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Compost barn system and its influence on the environment, comfort and welfare of dairy cattle

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Abstract. The aim of this study was to evaluate the effect of the thermal environment on behavioral and physiological parameters of crossbred cows of different productivity levels confined in a compost barn system. For this, air temperature (T_{db}) and relative humidity (RH) data were measured using sensors/registers and wind speed (Vair) was recorded with the aid of an anemometer. Subsequently, these data were used to calculate the Temperature and Humidity Index (THI). Bedding material variables (pH and humidity) were also evaluated. The animals were evaluated for physiological variables (respiratory rate – RR and surface temperature – ST), scores (body condition, locomotion and dirt) and behavior. The analyses were carried out on two groups of cows (Group 1: high production vs. Group 2: medium and low production). The average pH of the bedding material was 8.5, within the recommended range. In the case of the physiological responses of the cows, the respiratory rate (RR) of Group 1 indicated better conditions of thermal comfort in the morning vs. the afternoon. The system was efficient in both groups based on body condition score, indicating favorable conditions for the health of the animals. Regarding the behavioral evaluation, Group 1 and 2 were statistically similar and had the longest rumination times, in relation to the other evaluated behaviors. Regarding active periods, medium production were the most active. Regarding idle time, low production spent more time idle than the other animals.

Key words: dairy cattle, animal welfare, installations.

INTRODUCTION

The use of confinement systems for dairy cows has been the option adopted by many producers to meet the demands of the consumer market, as in addition to facilitating the handling of animals, when properly and technically conducted it increases productivity, improves the sanitary and nutritional quality of milk, reduces injuries and diseases in the animals, and potentially increases earnings and reduces the costs of the activity in the long term.

In Brazil, dairy production is carried out on about one million rural properties. The country is one of the world's largest milk producers, with the dairy industry making a major contribution to the country's economy (Costa, 2020). Among the existing confinement systems, the compost barn has aroused the interest of dairy producers for promoting improved animal welfare and increased milk production, in addition to reducing hoof problems (Damasceno, 2020).

Although milk production occurs in all regions of the country, climatic conditions are considered an obstacle in establishments where confinement systems are adopted, and maintaining the thermal comfort of the herd is a major challenge. In situations of thermal discomfort, animals use physiological mechanisms to regulate body temperature, which can result in a high level of stress and, as a result, a lower degree of welfare. In this sense, the sensitivity of animals to high temperatures is a key factor for the success of the sector, as they need an ambient temperature between 4 and 26 °C (Perissinotto & Moura, 2007). As Brazil has a tropical climate, it is possible to find values above this range for most of the year (Morais et al., 2008).

In homeothermic animals, such as dairy cows, the ability to thermoregulate is strongly related to energy balance (Aksit et al., 2006). During thermal changes, physiological mechanisms undergo changes, increasing energy expenditure rates (Shinder et al., 2007; Stewart et al., 2017). Thus, ambient temperature and humidity play an important role in contributing to heat stress, especially in dairy cows (Berman et al., 2016). Dairy cattle respond to heat stress through changes in respiration rate, sweating, panting, milk production, and reproductive performance (Polsky & Von Keyserlink, 2017). Thus, inadequate environmental conditions in animal production result in a decrease in the level of animal welfare, with negative impacts on productivity, such as the reduction of milk production (Ribeiro et al., 2018).

Among the different breeds used in dairy production, heat stress can negatively affect the productivity and longevity of cows, especially dairy cows with high productive capacity (Kadzere et al., 2002).

To maintain the welfare of a herd it is essential to provide the animals with a good quality of life. For this to occur, they must have access to comfort and also the satisfaction of their basic needs, in addition to being free from hunger, pain, fear, stress and other states that provide discomfort, and it is essential that management is carried out correctly to avoid malnutrition and disease (Fundação Roge, 2017). Thus, assessing the comfort of cows on dairy farms is essential in the search for strategies aimed at maintaining welfare, health and production rates, or even improving these (Fernández et al., 2020).

As a way to improve and control the breeding environment, there is a growing and continuous interest of producers in the search for more effective management strategies to guarantee an increase in productivity and milk quality, combined with the rational use of resources (Andrade et al., 2022b). In this sense, the compost barn indicates to be an interesting management alternative that suggests mitigating the negative effects of thermal stress in dairy farming, reducing the thermal magnitude of the environment during the hottest seasons and the hottest hours of the day (Andrade et al., 2022a).

