the ‘i’th treatment, with ‘i’=1, 2 and 3;
- \(\text{IBW}\) = Initial body weight as a covariate;
- \(e_{ijk}\) = independent experimental error associated with all observations \((Y_{ijk})\), assumed to be normally distributed with zero mean and unit variance.

Data on feeding behaviour and respiratory rate were analysed as a split-plot completely randomised design with three treatments and four evaluation periods with five replicates according to the following model:

\[
Y_{ijk} = \mu + T_i + P_j + T_iP_j + \text{IBW} + e_{ijk}
\]

where

- \(Y_{ijk}\) = observed response of the ‘j’th bull from the ‘i’th treatment at the ‘j’th period;
- \(\mu\) = overall mean;
- \(T_i\) = Effect of the ‘i’th treatment, with ‘i’=1, 2 and 3;
- \(P_j\) = Effect of the ‘j’th evaluation period, with ‘j’=1, 2, 3 and 4;
- \(T_iP_j\) = Effect of the interaction between treatments ‘i’ and evaluation periods ‘j’;
- \(\text{IBW}\) = Initial body weight as a covariate;
- \(e_{ijk}\) = independent experimental error associated with all observations \((Y_{ijk})\), assumed to be normally distributed with zero mean and unit variance.

When significant by the F test, the treatment means were compared using Tukey’s test. Mean values were considered different at \(p < .05\), and trends were declared at \(0.05 < P \leq 0.10\).

**Results**

There was a significant effect of shading strategies on air temperature \((p = .02)\), black globe temperature \((\text{Bgt}; p < .01)\), and radiant heat load \((\text{RHL}; p < .01)\), which were 3.63%, 44.0%, and 44.10% higher in the full sun pen than in natural shade pen, respectively. On the one hand, the air temperature, Bgt, RHL, and BGHI were highest in the full sun pen. On the other hand, the lowest values for air temperature, Bgt, RHL, and BGHI, and the highest relative humidity were recorded in the pen with natural shade. The wind
The intakes of EE, NDF, NFC, TDN, and iNDF, expressed in kg/day and percentage (%) of BW, were higher in bulls kept in the pen with artificial shade than in animals kept in the artificial shade pen. Animals kept in pens with artificial and natural shade had better NFC digestibility than bulls kept in the full sun pen.

There was no interaction ($p = .37$) between shading strategies and evaluation periods on feeding time in hour/day ($p = .37$), min/kg DM ($p = .42$) and min/kg NDFap ($p = .43$). The longest feeding time ($p = .02$) was observed in animals kept in the artificial shade pen. There was no effect of evaluation periods on feed time ($p = .08$), averaging 2.25 h/day (Table 6). A significant interaction ($p < .01$) was observed between shading strategies and evaluation periods on the other variables of feeding behaviour.

Ruminating time was longest in bulls kept in the pen with natural shade on the 1st day of evaluation. Animals kept in the full sun pen at the 15th and 22nd days spent more time resting and had higher number of chews per bolus compared with other treatments. The time spent chewing was highest in bulls kept in pens with artificial and natural shade on the 1st day of evaluation.

There was a significant interaction ($p = .03$) between shading strategies and evaluation periods on the number of periods for feeding, ruminating, and resting (Table 7). There was no significant interaction ($p = .24$) between shading strategies and evaluation periods on feed efficiency. The best feed efficiency (g DM/h) was observed on the 22nd day of the experiment. There was no difference between shading strategies on feed efficiency, averaging 4,211 g DM/h. Feed efficiency in g NDFap/h was better in animals kept in the full sun and natural shade pens ($p = .02$) on the 22nd day of the experiment ($p = .05$) than in animals kept in the artificial shade pen.

There was a significant interaction between shading strategies and evaluation periods on rumination efficiency. Rumination efficiency (bolus/day) was higher in animals kept in the pen with natural shade in the 1st evaluation period. Bulls kept in the full sun pen had higher rumination efficiency in g DM/h and g NDF/h in the 15th day of evaluation period compared with other treatments and periods.

