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ORIGINAL PAPER

Thermoregulatory, behavioral, and productive responses and physical integrity of primiparous and multiparous cows on compost barn in Brazilian tropical conditions

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Abstract
The compost barn is presented as a system which is capable of providing a suitable environment for dairy cows, but this must be assessed for different climatic regions. Few studies have been carried out evaluating the physics of the thermal environment of this system under tropical conditions. In this study, we evaluated thermoregulatory, behavioral, and productive responses and physical integrity in primiparous and multiparous cows housed in a compost barn system under tropical conditions. From a total of 121 clinically healthy dairy cows aged 3 to 6 years, 30 Girolando cows (7/8) were randomly selected, divided into two groups, according to calving order (primiparous and multiparous), body weight, lactation curve and milk production for the evaluations. Thus, group 1 (primiparous) with an average weight of 524 kg and production of 30 kg was characterized, and group 2 (multiparous) with an average weight and production of 635 kg and 36 kg, respectively. The enthalpy was higher ($P < 0.05$) in the internal environment of the shed at the three evaluated times (3:30 a.m., 11:30 a.m., and 6:30 p.m.), but the humidity did not vary ($P > 0.05$) between the internal and external environments at the evaluated times. Respiratory rate was higher ($P < 0.0001$) in multiparous cows at 11:30 a.m., but was similar at 3:30 a.m. and 6:30 p.m. when compared with primiparous cows. The coat surface temperature was higher ($P < 0.001$) at 3:30 a.m., but similar at the other two times. For the variables lameness and dirtiness, the vast majority of animals presented scores considered adequate (1 and 2), indicating that it was able to provide an ideal physical environment. Regarding animal behavior, panting (O) and lying idle (OD) were higher ($P < 0.05$) in multiparous cows. Multiparous cows have higher ($P < 0.0001$) milk production. Milk production has a negative correlation with enthalpy. The CB system was not able to provide a suitable thermal environment for the animals. Multiparous cows present higher heat stress with change in behavioral responses, especially at midday, but with higher milk production when compared to primiparous cows in compost barn under tropical conditions.

Keywords Scores · Lameness · Dirt · Thermoregulation · Animal welfare

Introduction

Increasingly, discussions about how environmental factors, such as air temperature and relative humidity, associated with the calculation of comfort indices, such as, for example, the temperature and humidity index (THI) and enthalpy (H), have influenced the physiological and productive responses of the animals, impacting the producer's economy (de Castro Júnior and Silva 2021; Salvian et al. 2023).

This discussion has intensified in places under tropical conditions, where heat stress is constantly present in dairy farms, causing a drop in milk production and quality, in addition to reduced feed consumption and increased water intake by animals (Vieira et al. 2021; Silveira et al. 2021). In animals under heat stress, several physiological changes occur, the most easily observed being the increase in respiratory rate (RR) and coat surface temperature (CST) (Vasconcelos et al. 2021). Consequently, the behavioral responses and the welfare and productivity indices of a herd are influenced, such as lameness and dirtiness of the

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animals, as such injuries are closely linked to the productive and sanitary indices of the herd (Guesine et al. 2023).

Seeking to solve these problems, several dairy farms have adopted the intensive rearing of dairy cattle, such as loose housing, tie stall, free stall, and compost barn (CB) (Eckelkamp et al. 2016). Although some studies have reported on the preference of dairy farmers in adopting the CB system in tropical conditions (Vieira et al. 2021; Guesine et al. 2023), there is already a report that in hotter months, the CB was unable to provide an environment within the thermal comfort zone for animals (Pilatti et al. 2019).

Intensive rearing systems, especially CB, have been adopted because they have a substantial impact on the general health and longevity and reduce heat stress in animals (Frigeri et al. 2023), but if the animals are not well managed, there are several factors that can affect their welfare in an intensive production system, such as thermal stress, physical integrity (lameness and dirt), and health, causing behavioral changes, losses in production, and reproductive rates (Frigeri et al. 2023; Guesine et al. 2023). In addition to these considerations, attention should be paid to the calving order of the animals, which presents specific behavioral, thermoregulatory, and productive responses (Reece 2007; Vieira et al. 2021). Therefore, *our main question to be answered in this study is whether there are differences in thermoregulatory, behavioral, and productive responses and physical integrity of primiparous and multiparous cows in CB under tropical conditions?* Our hypothesis is that the CB system does not satisfactorily meet the needs of dairy cows.

Given this information and due to the need for further case studies on the system in order to facilitate the decision-making of producers regarding the adoption of the CB system, the objective was to evaluate the thermoregulatory, behavioral, and productive responses and the physical integrity of primiparous and multiparous cows raised in a compost barn in a tropical climate region.

Material and methods

Study regulation

The research was approved by the Ethics Committee on the Use of Animals of the "Luiz de Queiroz" College Agricultural (ESALQ/USP) (Protocol N^{o}. 2018.5.2288.11.3).

Research location, system characterization, management, and installations

The research was carried out in February 2019 in a commercial dairy farm which adopts the compost barn system, located in southeastern Brazil (latitude 18°52′15″ S and longitude 48°52′51″ W, and 749 m above sea level). The climate of the region is predominantly humid subtropical with dry winters and hot summers (Cwa), according to the Köppen classification, with annual rainfall ranging from 1300 to 1500 mm, (average 1250 mm), temperatures from 16 to 31 °C (average 25 °C), and relative humidity (RH) levels from 20 to 80% (average 60%) (Alvares et al. 2013).