The compost barn is an alternative system to the well-known loose housing system, in which animals remain loose and can walk freely inside the facility, aiming in this way to improve their comfort and well-being and, consequently, improve their productivity rates (Black et al., 2013). This system offers a collective area that allows the exercise, rest, natural behavior and socialization of cows, characteristics that make the compost barn an advantageous breeding system for producers who aim not only to produce milk, but also to provide a high level of welfare for their animals (Galama, 2014; Leso et al., 2020).

In view of this, the objective of this study was to evaluate the effect of the thermal environment on behavioral and physiological parameters of crossbred cows (Dutch and Jersey) with different levels of productivity confined in a compost barn system.

MATERIALS AND METHODS

The experiment was carried out at Fazenda Campo Alegre, located in Ritápolis – MG, Brazil (latitude 21°01’46’’S, longitude 44°23’51’’W, altitude 1,029 m and atmospheric pressure of 1,014 hPa). The region has a mild climate throughout the year.

As indicators of the level of animal welfare, data such as surface temperature, respiratory rate, body condition scores, locomotion and cleanliness, together with values of environmental variables and animal behavioural.

Architectural characterization of the facility

The study was carried out during the summer of 2020 in a compost barn facility with an east–west orientation. The facility consisted of a 4.5 m wide central feed corridor, two bed areas 14.0 m wide by 72.0 m long (each side), with a 4.0 m long feeding track and 0.60 m long trough per animal, two drinking fountains 5.0 m wide and 1.0 m long salt troughs. Three fans were arranged linearly along the center of the facility (Mamute®, 2.0 m diameter, with five propellers, rotation 1,750 rpm, power of 2.24 kW, flow of 120,000 $m^3 \cdot h^{-1}$) and five fans (ZIEHL–ABEGG, diameter 1.52 m, three propellers, rotation 520 rpm, power 1.25 kW, flow 24,500 m^3 h^{-1}) were placed above the access route to the feeding trough, with sprinklers spaced 1.60 m apart. A total of 240 adult lactating crossbred animals (Jersey/Dutch) were housed in this system, with a housing density of 7 $m^2 \cdot animal^{-1}$.

The animals were divided into two groups: Group 1, located on the righthand side of the facility, comprised animals that had spent up to 120 days in lactation (DIM) and produced an average of 26 L d^{-1} (liters of milk per day) (high production); and Group 2, on the lefthand side, comprised medium production (with an average production of 18 L d^{-1} and DIM between 120 to 200 days) and low production (with DIM greater than 200 days and average production of 15 L d^{-1}).

On both sides of the facility, the bedding material consisted of shavings with a depth of 0.40 m. The bedding was turned over twice a day (during milking times) using a plow to break up any clods and then a subsoiler. Bedding material was replaced every 24 months (Fig. 1).