There was no effect of treatments on the initial body weight ($p = .64$), averaging 293.58 kg (Table 8). Animals kept in the pen with natural shade had the highest final body weight ($p = .05$) and average daily

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**Figure 1.** Respiratory rate (± standard error of the mean for each treatment) in Nellore cattle finished in feedlot on different shading strategies in the pen and times throughout the day (interaction between assessment strategies and times: $p = .18$).

speed was lowest in the full sun pen but was similar in shaded areas (natural vs. artificial; Table 4).

There was no interaction ($p = .13$) between shading strategies and evaluation periods on respiratory rate (Figure 1). Bulls kept in the full sun pen had had the highest respiratory rate, which was 6.09% and 9.34% higher than that of animals kept in pens with artificial and natural shade, respectively.

The lowest mean respiratory rate was observed at 9:00 a.m. The respiratory rate was similar among other evaluation times, with an average of 42.59 mov/min ($p > .05$; Figure 2).

There was a significant effect of shading strategies on the intakes of dry matter (DMI; $p = .03$), crude protein (CP; $p < .01$), neutral detergent fibre (NDF; $p = .02$), non-fibrous carbohydrates (NFC; $p = .02$), total digestible nutrients (TDN; $p = .01$) and indigestible neutral detergent fibre (iNDF; $p = .01$) (Table 5). The DMI of bulls kept in the pen with natural shade was 14.76% higher than that of animals kept in the full sun pen (mean of 7.39 kg DM/day). The DMI relative to body weight of bulls kept in the pen with natural shade was 14.91% higher than in animals in the full sun pen (mean of 2.51% of body weight).

The CP intake was lower in bulls kept in the full sun and artificial shade pens (mean of 0.88 kg/day) than in animals kept in the pen with natural shade. The intakes of EE, NDF, NFC, TDN, and iNDF, expressed in kg/day and percentage (%) of BW, were higher in bulls kept in the pen with natural shade than in animals kept in the full sun pen. Bulls kept in the pen with artificial shade showed intermediate nutrient intakes, except for the CP intake. The DM digestibility was 6.76% and 9.79% higher ($p < .01$) in animals kept
gain \( (p < .01) \). There was no difference between treatments on feed efficiency, averaging 0.184 kg/kg DM. There was a trend \( (p = .09) \) towards higher hot carcase weight for animals kept in the pen with natural shade compared with other treatments. Hot carcase yield \( (p = .42) \) and carcase transfer \( (p = .63) \) were not affected by treatments, averaging 56.68% and 69.67%, respectively.

### Discussion

Air temperature is used as a reference for monitoring the thermal comfort of animals. In our study, the means for air temperature were higher than those recommended for Zebu cattle, ranging from 10 to 27 °C (Furtado et al. 2012). There were significant variations in air temperature in the pens with different shading strategies. Air temperature was highest in the full sun pen (31.09 °C) and lowest in the pen with natural shade (29.96 °C). This is explained by the microclimate created by trees. According to Baêta and Souza (2010), leaves convert solar energy into latent chemical energy during the process of photosynthesis, thereby reducing the radiant heat load during the day.

The relative humidity was highest in the pen with artificial shade (50.97%). However, regardless of shade strategy, the means for relative humidity were within the ideal range for most domestic species, which ranges from 40 to 70% (Ferreira 2011). The combination of air temperature, relative humidity, and black globe temperature allows stratifying the thermal environment into thermal comfort ranges through the BGHI. According to Buffington et al. (1981), a BGHI below 74 indicates a comfort situation for animals, while values from 74 to 78 indicate alert, and values from 79 to 84 indicate danger. A BGHI above 84 is considered an emergency status for cattle. Thus, the

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### Table 5. Intake and digestibility of nutrients in Nellore cattle finished in feedlot on different shading strategies in the pen.

