Research, Society and Development, v. 9, n. 8, e445985198, 2020
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i8.5198

Compost Barns **na região subtropical brasileira (Parte 1): instalações, manejo de cama e características do rebanho**

Compost barns in Brazilian Subtropical region (Part 1): facility, barn management and herd characteristics

Compost Barns en la región subtropical brasileña (Parte 1): instalaciones, manejo de camas y características del rebaño

Recebido: 02/06/2020 | Revisado: 29/06/2020 | Aceito: 01/07/2020 | Publicado: 13/07/2020

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Resumo

O objetivo deste estudo foi descrever práticas de manejo nos estábulos e avaliar a locomoção, higiene e lesão de jarrete de vacas leiteiras alojadas em Compost Barns (CB) localizados na região subtropical do Brasil. Os CB demonstraram resultados satisfatórios em relação ao conforto e produtividade dos animais. No entanto, modificações nas recomendações americanas iniciais estão sendo feitas pelos produtores, para adaptá-las a diferentes condições. Foram analisadas trinta fazendas leiteiras quanto a medidas e disposição estrutural, práticas de manejo, características do leito e do rebanho. Os principais resultados destacados foram o espaço de descanso de 14,6 m^2/vaca, a maioria das fazendas (87%) possuía instalações recém-construídas e apenas 43,3% foram construídas na direção leste-oeste. A maioria das fazendas não possuía abertura do lanternim e 60% possuíam ventiladores na área de cama, que era revolvida geralmente duas vezes por dia. Cerca de um terço das fazendas usava CB apenas nas horas mais quentes do dia ou nos períodos chuvosos, com acesso às pastagens o restante do tempo. O material de cama teve uma média de 48,4% de MS, pH de 8,68, C: N de 5,90 e temperatura de 42,52 °C à 20 cm de profundidade. O escore de locomoção mostrou que a maioria das vacas possuía uma marcha normal (95,5% das vacas pontuaram 1 ou 2 para locomoção). Foram observadas lesões de jarrete em 15,5% dos animais e 84,0% das vacas estavam limpas ou apenas levemente sujas. Este estudo indicou características ou questões para iniciar um processo de melhoria no uso de CB na região subtropical brasileira. O conforto da vaca foi considerado adequado, com base nos resultados de locomoção, lesões e pontuação de higiene.

Palavras-chave: Sistemas agrícolas; Bem estar animal; Vacas leiteiras.

Abstract

The objective of this study was to describe barn management practices and to evaluating cow locomotion, hygiene and hock lesion prevalence of dairy cows housed in Compost Barns (CB) located in the subtropical region of Brazil. The CB has demonstrated satisfactory results in relation to animal comfort and productivity. However, modifications to the initial American recommendations are being made by producers in order to adapt it to different conditions. Thirty dairy farms were analyzed regarding structural measurements and layout, management practices, bedded pack and herd characteristics. The main results highlighted were the resting space of 14.6 m^2 cow^{-1}, most of the farms (87%) had newly built facilities and only 43.3% were built in E-W direction. Most farms did not have ridge opening and 60 % had fans in the bedded pack area, which is mostly stirred twice a day. About a third of the farms used CB only during the hottest hours of the day or rainy periods, with pasture access the remainder of the time. The bedded pack material averaged 48.4% DM, pH of 8.68, C:N of 5.90 and deep bedding temperature of 42.52 ºC. Locomotion scoring showed majority of the cows with a normal gait (95.5% of cows scoring 1 or 2 for locomotion). Hock lesions were observed in 15.5% of the animals and 84.0% of the cows were clean or only slightly dirty. This study indicates characteristics or issues to start an improvement process on CB usage in Brazilian subtropical region. The cow comfort was considered adequate, based on results of cow locomotion, lesions and hygiene scoring.

Keywords: Agricultural systems; Animal welfare; Dairy cows.