The installation is characterized by a total area of 1750 m^2 (70 m × 25 m), with a bedding area of rice straw as substrate, with about 1050 m^2 (70 m × 15 m), a feeding lane and drinking troughs of 350 m^2 (70 m × 5 m) each, ceiling height of 5 m, open sides, 3-m eaves, roof structure with metal coverage, centralized skylight, and a milking parlor next to the shed (channeled herringbone type) (Fig. 1). The ventilation system consisted of ten fans with an airflow capacity of 37,638 m^3/h, distributed in two lines with five fans on each side, at a height of 3.5 m from the floor, with an average activation time of 18 h/day.

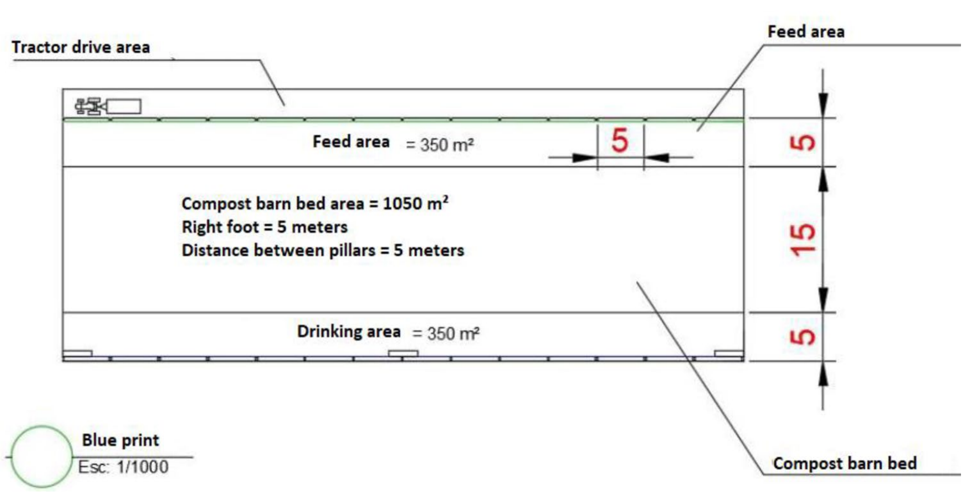

Fig. 1 Compost barn floor plan

The litter was turned twice a day, at 07:00 and 16:00, aiming to aerate the material, improve the level of compaction, and control the humidity of the litter.

The animals received a ration according to the requirements for primiparous and multiparous cows by NRC (2001). Feed was offered at three times (6 a.m., 12 a.m., and 6 p.m.). The diet consisted of soybean meal, citrus pulp, limestone, and a complete vitamin mineral. After supplementation with a concentrated feed, the animals received corn silage as bulk feed. Water supply was ad libitum. The health calendar contained immunization for the main diseases and combating ectoparasites and endoparasites.

Animals

From a total of 121 clinically healthy dairy cows aged 3 to 6 years with 60 ± 5 days in lactation, 30 Girolando cows (7/8) were randomly selected, divided into two groups, according to calving order (primiparous and multiparous), body weight, and milk production for the evaluations. Thus, group 1 (primiparous) with an average weight of 524 kg and production of 30 kg was characterized, and group 2 (multiparous) with an average weight and production of 635 kg and 36 kg, respectively.

Data collect

Data acquisition was carried out for 30 consecutive days, during the summer. The microclimatic variables of the internal and external environment, in addition to thermoregulatory, behavioral, and productive responses, and physical integrity were recorded.

Environment monitoring

The monitoring of the climatic conditions of the environment was carried out by recording the air temperature (dry bulb temperature) and relative humidity, using four HOBO® brand dataloggers (U10-003) at 30-min intervals, throughout the entire trial period.

Through the recorded climatic variables, the temperature and humidity index (THI) was determined, proposed by Hahn (1999):

$$\mathrm{THI} = \mathrm{AT} + (0.36 \times \mathrm{DPT}) + 41.5 \tag{1}$$

in which

AT air temperature (°C).
DPT dew point temperature (°C).

The amount of heat in the dry air mass was determined by the specific enthalpy of air, proposed by Rodrigues et al. (2011):

$$\mathrm{H} = \left\{1.006 \times \mathrm{AT}\left[(\mathrm{RH/BP}) \times 10(7.5 \times \mathrm{AT}/237.3 + \mathrm{AT})\right]\right\} \times (71.28 + 0.052 \times \mathrm{AT}) \tag{2}$$

in which

H enthalpy (kJ/kg dry air)
AT air temperature (°C)
RH relative air humidity (%)
BP barometric pressure (mmHg)

*The local barometric pressure considered was 697.28 mmHg.

Physiological variables

The physiological variables evaluated were respiratory rate (mov/min) and coat surface temperature (°C). The recording of such variables occurred during the 30 days, always 30 min before each milking (03:30, 11:30, and 18:30), period in which the animals were on the CB bedding. The respiratory rate was recorded by the focal animal method, through the movements that the animal exerts in the flank region for 15 s, being later multiplied by four, obtaining the value in movements per minute, according to Martello et al. (2004) and Castro et al. (2020).

The animals' coat surface temperature was recorded using a digital infrared thermometer with a laser sight, Minipa MT-320A. It was positioned at a distance of 60 cm from the animal, and data were collected at four different points (head, back, udder, and shin), following the methodology proposed by Pinheiro et al. (2005), which weights different weights for different body areas, as follows:

$$\mathrm{CST} = 0.10 \times \mathrm{T_{head}} + 0.70 \times \mathrm{T_{back}} + 0.12 \times \mathrm{T_{shin}} + 0.08 \times \mathrm{T_{udder}} \tag{3}$$

in which

T_{head} head temperature (°C)
T_{back} back temperature (°C)
T_{shin} shin temperature (°C)
T_{udder} udder temperature (°C)

Physical integrity

Dirt assessments were performed three times a day, during the period in which the animals were taken to the milking parlor, by means of previously trained evaluators, using the focal animal evaluation method. The regions evaluated were the lateral region of the right tail, hind limbs (right lateral and caudal), and udder, according to the hygiene score proposed by Cook and Reinemann (2007).