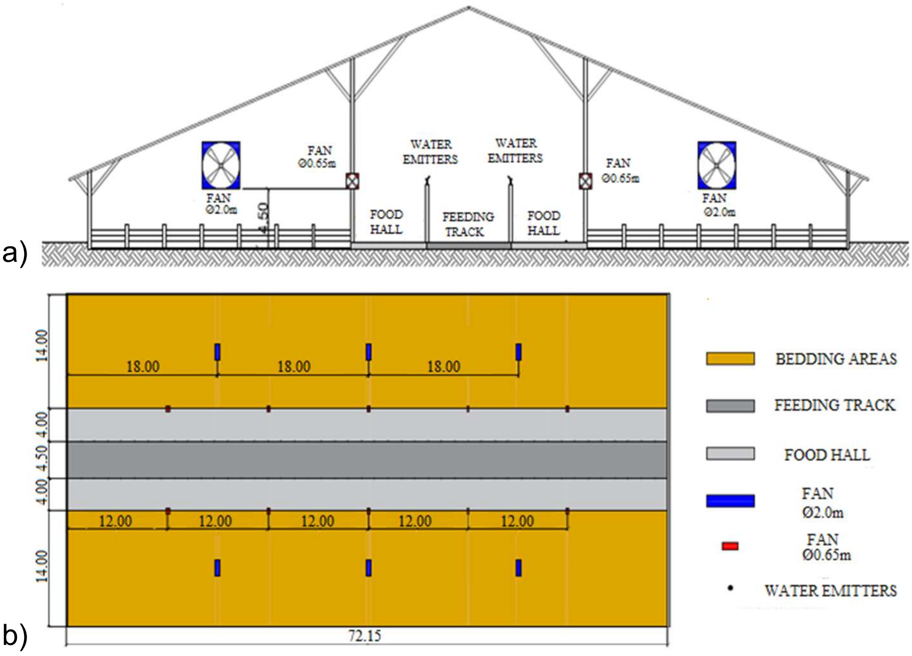

Figure 1. Installation of Compost Barn with center track. (a) Cross-section schematic representation and (b) Floor plan schematic representation.

Instrumentation and measurements to characterize the thermal environment

The thermal environment was evaluated using the following environmental variables: dry bulb air temperature (T_{db}, °C) and relative humidity (RH, %), obtained with the aid of sensors/registers (Instrutherm, mod. HT-500 and precision ± 3%) programmed to collect environmental variables every 10 minutes during the experimental period. The sensors were installed in the center of the bedding area on both sides of the facility, 1.50 m above ground level. Air velocity (Var, $m.s^{-1}$) was measured with the aid of a digital helix anemometer (accuracy of ± 0.03 $m.s^{-1}$). Afterwards, the values of the collected variables were used to calculate the THI.

Instrumentation and measurements to characterize bedding variables

The bedding material characteristics on both sides of the facility were evaluated by measuring the bedding surface temperature (T0), temperature at a depth of 20 cm (T20), bedding moisture and pH. In order to cover the greatest possible area, the variables were measured at five different points (center of the bedding area, at the ends on the right and left sides, 2 m away from the gate) on both sides of the facility. To measure the T0, an infrared digital thermometer with laser sight (INCOTERM, mod. ST-500 and accuracy of ± 1.5 °C) was used. To obtain the T20, a digital dipstick thermometer (Pyromed®, model TP101, with a scale from 0 to 300 °C and accuracy of ± 0.1 °C) was used.

To determine the moisture and pH of bedding material in the surface layer (pH0) to a depth of 20 cm (pH20), bedding material samples were collected at marked points, using an mechanical digger. The collected material was homogenized in a bucket and later placed in closed and labeled plastic containers and taken to the Laboratory of Rural

Constructions and Waste Treatment at the Federal University of Lavras. Bedding material data were collected weekly around 6 a.m before bedding turning.

The pH analysis was performed according to the methodology described by Zhao et al. (2012). The readings were taken using a benchtop digital pH meter (Even®, model PHS-3E, with a pH measurement range between 0 and 14, accuracy ± 0.01, and operating temperature between 0 and 100 °C), duly calibrated.

The moisture of bedding material was determined according to the methodology proposed by Teixeira et al. (2017).

Measurement of physiological responses

The respiratory rate (RR) was evaluated in standing animals by counting the movements of the animal's flank for 15 seconds, and then the value was multiplied by four to obtain the RR per minute. The body surface temperature (ST) was measured using a digital infrared thermometer with laser sight (INCOTERM, mod. ST-500 and precision of ± 1.5 °C), held approximately 50 cm away from the animal on the scapula and on the flank, and the average of the results observed at the measurement points was calculated, according to the method adopted by Domingos et al. (2013). The RR and ST evaluations were carried out in 30 animals, twice a day (09:00 am / 03:00 pm) during the experimental period, with the RR being measured first.

To facilitate the measurement of physiological responses the animals were marked between the sacral bones, ileum and ischium, enabling identification of each animal during the assessments.

Measurement of body condition, mobility and cleanliness scores

The body condition score (BCS) was evaluated on the first experimental day after milking in the afternoon through visual observations of the body condition of each animal, using a scale from 1 to 5, with subunits of 0.50 points, in which 1 represents a very thin cow and 5 obese (Edmonson et al., 1989). In the evaluation, the anatomical parts of the ribs, transverse processes of the lumbar vertebrae, ends of the ilium, ischium and tail insertion were considered. The amount of adipose tissue and musculature covering the bone ends was evaluated at all points.