Resumen

El objetivo de este estudio fue describir las prácticas de manejo del establo y evaluar la prevalencia de locomoción, higiene y lesiones de corvejón en vacas lecheras alojadas en Compost Barns (CB) ubicadas en la región subtropical de Brasil. Los CB demostró resultados satisfactorios en relación con la comodidad y la productividad de los animales. Sin embargo, los productores están haciendo modificaciones a las recomendaciones iniciales de América para adaptarlas a diferentes condiciones. Treinta granjas lecheras fueron analizadas para medidas y disposición estructural, prácticas de manejo, características del lecho y del rebaño. Los principales resultados destacados fueron el espacio de descanso de 14,6 m²/vaca, la mayoría de las granjas (87%) tenían instalaciones recientemente construidas y solo el 43,3% se construyeron en dirección este-oeste. La mayoría de las granjas no tenían una abertura para la linterna y el 60% tenía ventiladores en el área de la cama, que generalmente giraba dos veces al día. Alrededor de un tercio de las granjas usaban CB solo en las horas más calurosas del día o en períodos lluviosos, con acceso al pasto el resto del tiempo. El material del lecho tenía un promedio de 48,4% de MS, pH de 8.68, C:N de 5,90 y una temperatura de lecho profundo de 42,52 °C. El puntaje de locomoción mostró que la mayoría de las vacas tenían una marcha normal (95,5% de las vacas obtuvieron 1 o 2 para la locomoción). Se observaron lesiones de corvejón en el 15,5% de los animales y el 84,0% de las vacas estaban limpias o ligeramente sucias. Este estudio indicó características os problemas para iniciar un proceso de mejora en el uso de CB en la región subtropical brasileña. La comodidad de la vaca se consideró adecuada, basada en los resultados de locomoción, lesiones y puntajes de higiene.

Palabras clave: Sistemas agrícolas; Bienestar de los animales; Vacas lecheras.

1. Introduction

Compost bedded pack barns (CB) first appeared in the United States and are spreading worldwide, in countries such as Israel (Klaas et al., 2010), the United States of America (Barberg et al., 2007a; Barberg et al., 2007b; Janni et al., 2007) and Brazil (Fávero et al., 2015; Costa et al., 2018; Pilatti et al., 2018). This housing system has demonstrated satisfactory results in relation to animal comfort (Pilatti et al., 2018; Mota et al., 2019), improved hygiene and lameness scores (Costa et al., 2018; Pilatti et al., 2018), as well as good productivity per animal (Barberg et al., 2007a; Black et al., 2013). The CB includes a resting bedded pack area, usually filled with organic material and where the composting process takes place. Cows can move freely and lie down in different positions in the bedded pack area. In addition to the bedded pack area, there is a concrete feed alley, where animals have access to feed and water (Shane et al., 2010). The bedded pack area is delimited by concrete walls of 1.20 m (Janni et al., 2007).

Field observations and industry reports indicate that the use of the CB systems in Brazil has followed US standards, in which the same facility layout and barn management were adopted as CB originated in the US (Janni et al., 2007). However, it has been suggested that modifications to the initial recommendations may have been made by producers in Brazil and are continuously being implemented in order to adapt the system to different local conditions.

Industry estimates indicate that in the Southern region of Brazil, the adoption of CB has grown at an accelerated pace. An investigation of CB characteristics in this region of Brazil is warranted. Therefore, the objective of this study was to describe barn management practices and to evaluating cow locomotion, hygiene and hock lesion prevalence of dairy cows housed in CB located in the subtropical region of Brazil.

2. Material and Methods

The experimental protocol of this study was approved by the Institutional Animal Care and Use Committee (CEUA) of the Santa Catarina State University under N. 7896060317. This study was conducted on 30 CB dairy farms located in eight municipalities in the Western region of Santa Catarina State, Brazil. Farms were visited once, between January and March 2017. Farms were selected based upon use of the facility for at least three months prior to the initiation of the study. Farms were identified with help from the State Department of

Agriculture and dairy industry advisors. The climate of these municipalities is classified as Subtropical (humid mesothermic, with hot summers), where the annual average temperature is 18 to 19 °C, average annual precipitation is 1,700 to 1,900 mm, and average air relative humidity between 76 and 78%, according to the Koppen-Geiger classification (Peel et al., 2007).