The lameness assessment was also performed three times a day, by a previously trained assessor, using the focal animal assessment method. The animals were also classified by scores, according to the evaluation proposed by Sprecher et al. (1994). To score the animals, the gait of the animals to the milking parlor, as well as the alignment of the back, was considered.

Behavior response

The behavioral assessment of the animals was performed using a work ethogram. The analyses were performed using the focal animal technique, with the behaviors being divided by the position of the animals, and positive and negative actions performed. The evaluations took place twice a week, with an interval of 10 min, being in the morning from 08:00 to 11:00 and in the afternoon from 15:30 to 18:00, totaling 05 h and 30 min of evaluations per day, totaling 44 h of observations throughout the experimental period.

Data were recorded in a field worksheet, adapted from the method proposed by Endres and Barberg (2007). The behaviors are described below:

- Position:
- Standing idle (SI): recorded when the animal was with all four limbs stretched out, supported on the floor, head erect or low, without performing any activity (ruminating, eating, etc.…).
- Lying idle (LI): recorded when the animal was with all four limbs flexed, belly leaning on the floor and head erect or low on the bed.
- Ruminating while standing (RS): recorded when the animal was with all four limbs stretched out, supported on the floor, head erect or low, and ruminating.
- Ruminating lying down (RD): recorded when the animal was with all four limbs flexed, belly leaning on the floor, head erect or low on the bed and ruminating.
- Positive action:
- Eating (E): recorded when the animal was ingesting food on the feeding track.
- Ingesting water (IW): recorded when the animal was ingesting water in the troughs.
- Walking (W): recorded when the animal moved over the bed or feeding track.
- Licking (L): recorded when the animal licked itself and/or received licks from another animal anywhere on the body.
- Playing with the bed (PB): recorded when the animal, from head and limb movements, threw the bed up or to the sides.
- Negative action:
- Headbutt (HB): recorded when the animal performed strong head movements against the body of another animal, without causing displacement of the reactor animal.
- Pushing (PG): recorded when the animal performed movements with which it pushed the body of another by sudden and direct physical contact, causing the other to move.
- Pursuit (PT): recorded when the animal approached less than 0.5 m from another animal, causing it to move, without physical contact.
- Panting (P): recorded when the animal had an open mouth and excessive salivation.

Milk production

The milking system on the farm was performed three times a day (4–6 a.m., 12 a.m.–2 p.m. and 7 p.m.–9 p.m.). The entire record of milk production was performed automatically.

Data analysis

Before carrying out the experiment, the sample size was calculated (power test) to ensure that the sample n had sufficient power to detect differences in the results, with 30 dairy cows, the ideal number to evaluate our hypotheses for thermoregulatory, behavioral, and productive responses and physical integrity.

The normality of the residues and the homogeneity of the variances for the thermoregulatory and productive responses and climatic variables and thermal comfort index were previously confirmed by the Shapiro-Wilk (Shapiro and Wilk 1965) and Bartlett (Levene 1960) tests, respectively. Behavioral responses and physical integrity are not normally distributed.

Climatic variables and thermal comfort index

A completely randomized design was adopted in factorial arrangement: 2 types of thermal environment (indoor and outdoor) and 3 times (3:30 a.m., 11:30 a.m., and 6:30 p.m)..

The following general linear model was used in the analysis:

$$\mathrm{Y_{ijk}} = \mu + \mathrm{G_i} + \mathrm{S_j} + \left(\mathrm{G_i} \times \mathrm{S_j}\right) + \mathrm{e_{jk}} \tag{4}$$

where Y_{ijk} represents the responses of the set of dependent variables, μ is the overall average, G_i is the effect of the ith thermal environment (i = indoor and outdoor), S_j is the effect of the jth time (j = 3:30 a.m., 11:30 a.m., and 18:30 p.m.), $G_i \times S_j$ is the thermal environment order and time interactions, and e_{ijk} is the random error. Interactions were excluded from the initial model when they were not significant.

Data were subjected to analysis of variance (ANOVA) to assess thermal environments and times and interaction effects. Tukey's test was used considering a 5% significance of error probability. Finally, the correlation matrix of environmental variables and thermal comfort indexes was calculated with all the variables under study to understand the relation between the sets of data.

Thermoregulatory and productive responses

A completely randomized design was adopted in a factorial arrangement, 2 lactation orders (primiparous and multiparous cows) and 3 times (3:30 a.m., 11:30 a.m., and 18:30 h) for the thermoregulatory and productive variables

The following general linear model was used in the analysis:

$$Y_{ijk} = \mu + G_i + S_j + \left(G_i \times S_j\right) + e_{ijk} \quad (5)$$

where Y_{ijk} represents the responses of the set of dependent variables, μ is the overall average, G_i is the effect of the ith calving order (i = primiparous and multiparous cows), S_j is the effect of the jth time (j = 3:30 a.m., 11:30 a.m., and 6:30 p.m.), $G_i \times S_j$ is the effect of lactation order and time interactions, and e_{ijk} is the random error. Interactions were excluded from the initial model when they were not significant.

Data were subjected to analysis of variance (ANOVA) to assess calving order and times and interaction effects. Tukey's test was used considering a 5% significance of error probability.

Behavioral responses and physical integrity

The Kruskal–Wallis test was used for variables with non-normal distribution considering significance at 5% probability ($P < 0.05$). Bonferroni adjustment was applied in post hoc comparisons for variables with non-normal distribution to the significance obtained to control the type I error rate.

All statistical analyzes were performed using the SAS program (Statistical Analysis System).