The locomotion score (LS) was also assessed on the first experimental day after afternoon milking by direct observation of standing and moving cows, with a score from 0 to 4 points (Barker et al., 2010), using a scale from 0 (normal locomotion) to 3 (severe claudication).

For the assessment of cleaning score (CS) the methodology proposed by Cook (2002) was used, with scores from 1 to 4 as follows: where (1) the animal shows no signs of dirt; (2) a few splatters of dirt can be seen; (3) there is a dirt plate between the hairs; (4) there are concentrated dirt plates. The udders, hindquarters and hind legs of the animals were evaluated. Observations were carried out during the 20 experimental days after morning milking.

To obtain the BCS, LS and CS scores, 30 animals were evaluated, the same animals being evaluated for each parameter.

Evaluation of animal behavioural variables

The idle time, rumination time and active time (eating, walking, scratching, among others) were recorded with the aid of a sensor attached to a collar worn by the animals.

All these behaviors were computed in minutes per hour and in minutes per day using software (COWMED) in the cloud with internet access. Thirty animals were observed on 19 separate occasions, for a duration of 24 hours on each occasion, totaling 456 hours.

Experimental design

The experiment was set up according to a split-plot scheme, with the group of animals in the plots and the evaluation times in the sub-plots, in a randomized block design, with repetitions corresponding to the measurement days. Data were analyzed using analysis of variance. For the qualitative factor, the means were compared using the Tukey and *F* test at the 1.0% probability level.

RESULTS AND DISCUSSION

There was a significant difference ($p < 0.01$) between the two groups (Table 1) and between the time of measurement of the environmental variables: T_{db}, RH and THI (Table 2).

Regarding the T_{db} values, a significant difference ($p < 0.01$) was observed between the two groups, as well as between measurements taken at different times of day. In all cases, the average values of T_{db} in the compost barn were within the range of thermal comfort for dairy cattle, which according to the literature can vary from 4 to 26 °C; in this range the body temperature is constant and homeothermy is maintained by heat exchange (Huber, 1990; Martello et al., 2004; Roenfeld, 1998). It is noteworthy that the morning period had a lower average value than the afternoon period (Table 2), which indicates better thermal conditions for the animals in the morning, especially in relation to high producers (Group 1), thus favoring their productive potential.

For RH, a difference was observed both between groups and times of day. However, in both cases, the mean valus observed were higher than the range considered favorable for the management of dairy cattle, which is between 50% and 70% (Almeida Neto et al., 2014). Thus, regardless of the evaluated environment, the measured RH may trigger stress conditions in the animals, since high values of relative humidity impair thermolysis (Silva, 2000; Pereira et al., 2005).

Table 1. Average values of environmental variables obtained in a compost barn

Group	Environmental variables		
	T_{db} (ºC)	RH (%)	THI
Group 1	23.53 b	82.51 a	72.00 b
Group 2	23.82 a	81.72 b	72.32 a
C.V. (%)	1.04	0.72	0.40

T_{db} = dry bulb temperature; RH: relative humidity; THI: temperature and humidity index. Means followed by the same letter in a column are statistically similar by *F* test at 1.0% significance.

Table 2. Average values of the environmental variables obtained in the compost barn as a function of the time of day

Period	Environmental variables		
	T_{db} (ºC)	RH (%)	THI
Morning	22.49 b	85.92 a	70.85 b
Afternoon	24.86 a	78.31 b	73.47 a
C.V. (%)	9.46	9.04	3.46

T_{db} = dry bulb temperature; RH: relative humidity; THI: temperature and humidity index. Means followed by the same letter in a column are statistically similar by *F* test at 1.0% significance.

The THI also differed significantly between groups and time of day. The mean THI observed was above the range described by Ferreira (2015), who stated that for highly productive dairy cattle, a THI of 68 indicates no stress, 69 to 71 indicates Light stress, 72 to 79 indicates mild stress, 79 to 89 indicates moderate stress and 90 to 98 indicates severe stress.

Regarding the variable temperature of the bedding (Fig. 2), the material under study was not within the range indicated for effective composting of the bedding, and may even allow the spread of pathogenic bacteria that can cause mastitis, since the values measured at a depth of 20 cm were below those referenced in the literature as default values for this variable (NRAES, 1992).