Data collected during each farm visit included building layout, ambient temperature, water quality and measurements of animal welfare. Data referent to the animals and their housing were collected, such as number of cows in each CB, time of permanence in the barn (total or partial), productivity, and herd composition. Amount of bedding material added at each new addition and its cost, criteria used to replace the bedded pack and frequency of replacement, material used in the bedded pack, and frequency of pack temperature measurement were also collected. In this sense, data from the present study were examined by both quantitative and qualitative research methods, as described by Pereira et al. (2018).

2.1 Building layout, temperatures and bedded pack characteristics

The CB housing characteristics measured were: total length and width of the barn, total bedded pack area and size of feed alley, sidewall height, number and dimensions of waterers, presence of curtains and ventilation systems, and style and height of the ridge opening. Based on the measurements collected, the bedded pack area available per animal and linear space of feed bunk and waterers per animal were calculated.

The internal CB dry bulb temperature (°C) and air relative humidity (%) were recorded by a thermo hygrometer (ONSET, HOBO U12-013, Cape Cod, Massachusetts, USA; accuracy of ±1ºC). The black globe temperature (°C) was recorded by a thermometer coupled to a hollow polyethylene ball painted in matte black, placed in the geometric center (considering the total area of the CB) of each barn. All environmental assessments were conducted between 14h30 and 18h30. The internal environmental variables of the barns were recorded every 10 min, and average, maximum and minimum were reported, considering the entire evaluation period. Weather measurements outside the barns were determined by a similar set of thermo hygrometers, installed 1.5 m above the ground, inside a weather shelter positioned in its Southern face. However, the outside records were collected hourly, considering the same period of evaluation.

To verify the thermal conditions of the facilities, the THI (Globe Temperature and Humidity Index) and Black Globe Temperature and Humidity Index (BGTHI) were used (Buffington et al. 1981), calculated from the weather variables obtained inside the CB.

The bedding surface temperature was measured at six points equally distributed throughout the barn, using an infrared thermometer (Series 60, Fluke®). The temperature was also measured at 20 cm depth at the same 6 points using a digital rod thermometer (Incoterm®), according to a methodology adapted from Black et al. (2013). Bedding depth was measured using a metal graduated rod inserted into the pack near the temperature collection points. After the measurements of temperature and depth, a sample of the bedding was collected (Black et al., 2013) to estimate its specific mass (kg of natural material/m^3; Jobim et al., 2007). Subsequently, composite samples by CB were used for chemical analysis. Analyzes of DM, ash and pH (AK103, Akso®) were performed in duplicate (Silva and Queiroz, 2000). Moisture content and organic matter were mathematically estimated based on results obtained from those analyzes. Nitrogen content was determined by the Kjeldahl method (Silva and Queiroz, 2000) and carbon content according to the methodology of Embrapa (1997). The C:N ratio was then calculated. Water retention capacity was also determined from the composite sample, according to a methodology adapted for soils (ISO 11465, 1993). The particle size distribution was performed by a methodology adapted from Damasceno (2012), where the unmodified sample was dried for 24h at room temperature and placed in an automatic shaker at 80% frequency for 3min using 9.5, 4.75, and 2 mm sieves, plus the bottom pan. After the shaking process, the percentage retained in each sieve was quantified.

2.2 Measurement of cow hygiene, locomotion, hock lesion and body condition score

Cow hygiene was evaluated in the udder, legs, thigh and flank regions, according to Schreiner and Ruegg (2002). At least 50% of the cows in each herd was evaluated when the animals were at the feed bunk. In addition, at least 50% of the animals in each herd were evaluated for locomotion (1 to 5 scale, with 1=normal locomotion, and 5=severely lame: ≥ 3 = lame; Sprecher et al., 1997) and hock lesions (scale of 1 to 3, with 1=no lesion, 2=hair loss, and 3=severe lesion) when they left the milking parlor. Body condition score was determined using a 5-point scale (1= emaciated and 5= fat; Edmonson et al., 1989).