Table 1 Compost barn external and internal environment variables

Times	Environments	Variables	SEM	*P* value
	Air temperature (°C)			
3:30 a.m	External environment	21.03 B	0.20	= 0.0014
	Internal environment	22.09 A	0.24	
	Relative humidity (%)			
	External environment	96.56 A	1.14	= 0.2225
	Internal environment	94.22 A	1.51	
	THI			
	External environment	69.58 B	0.23	= 0.0005
	Internal environment	70.88 A	0.26	
	Enthalpy (kJ/kg of dry air)			
	External environment	59.7B	0.49	< 0.0001
	Internal environment	65.56 A	0.63	
11:30 a.m	Air temperature (°C)			
	External environment	26.46 A	0.52	= 0.6454
	Internal environment	26.14 A	0.44	
	Relative humidity (%)			
	External environment	75.2 A	2.98	= 0.2958
	Internal environment	78.27 A	2.37	
	THI			
	External environment	75.2 A	0.48	= 0.9838
	Internal environment	75.19 A	0.44	
	Enthalpy (kJ/kg of dry air)			
	External environment	66.64 B	0.8	< 0.0001
	Internal environment	72.05 A	0.75	
18:30 p.m	Air temperature (°C)			
	External environment	26.35 A	0.7	= 0.7644
	Internal environment	26.63 A	0.62	
	Relative humidity (%)			
	External environment	73.34 A	3.26	= 0.7084
	Internal environment	74.99 A	2.92	
	THI			
	External environment	74.74 A	3.26	= 0.4898
	Internal environment	75.31 A	2.92	
	Enthalpy (kJ/kg of dry air)			
	External environment	63.86 B	0.47	< 0.0001
	Internal environment	69.83 A	0.54	

Averages with different capital letters on the lines differ from each other at the 0.05 level of probability by the Tukey's test

SEM standard error mean

Results and discussion

Climate variables

Table 1 presents climatic variables of the environment of the CB shed for the times related to the records of the physiological variables of the animals. Note that the amount of heat (specific enthalpy of air) was lower in the external environment when compared to the internal environment ($P < 0.05$) at the three times evaluated. At all times, there were no differences ($P > 0.05$) in the relative humidity values.

The fact that the enthalpy is higher inside the shed leads us to consider that the amount of heat produced from the animals, from the fermentation of the litter and from the different elements that contribute to the increase of the internal heat is considerable (Guisine et al. 2023). It is important to emphasize that the values 65.56, 72.05, and 69.83 kJ/

kg of dry air for the periods of 3:30 a.m., 11:30 a.m., and 6:30 p.m., respectively, were in the area considered critical according to the enthalpy tables generated by Livestock Environment Research Group (Núcleo de Pesquisa em Ambiência 2019).

For dairy cows, the thermoneutral zone is between 13 and 18 °C, with the upper critical temperature being 25 and 28 °C, i.e., the animals at both times under study were in a thermoneutral situation, but the RH values are above the recommended values, especially at 3:30 a.m., as the recommended range is between 40 and 60% (Guesine et al. 2023; Lima et al. 2022; Sejian et al. 2018; Castro et al. 2020). From an RH of 78%, the environment is considered highly uncomfortable for these animals (Kadzere et al. 2002). Therefore, based only on enthalpy, we concluded that the animals presented thermal discomfort in both shifts. In addition, the high RH registered at 3:30 h in the compost barn certainly hindered thermal exchanges.

Our results are equivalent to Vieira et al. (2021) who evaluated the spatial heterogeneity of the microclimatic conditions in the compost barn and found high values for air temperature, THI, RH, and wind speed, indicating the inefficiency of the ventilation management of the facility and that the animals were in a thermal stress condition.

Physiological variables

Table 2 displays the values for the RR and CST, both for primiparous and multiparous cows, at three different times throughout the experiment. It was observed that, for the variable RR, there was a significant difference ($P<0.05$) between the animals only for the time of 11:30 a.m., with the multiparous presenting a higher frequency when compared to the primiparous. It is also noted that at 11:30 a.m., when compared to the values found at the other evaluation times, it was the one with the highest RR values. This can be explained by the specific enthalpy of air in this period, which was higher, reaching values of 72.05 kJ/kg inside the shed, a value considered critical, influencing the RR of the animals. These results were expected precisely because it was the time of greatest solar radiation, in which the temperature of the external/internal environment was higher, favoring the results for the highest value of the amount of heat existing in the ambient air.

Following some authors, it appears that Hahn (1999) determined that the threshold for the respiratory rate of cattle to increase occurs when the values for air temperature are above 21 °C, values that, for 11:30 a.m., overcame the difference of 5 °C. Based on the classification proposed by Silanikove (2000), which characterized the thermal stress by the variation of the RR range, the following parameters are considered: milk cows with RR between 40 and 60 mov/min have a low level of thermal stress; values between 60 and 80 mov/min, average thermal stress; and values from 80 to 120 mov/min under high heat stress. According to these classification standards, both groups of animals were in the medium heat stress range during all evaluation periods, with the values obtained at 11:30 a.m. close to the high stress range, especially for multiparous animals.

In production environments in the CB system, the results of Vieira et al. (2021) can be considered, which identified that the RR did not exceed 80 mov/min for the afternoon period, corroborating the data obtained in the present work. Similarly, in Brazil, another study that evaluated 1020 animals raised in the CB system reported that the vast majority of animals had RR values around 40 to 80 mov/min (Radavelli 2018).