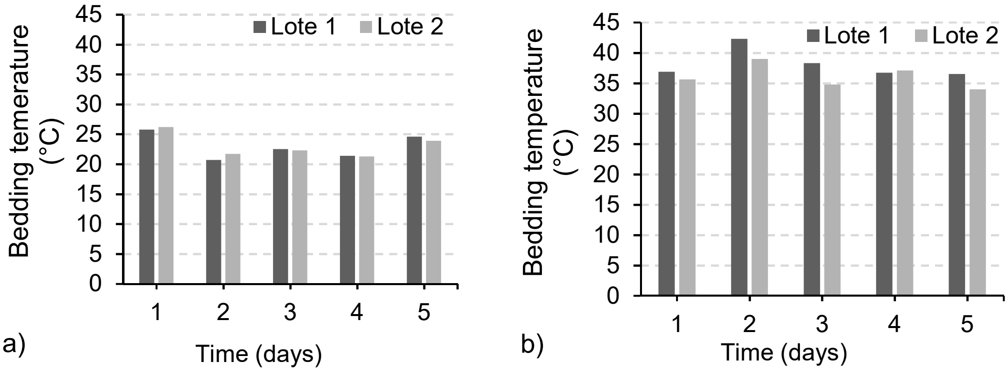

Figure 2. Average bedding temperature throughout the experiment, where: (a) T0 = surface temperature and (b) T20 = temperature at 20 cm depth.

The average bedding temperatures found in this study (23.01 °C at 0 cm - Group 1, 23.08 °C at 0 cm - Group 2; 38.16 °C at 20 cm - Group 1 and 36.11 °C at 20 cm - Group 2) were lower than those reported by Janni et al. (2007) and Bewley et al. (2013). According to NRAES (1992), for the composting process to be efficient, adequate temperature and humidity must be maintained, and a temperature range of 43.3 to 65.0 °C is recommended as the internal temperature of the compost barn at depths of 15 to 31 cm.

In relation to the pH of the bedding material (Fig. 3), the values were similar to those found by Favero et al. (2015). Furthermore, Oliveira et al. (2019) reported mean bedding pH values in compost barn facilities located in Minas Gerais that were also close to 9.0.

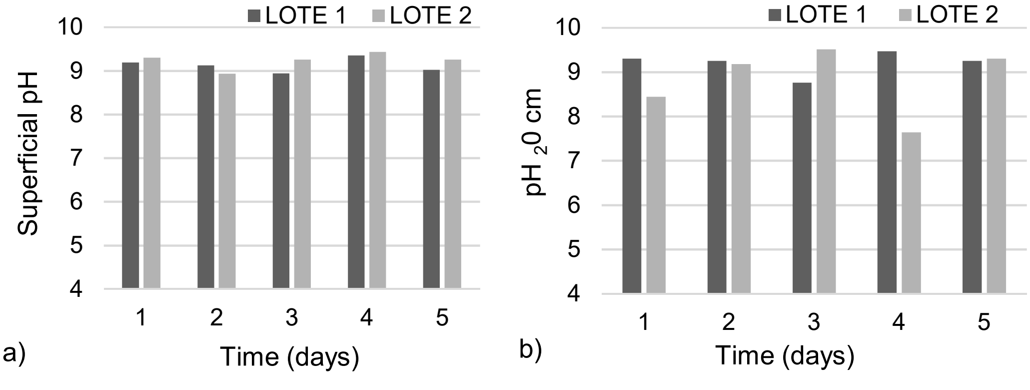

Figure 3. Mean pH of the bedding throughout the experiment, where: (a) pH in the surface layer and (b) pH 20 = pH at 20 cm depth.

The mean bedding moisture in Groups 1 and 2 was 47.8% and 41.8% at the surface and 45.8% and 38.4% at 20 cm, respectively. According to Janni et al. (2007) and Black et al. (2013), the ideal level of humidity for effective composting varies between 40% and 60 to 65%. Biasato et al. (2019) observed a mean value of 48.12 ± 5.85%, while Black et al. (2014) reported mean values of 56.1 ± 12.4%. According to Andrade et al. (2022b) animal density had a significant impact on litter moisture content and internal temperature, representing one of the main obstacles to the success of Compost barn installations.