| Shading         | Sun    | Artificial | Natural | SEM | \( p \) Value |
|-----------------|--------|------------|---------|-----|---------------|
| **Intake, kg/day** |        |            |         |     |               |
| Dry matter      | 7.39 b | 7.77 ab    | 8.67 a  | 0.34| .03           |
| Crude protein   | 0.87 b | 0.90 b     | 1.06 a  | 0.04| <.01          |
| Ether extract   | 0.49 b | 0.62 a     | 0.70 a  | 0.02| <.01          |
| Neutral detergent fibre | 1.65 b | 1.85 ab    | 1.96 a  | 0.07| .02           |
| Non-fibrous carbohydrates | 3.71 b | 4.19 ab    | 4.45 a  | 0.18| .02           |
| Total digestible nutrients | 5.63 b | 6.07 ab    | 6.81 a  | 0.26| .01           |
| \( \text{iNDF } \) | 0.68 b | 0.72 ab    | 0.83 a  | 0.03| .01           |
| **Intake, % BW** |        |            |         |     |               |
| Dry matter      | 2.51 b | 2.64 ab    | 2.95 a  | 0.11| .04           |
| Crude protein   | 0.29 b | 0.30 b     | 0.36 a  | 0.01| .01           |
| Ether extract   | 0.17 b | 0.21 a     | 0.24 a  | 0.00| .00           |
| Neutral detergent fibre | 0.56 b | 0.63 ab    | 0.67 a  | 0.02| .02           |
| Non-fibrous carbohydrates | 1.26 b | 1.42 ab    | 1.51 a  | 0.06| .02           |
| Total digestible nutrients | 1.92 b | 2.06 ab    | 2.31 a  | 0.09| .01           |
| \( \text{iNDF } \) | 0.23 b | 0.24 ab    | 0.28 a  | 0.01| <.01          |
| **Digestibility, g/kg** |        |            |         |     |               |
| Dry matter      | 554.4 c| 573.0 b    | 614.6 a | 59.0| <.01          |
| Crude protein   | 425.5 c| 510.9 a    | 443.9 b | 11.0| <.01          |
| Ether extract   | 882.7 a| 849.2 b    | 810.6 c | 4.0 | <.01          |
| Neutral detergent fibre | 574.2 a| 532.1 b    | 477.1 c | 59.0| <.01          |
| Non-fibrous carbohydrates | 750.9 b| 794.0 a    | 789.9 a | 17.0| <.01          |
| Total digestible nutrients | 480.3 b| 542.1 a    | 516.5 b | 10.0| <.01          |

*Means followed by same letter in the line does not differ by Tukey test \( (p < .05) \). BW: body weight.

**SEM**: standard error of the mean.

\( ^1p \): probability.
Table 6. Ingestive behaviour of Nellore cattle finished in feedlot on different pen shading strategies.