For the variable CST, there was a significant difference ($P<0.05$) between the animals only at 3:30 a.m., again with the multiparous showing higher values compared to the primiparous at 29.43 °C and 28.26 °C, respectively. It is possible that this higher CST is related to the dissipation of the heat stock of these animals, since they were more susceptible to thermal stress combined with the high RH recorded at 3:30 h (Table 1), which makes thermal exchanges between the animal and the environment difficult. The maintenance of the animal's coat temperature within certain limits is caused by fluid dynamics promoted by forced ventilation, associated with the exchange of energy between the bedding and the environment (irradiation, convection, and evaporation)

Table 2 Respiratory rate (RR) and coat surface temperature (CST) of dairy cows at different times

Dairy cows	Times	RR (mov/min)	SEM	*P* value	CST (°C)	SEM	*P* value
Primiparous	03:30 am	66.89 A	0.79	0.7668	28.26 B	0.21	0.0001
Multiparous		67.20 A	0.67		29.43 A	0.2	
Primiparous	11:30 am	73.32 B	0.85	<0.0001	31.25 A	0.57	0.0716
Multiparous		79.76 A	0.83		32.40 A	0.26	
Primiparous	18:30 pm	70.93 A	0.74	0.2381	29.69 A	0.24	0.790
Multiparous		72.27 A	0.85		29.77 A	0.21	

Averages with different capital letters on the lines differ from each other at the 0.05 level of probability by the Tukey's test

SEM standard error mean

(Silva et al. 2023) and with the animal's skin by contact, making CST influenced by different environmental factors, such as air temperature (°C), relative humidity (%), and wind speed (m/s) (Silva et al. 2023). TS values below 35 °C are enough for the animals to exchange heat with the environment (Collier et al. 2006). Following these patterns, the groups of animals studied were in the lower range, allowing them to perform heat exchanges in all evaluation periods with greater efficiency. Pilatti et al. (2019) found values for the CTS variable of 29.2 °C, 31.3 °C, and 31.1 °C for the hours of 9 a.m., 12 p.m., and 3 p.m., respectively. However, with multiparous cows always presenting a higher value when compared to primiparous cows at 30.8 °C and 30.3 °C, respectively, corroborating the data obtained in the work.

The differences found between the groups of animals studied, especially for the variable RR, can be explained, since multiparous cows have higher age, weight, milk production, and digestive tract filling capacity; consequently, the generation of metabolic heat is higher (Vieira et al. 2021; Vasconcelos et al. 2021; Lima et al. 2022). Besides, the values of the variables of the production environment to which the animals are submitted may have contributed to the difference found in the RR and CTS variables.

Assessment of physical integrity (claudication)

Figure 2 shows the values referring to lameness for both groups (primiparous and multiparous). There was a significant difference ($P < 0.05$) between them for scores 1, 2, 3, and 4, with none of the groups presenting a score classified as 5.

In general, it can be observed that, in both groups, the vast majority of the animals fit into a lameness score 1, considered good, being 82.95% for primiparous and 55.84% for multiparous. Such values were close to those found by Adams et al. (2016), in a study carried out with 191 dairy farms that use CB, showed that about 90.4% of the herds had a lameness score 1. Regarding the other scores presented, they were close to those found by Burgstalle et al. (2016), whose work carried out in 5 farms that use CB, showed that only 18.7% of the herd fell into a condition of lameness classified as score 3.

It is noted that the multiparous animals showed higher lameness values compared to the primiparous, since the scores that are already considered relevant and that end up revealing a certain degree of injury in the region of the locomotor limbs of the animals, these being the scores 3 and 4 were higher. This behavior of the data can be explained by several factors, among them the age of the animals, as older animals show up to twice the susceptibility to lameness (Manske et al. 2002; Guesine et al. 2023); the nutritional factor, which, according to the European Food Safety Authority (2009), because multiparous animals tend to consume a greater amount of concentrate, this leads to a greater predisposition to the formation of lesions on the animals' hooves. According to Guesine et al. (2023), due to the pressure that the hoof exerts on the ground during the animals' walk, and because these animals are heavier, it ends up facilitating the appearance of this disease.

Assessment of physical integrity (dirt)

Figure 3 shows the values referring to the soiling variable for both groups studied, with a significant difference ($P < 0.05$) between the animals (primiparous and multiparous) only for score 2, with none of the groups presenting a score classified as 4, which is the most serious value of this variable. Overall, it can be observed that the vast majority of the animals evaluated, in both groups, presented a dirtiness score of 1, followed by scores 2 and 3, with the primiparous showing a higher degree of dirtiness (Fig. 3).

These data corroborate those found by the study by Eckelkamp et al. (2016), in which the animals studied remained clean throughout the evaluations, with scores 1 and 2 being the most representative. They also confirm the results found by research by Pilatti et al. (2019), in which, among the groups evaluated, the primiparous had worse cleaning score averages than the multiparous ones, justified by the greater movement of the primiparous in the shed, though there were no animals that fit the dirt score 3.

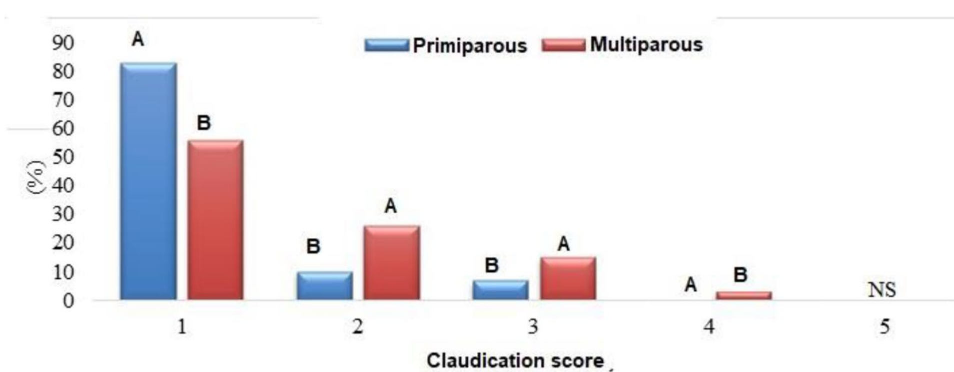

Fig. 2 Lameness score of animals raised in compost barn system. Means with different capital letters between the bars differ from each other at the level of 0.05 probability by the Kruskal–Wallis test