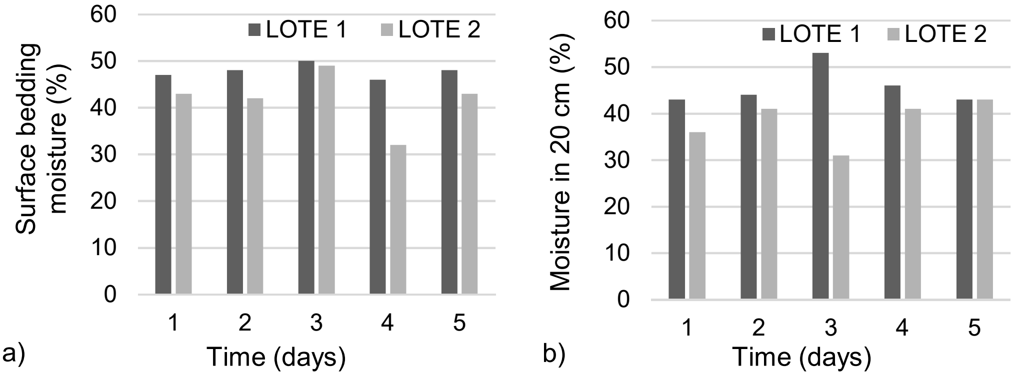

Figure 4. Mean bedding moisture content throughout the experiment: (a) moisture content at the surface of the bedding, and (b) moisture content at 20 cm depth.

The mean values collected for the physiological variable surface temperature can be seen in Table 3.

A significant difference was observed between the two groups for body surface temperature (ST), with low producers (Group 2) having a lower value of 32.65 °C for this variable. Despite the difference in ST observed, regardless of the productivity of the animals, the confinement system led to an average surface temperature below 35 °C in all groups, which is necessary for thermal exchange to occur due to the generation of a gradient sufficient to cause heat loss between the body core and the coat, with conduction being the mechanism that provides this exchange (Collier et al., 2006). Peixoto et al. (2019) analyzed the ST of animals confined in compost barn, in the afternoon, during the dry and rainy seasons. The authors observed mean ST values above the comfort range for the cows in both situations (37.1 in the dry and and 36.6 °C rainy seasons).

Table 3. Average surface temperature (ST, in °C) obtained in the compost barn as a function of the productive potential of the animals and the evaluation period

	Productivity			Period	
	High	Medium	Low	Morning	Afternoon
ST	33.41 a	33.30 a	32.65 b	32.16 a	34.16 b
C.V (%)	6.37			4.84	

Means followed by the same letter are statistically similar by Tukey at 1% significance.

For respiratory rate (RR), a significant difference was observed between the two groups, and there was a significant interaction between group and the evaluation period, with the breakdown of the interaction presented in Table 4.

Table 4. Means of respiratory rate (RR, in movements per minute) obtained in the compost barn as a function of the productive potential of the animals and the evaluation period.

	Production x Period (Morning)			Production x Period (Afternoon)		
	High	Medium	Low	High	Medium	Low
RR	60 a	60 a	61 a	65 a	64 ab	62 b
C.V (%)	11.59				8.47	

Means followed by the same letter are statistically similar by Tukey at 1% significance.

The ability of the animals to resist heat stress conditions is physiologically reflected by changes in RR. The results show that the afternoon promoted stress situations in both groups according to the average RR. Silanikove (2000) classified stress in cattle according to the RR as low (40 to 60 movements per minute), medium (60 to 80 movements per minute), high (80 to 120 movements per minute), and severe stress (above 150 movements per minute). Andrade et al. (2022b) analyzing the RR of dairy cows confined in compost barn in two seasons (summer and winter), observed a RR value of 63 (summer) and 53 (winter) in the afternoon. According to Peixoto et al. (2019), RR averages above the comfort value, in addition to providing more severe heat stress to the animals, may indicate greater risks for respiratory diseases.

The averages referring to the body condition, locomotion and cleanliness scores are presented in Table 5.