| Item* | Sun | Artificial | Natural | SEMb | 1 | 8 | 15 | 22 | SEM | Shading | Period | Shading x Per |
|-------|-----|-----------|---------|------|---|---|----|----|-----|---------|--------|-------------|
| Feeding | hours/day | 2.11 ab | 2.66 a | 2.00 b | 0.16 | 2.05 a | 2.06 a | 2.24 a | 2.68 a | 0.19 | 0.02 | 0.08 | 0.37 |
| min/kg DM | 13.97 ab | 18.85 a | 13.67 b | 1.27 | 19.43 | 16.41 | 15.06 | 15.10 | 1.47 | <0.01 | 0.05 | 0.01 | 0.02 |
| min/kg NDFap | 67.68 b | 88.86 a | 60.29 b | 5.55 | 84.69 | 71.63 | 65.77 | 67.01 | 6.41 | <0.01 | 0.15 | 0.43 |
| Rumination | hours/day | 4.39 b | 5.05 b | 6.56 a | 0.22 | 5.86 a | 5.58 ab | 5.13 a | 4.77 b | 0.25 | <0.01 | 0.02 | <0.01 |
| min/kg DM | 35.08 b | 36.58 b | 45.53 a | 2.13 | 43.03 | 40.77 a | 36.54 a | 34.72 a | 2.46 | <0.01 | 0.08 | <0.01 |
| min/kg NDFap | 139.90 b | 168.15 b | 200.78 a | 9.16 | 186.11 | 176.22 a | 162.38 a | 153.72 a | 10.57 | <0.01 | 0.15 | <0.01 |
| Resting | hours/day | 17.48 a | 16.22 b | 15.42 b | 0.26 | 15.37 b | 16.17 ab | 16.8 a | 17.16 a | 0.30 | 0.00 | 0.00 | 0.00 |
| number/bolus | 57.79 a | 51.99 b | 55.68 ab | 1.22 | 53.06 | 53.88 a | 57.23 a | 56.44 a | 1.41 | 0.01 | 0.13 | <0.01 |
| Total, hours/day | 6.51 b | 5.71 a | 8.57 a | 0.26 | 8.54 | 7.82 ab | 7.2 a | 6.83 b | 0.30 | <0.01 | <0.01 | <0.01 |
| seconds/bolus | 53.91 a | 49.51 b | 54.49 ab | 1.02 | 52.06 | 52.57 a | 57.23 a | 56.44 a | 1.18 | <0.01 | 0.81 | <0.01 |

*aMeans followed by same letter in the line does not differ by Tukey test (p < 0.05). DM: dry matter; NDFap: neutral detergent fibre corrected for ash and protein.

*bSEM: standard error of the mean.

*p: probability.

Table 7. Ingestive behaviour of Nellore cattle finished in feedlot on different shading strategies in the pen.

| Item* | Sun | Artificial | Natural | SEMb | 1 | 8 | 15 | 22 | SEM | Shading | Period | Shading x Per |
|-------|-----|-----------|---------|------|---|---|----|----|-----|---------|--------|-------------|
| Number of periods (n/day) |  |  |  |  |  |  |  |  |  |  |  |  |
| Feeding | 4.45 b | 7.1 a | 6.65 a | 0.40 | 6.80 a | 5.00 b | 6.00 ab | 6.46 ab | 0.46 | <0.01 | 0.05 | <0.01 |
| Rumination | 8.35 c | 11.95 b | 17.3 a | 0.56 | 12.13 a | 12.06 a | 13.06 a | 12.86 a | 0.65 | <0.01 | 0.02 | <0.01 |
| Idle | 18.75 b | 23.05 a | 23.4 a | 0.65 | 22.53 ab | 20.66 bc | 24.2 a | 19.53 c | 0.75 | <0.01 | 0.00 | <0.01 |
| Duration of periods (min) |  |  |  |  |  |  |  |  |  |  |  |  |
| Feeding | 29.21 a | 25.45 ab | 18.73 b | 2.26 | 24.94 ab | 31.00 a | 22.87 ab | 19.04 b | 2.61 | 0.01 | 0.02 | 0.03 |
| Rumination | 32.63 a | 26.66 b | 23.76 b | 1.21 | 30.04 ab | 32.59 a | 25.00 bc | 23.10 c | 1.40 | <0.01 | <0.01 | <0.01 |
| Idle | 60.81 a | 43.77 b | 40.65 b | 3.10 | 41.32 b | 48.7 ab | 44.54 b | 59.09 a | 3.58 | <0.01 | 0.01 | 0.01 |
| Feed efficiency | g DM/h | 4278.7 a | 3576.5 a | 4778.1 a | 3687.3 | 4268.2 ab | 4297.8 ab | 4990.0 a | 425.7 | 0.08 | 0.06 | 0.24 |
| g NDFap/h | 1073.1 a | 758.9 b | 1083.7 a | 86.9 | 754.6 b | 978.8 ab | 987.2 ab | 1167.1 a | 100.4 | 0.02 | 0.05 | 0.22 |
| Duration of periods (min) | Bolus/day | 300.1 c | 374.7 b | 439.6 a | 18.1 | 416.1 a | 379.7 ab | 356.2 ab | 333.8 b | 20.9 | <0.01 | 0.05 | <0.01 |
| g DM/h | 2131.7 a | 1741.5 b | 1422.6 b | 100.9 | 1492.3 b | 1613.2 ab | 2042.7 a | 1912.7 ab | 116.5 | <0.01 | <0.01 | <0.01 |
| g NDFap/h | 534.6 a | 369.5 b | 322.6 b | 24.3 | 339.6 c | 366.9 bc | 482.3 a | 446.9 ab | 28.1 | <0.01 | 0.81 | <0.01 |