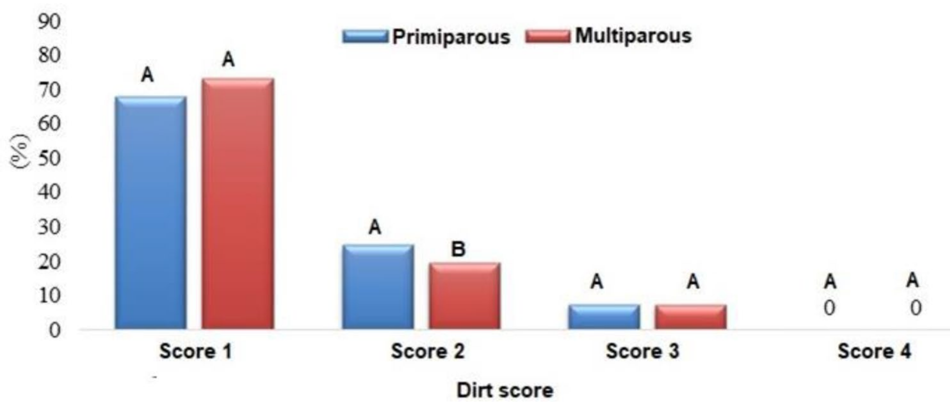

Fig. 3 Dirt from animals raised in compost barn system. Means with different capital letters between the bars differ from each other at the level of 0.05 probability by the Kruskal–Wallis test

The fact that the primiparous had a higher dirtiness score 2 than the multiparous ones can be justified by the place where these animals were exposed in the CB litter, since, in this specific case, the lot was located in the region where the rain, due to in the direction in which the shed was built (north–south), directly reached the bedding, making the compost material more humid and consequently increasing the dirtiness of the animals.

Behavioral response

It is known that the behaviors performed by animals in a production system generally determine how the environment is or is not suitable for them. Behaviors considered negative, such as stereotyping and fights, determine that the system often does not meet the precepts of animal welfare. In this context, the predominance of behavior of Girolando cattle in the CB system was analyzed.

Table 3 shows the values referring to the isolated behaviors for both groups of animals, with a significant difference ($P < 0.05$) only for the lying idle (LI) and panting (P) behaviors. Regarding panting, which was higher in multiparous cows, this can be explained by the higher RR (Table 2). This fact must be considered, as these animals suffer more from thermal stress, making it necessary to use the respiration mechanism to increase heat exchange with the environment.

The fact that the LI behavior was more evident in multiparous cows may be one of the most efficient methods of exchanging sensible heat with the environment is conduction (Frigeri et al. 2023), and considering that these animals presented greater panting and a greater frequency of lying down behavior, it is believed that due to the difference in surface temperature of the litter being lower than the surface temperature of the animal, this promoted a greater occurrence of this behavior as a form of heat exchange by conduction. Cecchin et al. (2014), evaluating the behavior of dairy cattle

Table 3 Frequency of occurrence of behaviors of primiparous and multiparous cows in compost barn

Behavior	Primiparous (%)	SEM	Multiparous (%)	SEM	*P* value
Standing idle	18.47 A (776/4200)	2.17	20.04 A (842/4200)	2.32	0.6288
Lying idle	19.48 B (818/4200)	1.54	26.57 A (1116/4200)	1.75	0.0089
Ruminating while standing	10.91 A (458/4200)	1.46	7.90 A (332/4200)	0.75	0.0979
Ruminating lying down	21.59 A (907/4200)	1.53	17.77 A (746/4200)	1.73	0.1216
Eating	23.90 A (1004/4200)	1.48	22.91 A (962/4200)	2.14	0.7096
Ingesting water	2.07 A(87/4200)	0.40	1.20 A (50/4200)	0.24	0.0859
Walking	1.94 A (81/4200)	0.20	1.92 A(81/4200)	0.21	0.9429
Licking	0.99 A (42/4200)	0.20	0.76 A (32/4200)	0.21	0.4383
Playing with the bed	0.00 A (0/4200)	0	0.00 A (0/4200)	0	-
Headbutt	0.36 A (15/4200)	0.24	0.21 A (9/4200)	0.16	0.6042
Pushing	0.17 A (7/4200)	0.12	0.00 A (0/4200)	0	-
Pursuit	0.00 A (0/4200)	-	0.00 A (0/4200)	-	-
Panting	0.07 B (3/4200)	0.07	0.69 A (29/4200)	0.25	0.0495

Averages with different capital letters on the lines differ from each other at the 0.05 level of probability by the Kruskal–Wallis test

SEM standard error mean

according to the type of bedding material used in free stall (FS) systems, concluded that the animals remained in the LI position for a longer time in structures with sand litter, precisely because this material provides a heat loss from the animal to the environment (conduction) more efficiently than the rubber bedding.

Even though there was no significant difference ($P > 0.05$) between the groups of animals for the other behaviors evaluated, it should be considered that the issue related to position involves in the evaluation of all associated behaviors such as eating, drinking water, walking, licking, playing with the bed, head butting, pushing, chasing, and panting, in which animals were considered standing.