Table 5. Mean scores observed throughout the experimental period

Parameter	Animals	
	Group 1	Group 2
body condition score	3.25	3.50
locomotion score	1.90	2.40
cleaning score	2.00	2.00

The results demonstrate that most of the animals evaluated in the present study were within the appropriate range of body condition scores for dairy cows (2.5 to 3.5), as reported by Fernandes et al. (2016). It is noteworthy that the nutritional condition reflects the health of the animals, as cows with low body condition scores are more vulnerable to metabolic and orthopedic imbalances (Buckley et al., 2003). In this context, Radavelli (2018) reported that about 94% of animals confined in a compost barn had a body condition score between 2.75 and 3.5 points.

Regarding the cleanliness score, the average score during the experimental period was the same for both groups, with most animals showing few dirt splashes, and therefore scoring 2. Thus, the score observed in this study was consistent with other reports in the literature that used compost barns as a confinement system, such as Pilatti et al. (2019) who reported that scores ranged between 1 and 2, whereas Lobeck et al. (2011) reported a score of 3.18 on a scale ranging from 1 to 5 (where 1 = clean and 5 = very dirty). When evaluating a herd composed of 1,010 animals in Brazil, Radavelli (2018) found that 848 animals (83.26%) had a cleanliness score of 2.

The averages observed for the behavioral variables are presented in Table 6.

For the variable 'rumination time', a significant difference was observed between cows with different levels of productivity, with the formation of two groups. The first comprised high and medium production, while the second comprised low production.

This result was consistent with that observed by Norring et al. (2012), who reported a positive association between milk production and the time cows spent ruminating. It is noteworthy that lactating cows spend an average of 7 hours and 40 minutes ruminating each day (Dado & Allen, 1994). It was also observed that inin high and medium production, rumination accounted for a larger part of the day than idleness and activity.

Table 6. Mean duration and standard deviation of behavioral activities (min. day^{-1})

Animals	Behavior		
	Rumination	Activity	Idle
Group 1	669.9 ± 7.1a	201.0 ± 5.5b	569.1 ± 8.0b
Group 2 (average production)	676.3 ± 6.4a	224.3 ± 5.0a	539.5 ± 7.2c
Group 2 (low production)	532.2 ± 7.1b	157.4 ± 5.5c	750.3 ± 8.0a

Means followed by the same letter within a column are statistically similar by Tukey at 5% significance.

With regard to 'active time', it can be inferred that milk production interferes with cows' activity, as there was a significant difference between all groups, with more activity as productivity decreased.

With regard to ‘idle time’, a significant difference was observed between animals with different levels of productivity. It can be inferred that low producers spend more time idle to the detriment of other activities. In this study the time spent idle was around 12 h 35 min, which can be attributed to the soft conditions offered by the bedding in the compost barn. In this context, Eckelkamp (2014) reported that animals spent more time lying in a compost barn compared to those confined in a free stall with access to pasture, with values of 13.1 ± 0.5 and 9.6 ± 0.5 hours/day being reported, corroborating the results observed in the present study.

CONCLUSIONS

According to our data, although the mean T_{db} observed in the compost barn were within the thermal comfort range, the mean THI and RH were outside the thermal comfort zone for the cows, indicating that intervention would be needed to ensure that the environment would be suitable for animals housed in this type of enclosure.

The average bedding temperature was 37.13 °C at 20 cm depth, which is slightly lower than the recommended limit. A higher temperature was observed where Group 1 was housed. In the case of litter humidity, the average value was higher where Group 2 was housed, probably due to the lower animal density. The pH showed an average value of 8.5, which was within the recommended range.

The average respiratory rate (RR) of the animals in Group 1 (high producers) was 60 mov. min^{-1} in the morning. The average surface temperature (ST), regardless of group and time of day, was below 35 °C.

Regarding the behavioral evaluation, high and medium production were statistically similar and had the longest rumination times, at 669.9 and 676.3 min.day^{-1}, respectively. Regarding the time spent active, medium producers showed the most activity (224.3 min.day^{-1}). Meanwhile low producers spent more time idle (750.3 min.day^{-1}) than the other animals.

Based on the results obtained, strategies can be devised to improve the construction typology of the facilities, the ventilation system used and the management of the herd to improve the climatic conditions inside the facility, minimizing the impact on animal welfare.

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