*aMeans followed by same letter in the line does not differ by Tukey's test (p < 0.05). DM: dry matter; NDFap: neutral detergent fibre corrected for ash and protein.

*bSEM: standard error of the mean.

*p: probability.

Table 8. Productive performance and efficiency of Nellore cattle finished in feedlot on different shading strategies in the pen.

| Item* | Sun | Artificial | Natural | SEMb | p Valuec |
|-------|-----|-----------|---------|------|---------|
| Initial body weight, kg | 293.72 | 294.70 | 292.33 | 1.85 | .64 |
| Final body weight, kg | 436.06 b | 439.42 ab | 451.30 a | 4.16 | .05 |
| Average daily gain, kg/day | 1.41 b | 1.43 b | 1.55 a | 0.03 | .02 |
| Feed efficiency, gain/kg DM 0.190 | 0.183 | 0.179 | <0.01 | .21 |
| Hot carcass weight, kg | 246.21 b | 250.86 ab | 254.02 a | 2.78 | .09 |
| Hot carcass yield, % | 56.63 | 57.11 | 56.31 | 0.48 | .42 |
| Carcass transfer, % | 70.35 | 70.34 | 68.34 | 1.39 | .63 |

*aMeans followed by same letter in the line does not differ by Tukey's test (p < 0.05). DM: dry matter.

*bSEM: standard error of the mean.

*p: probability.

The RHL is associated with the black globe temperature, expressing the amount of radiation incident on a body. On the one hand, the RHL was highest in pens without shade and with artificial shade. On the other hand, the pen with natural shade had the lowest RHL (429.20 W m⁻²). Feedlot cattle with no access to shade are more exposed to solar radiation. According to Silva (2000), the lower the RHL, the greater the thermal comfort the environment provides to the animals.

The first signs of the environment’s effect on the welfare of livestock animals are express by the respiratory rate, which ranges from 40 to 60 movements per minute in adult cattle (Silanikove 2000). In this study, bulls kept in the full sun pen had the highest respiratory rate (44.3 mov min⁻¹) and the highest BGHI values. Therefore, the lack of shade triggered thermoregulation mechanisms of animals. In several...
feedlots in Europe and North America, Grandin (2016) observed that the lack of shade in feedlot pens increased the respiratory rate of cattle, thereby indicating thermal stress. In Brazil, Nellore animals are known for their adaptability to hostile environments such as those in the semi-arid and tropical regions. Farmers choose not to use shade in feedlot pens because of this adaptation associated with the short finishing time in Brazil (80–120 days), which is pointed out by Grandin (2016) as a possible failure in intensive production systems.

Environmental and genetic factors can also affect animal performance and interfere with dry matter intake (National Research Council (NRC) 2016). In this study, animals kept in the pen with natural shade had higher DMI in the last 37 days of finishing than in animals in the full sun pen (7.39 vs. 8.67 kg/day). It is explained by the chemical composition, ruminal degradability and greater dry matter and non-fibrous carbohydrates digestibility of diets associated with the lower BGHI value (76.8 in the pen with trees). Moreover, the highest RHL observed in full sun and artificial shade pens increased the respiratory rate, causing apparent thermal discomfort for animals. Moreover, despite using Nellore cattle adapted to tropical conditions, the lack of shade in the pen affected the DMI because the diet was the same, regardless of the treatment, which justifies the variation in the DMI. As a result, animals kept in the full sun pen had fewer feeding periods than animals kept in shaded pens.