In this case, one cannot simply assess the comparison between SI and LI. Anyway, with the data obtained in this research, it appears that the lying down behavior is directly related to the thermal conditions of the environment, as can be seen in Fig. 4, showing a direct correlation with the maximum enthalpy of ambient air of 0.925 for the primiparous and for multiparous 0.682. It should also be considered that when the animal is lying down, it is generally looking for a way to exchange heat with the environment (bed). This behavior was observed when the amount of heat in the environment was greater ($> H$), characterizing a thermal discomfort. On the other hand, when observed on days, when there is a reduction in enthalpy ($< H$), there is also a reduction in the lying position, that is, an increase in the standing position. This fact makes it evident that when the animal is in thermal discomfort, it tends to be lying down, exchanging heat by conduction, which will probably be greater than the heat exchange by convection when it is standing, and not in conditions of well-being as most studies determine. This finding contradicts the statements made by Fregonesi and Leaver (2001), who determined that the behavior of lying down is the most observed in animals raised in CB systems, which is an indicator of well-being. They also contradict the information generated by Endres et al. (2007) who justify the longer time spent in the CB by the animals because the system provides a soft surface (bed) for resting and performing a more effective thermal exchange (conduction) with the environment.

Regarding the ruminating behavior (Table 3) being more present with the animals lying down compared to the standing position, in both groups evaluated, this can be explained because cattle tend to prefer the lying position to perform rumination (Broom and Fraser 2010).

Regarding the behaviors considered negative, which can be observed in episodes of disputes for space or hierarchy in groups of animals, such as headbutting (HB), pushing (PG), and pursuit (PT), these were rarely observed in both groups evaluated. Such data can be justified with Sárová et al. (2013), who determine that the hierarchy in dairy cattle

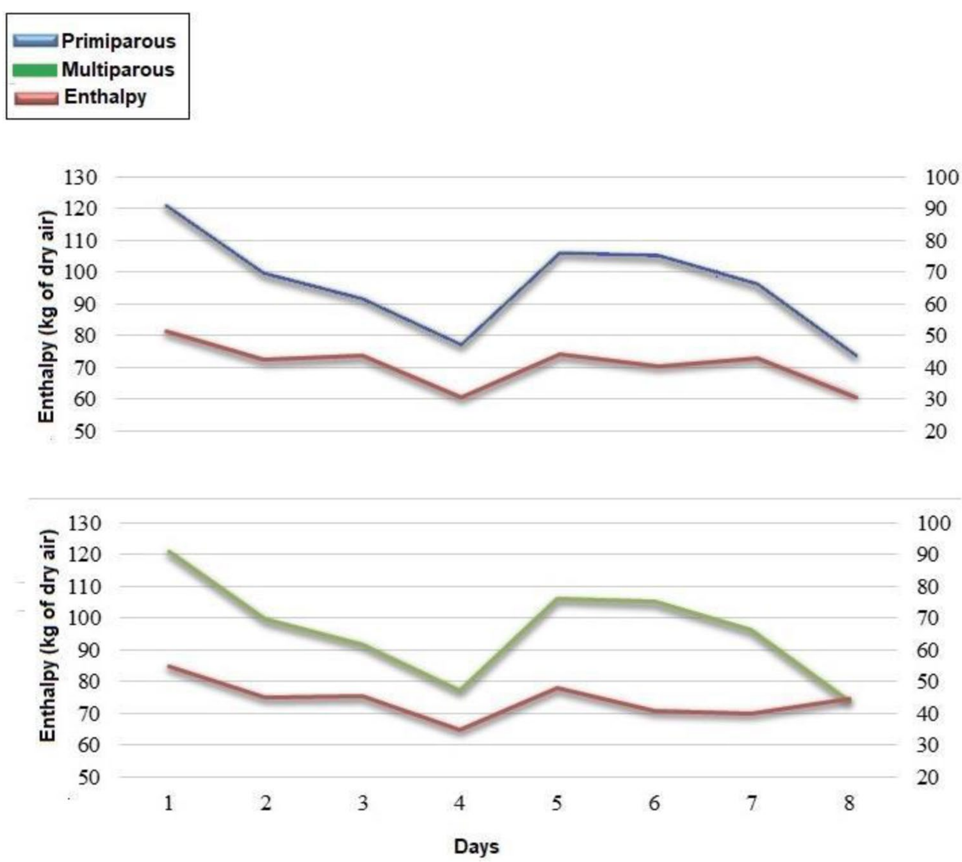

Fig. 4 Correlation between the lying down behavior and the maximum enthalpy of the internal environment of the composting shed for primiparous and multiparous cows

is given by age and weight, and because the animals are divided into batches by weight (kg), farrowing, and milk production (kg), such factors may have helped in these results. It can also be justified because the animal stocking rate is adequate, because this variable is not adequate, it can influence the occurrence of aggressive behaviors.

It should be considered that evaluating the behavior of animals is a difficult task to perform because this is a multifactorial observation, which must be controlled for appropriate comparisons and conclusions. Many authors report behaviors performed differently, that is, focal animal or scanning methods; however, these results cannot be compared equally (Bosholn, and Anciães 2018). Accordingly, when it comes to observation periods during different intervals, such as diurnal or nocturnal habits, they cannot be concluded together.

During the evaluation of this research, we realized that the behavior often performed by the animal is not simply a search for the best condition of animal welfare, but for the organism's self-defense in maintaining the thermal balance, using the existing possibilities, such as bed, shade, water intake, and other resources to reduce stress.

Productive response

Table 4 shows the average values referring to milk production during the three milking times, for the groups of animals (primiparous and multiparous) selected. Among the three milkings evaluated, there was a significant difference ($P < 0.05$) between the groups of animals only for the hours of 04:00 to 06:00 h and 12:00 to 14:00 h, with the multiparous cows showing a higher production at both times.