Variations in DMI are a physiological response that modifies basal metabolism in order to generate less body heat during rumination (Sullivan et al. 2011; Washington and D. C. National Research Council (NRC) 2016). Hagenmaier et al. (2016) also observed an increase of 2.77% in the DMI of feedlot cattle kept in the pen with artificial shade compared with animals kept in full sun areas, while in this study the DMI increase by 14.76%.

According to BR Corte (2016), a DMI of 8.74 kg/day is estimated as ideal for intact Zebu cattle for an average daily gain of 1.45 kg. This estimate is similar to the actual DMI observed in animals kept in the pen with natural shade. However, the DMI was lower than estimated in animals kept in full sun and artificial shade pens. Bulls kept in pens with artificial shade showed intermediate DMI values (mean of 7.77 kg/day) compared with other treatments because the shade cloth made of polyethylene, which intercepts 50% of sunlight, did not reduce the RHL and air temperature in comparison with animals kept in the full sun. It led to thermal stress as justified by the BGHI value above 79. The lower DM digestibility observed in animals kept in the full sun pen reflects the longer resting time and lower ruminating time due to the higher RHL and BGHI throughout the day.

According to the Washington and D. C. National Research Council (NRC) (2016), cattle exposed to temperatures outside the thermoneutral zone spend more energy dissipating body heat for thermoregulation through evaporative processes, including sweating and breathing. Consequently, bulls kept in the full sun pen had higher respiratory rates and spent more time resting but less time ruminating and chewing than animals kept in shaded pens. Animals kept in the full sun pen compensated for the shorter ruminating and chewing times in hours/day by increasing the number of chews per bolus.

The higher final body weight, ADG, and hot carcase weight in bulls kept in the pen with natural shade are justified by the higher DMI, nutrient intake and digestibility and better thermal conditions in relation to the other treatments. Data on thermal variations and feeding behaviour evidence the ability of Nellore cattle to adjust their body metabolism to the adverse environmental conditions during the day, especially in the semi-arid tropical regions. Nevertheless, animal performance was affected.

The importance of natural shade in feedlot pens to animals’ thermal comfort and well-being becomes evident in this study. The use of artificial shade made of polyethylene in feedlot pens is still controversial in terms of animal performance, although the animals were observed standing under the artificial shade. An important climatic finding in this study was the high relative humidity in the pen with artificial shade, forming a microclimate. However, the low light interception (50%) of the shade cloth was not sufficient to reduce the RHL in a semi-arid region and to improve animal performance compared with animals kept in the full sun pen. Hagenmaier et al. (2016) also did not observe improvements in the performance of animals kept in a pen with artificial shade in relation to animals kept in pens without shade. However, these authors stated there may be deaths due to the high level of stress associated with respiratory diseases due to low relative humidity under conditions of high BGHI as observed for bulls kept in the full sun pen. In this study, the importance of the natural shade in feedlot pens is evident due to the improvement of climatic conditions and animal performance in relation to the other strategies, even in a short finishing period. In the semi-arid region, solar radiation...
associated with high temperature, even in the winter period, can impair animal performance in the feedlot, as also verified by Grandin (2016).

Conclusion
The natural shading in feedlot pens in the semi-arid region of Brazil improves climatic conditions, nutrient intake and digestibility, feeding behaviour, respiratory rate, and productive performance of feedlot-finished Nellore cattle.

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Ethical approval
All procedures involving animals were approved by the institutional animal use committee (protocol number 185/2019).

Disclosure statement
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