There was a significant difference ($P < 0.05$) for milk production in both groups studied in all three milking schedules,

Table 4 Productive response (kg/milk) of animals at different milking times

Dairy cows	Times	Milk production (kg)	SEM	*P* value
Primiparous	04:00 a.m.–06:00 a.m	10.51 B	0.10	< 0.0001
Multiparous		11.18 A	0.11	
Primiparous	12:00 a.m.–2:00 p.m	10.07 B	0.11	= 0.0023
Multiparous		10.42 A	0.13	
Primiparous	7:00 p.m.–9:00 p.m	9.10 A	0.11	= 0.2704
Multiparous		9.29 A	0.12	
Primiparous	General	29.73 B	0.23	< 0.0001
Multiparous		31.16 A	0.23	

Averages with different capital letters on the lines differ from each other at the 0.05 level of probability by the Tukey's test

SEM standard error mean

considering that, for primiparous animals, the production was 29.73 kg milk/day and, for the multiparous animals, the production was 31.16 kg milk/day. This result can be explained by the fact that multiparous cows are animals that, in addition to consuming a greater amount of food generating a greater amount of energy with a good part of it destined to the production of milk from the mammary glands, underwent a greater amount of pregnancies and parturition, influencing a greater development of the mammary system, as well as an increase in the milk storage capacity by the cisterns of the gland and the roof of the animals (Reece 2007).

It is verified that the animals throughout the period produced in a condition of caloric challenge; considering the amount of heat existing in the external environment of the CB shed, it is noted that the values are far above the ideal range (Fig. 5). According to the enthalpy tables by Livestock Environmental Research Group (Núcleo de Pesquisa em Ambiência 2019), the ideal ranges are minimum ideal (21.1 kJ/kg) and maximum ideal (61.9 kJ/kg).

The enthalpy psychrometric variable was used because it expresses the amount of heat in the dry air layer at a given location and considers in its mathematical modeling the easily obtainable climatic variables (dry bulb temperature and relative humidity), as well as the barometric pressure of the place, being the model proposed by Rodrigues et al. (2011) the most recommended to assess whether the specific system is capable of providing an ideal environment (climate) range for the species studied or not.

When considering the days of greatest discomfort ($> H$), which in this case were days 23, 24, and 25, milk production in both groups of animals decreased in comparison to the days of lower enthalpy, which means the amount of heat existing in a CB system directly influences the production. Among the several factors that can cause a drop in milk production in dairy cattle, heat stress is quite participatory, mainly because the animal in hyperthermia has difficulties in dissipating body heat, with adaptive changes such as a drop in feed intake in order to reduce the production of metabolic heat; however, it generates less energy destined for milk production (Ammer et al. 2017). This fact will consequently affect the animal behavior, as discussed above, its time spent standing or lying down as a way to improve heat exchanges in the environment in which it is inserted.

Conclusion

The compost barn shed was not able to provide a thermal environment of comfort to the animals, as the amount of heat in the internal environment was greater than that of the external environment, and at midday, the cows, especially the multiparous ones, activated the latent thermoregulation

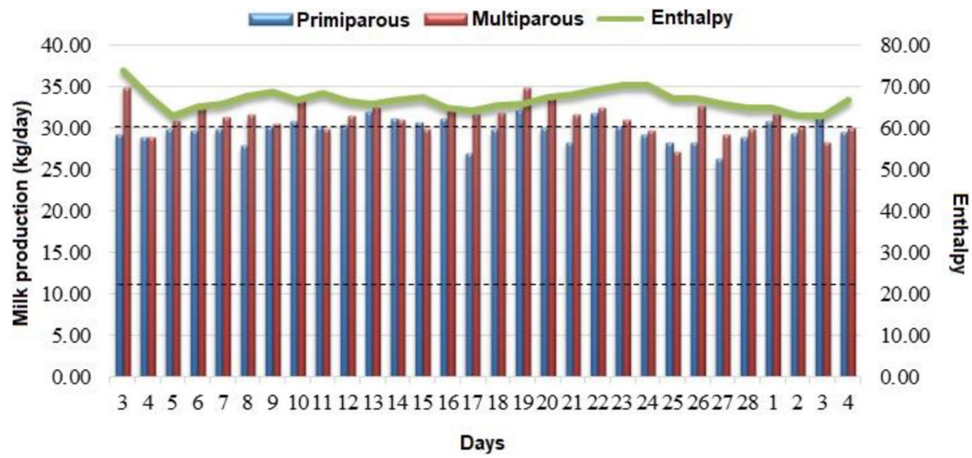

Fig. 5 Average values of milk production of both groups of animals and average values of specific enthalpy of air in summer. Dashed lines in bold delimit the ideal range of the studied variable for the species

mechanisms to dissipate heat to the environment, which changed behavioral responses such as panting. Multiparous cows also spend more time in the lying position, both in leisure and ruminating, which is indicative of the animal's attempt to lose heat to the environment (bed) due to the high level of heat in the environment. The lying behavior externalized the thermal discomfort of the animals in the CB environment. Regarding the physical integrity of the animals, the aspects of dirtiness and lameness, the CB was able to provide the animals with a suitable environment, since the bovines showed mostly scores considered appropriate for the species. Finally, the values of milk production evidenced that the animals produced in a challenge condition throughout the period, since the amount of heat in the internal environment of the CB was far above the ideal range. It was found that on days of greater thermal discomfort, there was a reduction in milk production.

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Author contribution G. D. Guesine and I. J. de O. Silva led the research and investigation process, data collection, formal analysis, wrote the original draft, and participated in conceptualization and methodology and the project administration. R. M. F. Silveira participated in the critical review and in conceptualization.

Data availability Data will be made available on request.

Code availability Not applicable.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Conflict of interest The authors declare no competing interests.

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