Respiratory rate (breaths/min) was measured by counting the movements of the flank for 15 sec then multiplying by 4 to obtain the count/min. Afterwards, the surface temperature

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of the animals (ºC) was obtained from the flanks, rump and rear area, (Montanholi et al., 2008), and expressed as the average of the three areas evaluated, using an infrared thermometer (Series 60, Fluke®). Fifty percent of the animals housed in the CB had their surface temperature taken.

3. Results and Discussion

Compost bedded pack barns have attracted increasing interest as a housing system for dairy cows in Southern Brazil. The main influence for the use of CB in Brazil comes from the US, through the dissemination of technical and scientific materials, e.g. Barberg et al. (2007a), Bewley et al. (2012), and Black et al. (2013). However, due to the lack of technical support for most dairy producers in Brazil, many variations can be expected. For instance, this is the first study to record the partial use of CB in Brazil, i.e., the cows are housed on CB only at the hottest hours of the day or during rainy periods.

All the farms enrolled in the study were located in the Western region of Santa Catarina, which produces more than 75% of the milk in the entire state. The average land area used for milk production for the farms in the study was 30 (± 22) ha, ranging from 7.6 to 130 ha, that is, most of the farms can be considered small, with few exceptions. Total herd size was 115 ± 98 animals, ranging from 22 to 500 animals. The median number of lactating cows was 49.5, ranging from 12 to 290. Number of dry cows was 11 ± 9.9 (range of 2 to 35 cows). Daily milk yield for the observed period was 21.7 ± 3.7 kg, with a range of 15.4 to 30.3 kg/cow. These values are modest for animal productivity in confined systems. However, this productivity can be influenced by several factors, such as feeding management, genetics, and the environment. Herd characteristics were similar to a subset of 12 CB evaluated by Costa et al. (2018) in Parana State, also located in Southern Brazil. About 86.7% of the CB used for housing dairy cows were newly built and only 13.3% of the facilities were retrofitted. When facilities were built specifically to house dairy cows, they could be better designed. However, retrofitting could have the lowest cost.

3.1 Housing characteristics

Regarding barn orientation, about 50% of the CB were in the direction considered adequate (E-W), which avoids the direct solar radiation in the resting area during the hotter hours of the day. Having the barn build in the E-W orientation can also avoid the bunching of animals in certain areas, a factor that can compromise bedded pack quality. However, due to the hilly terrain on most farms, the location of CB was based primarily on the availability of space (also near to the milking parlor); therefore, the orientation of the building was, in some cases, a less important aspect of the project. This last condition was registered in 26.7% of the CB that had the N-S or SW-NE orientation and 30% in the NW-SE orientation.

The characteristics of compost bedded pack barns are available in Table 1. In the present study, 40% of the CB had a feed bunk in a different location, not located next to the bedded pack area. For the CB that had the feed bunk next to the bedded pack area, the majority (50%) were parallel to the pack and 10% were center to the pack. According to Janni et al. (2007), feed bunk space between 46 and 76 cm per animal results in less aggressive behavior, improving feed intake of lactating cows. The feed alley was cleaning in 30% of the CB, two to six times a week in 43.3% CB and no cleaning in 26.7%. In the present study, available feed bunk space per animal met industry recommendations (Table 1). The average feed alley width (2.62 m) (Table 1) was less than recommended by Bewley et al. (2012). Some of the barns did not have a 1.2 m wall between the feed alley and the bedded pack which can help retain the bedding material. The mean values for height of the sidewalls (Table 1) were below the recommended by Janni et al. (2007) of 4.9 m. In addition, barns did not have side curtains which can help reduce water addition to the pack from heavy rains. In addition, some barns had waterers in the bedding area, or nearby where the animals could drink while standing in the bedding area, which can add moisture to the pack and potentially influence the composting process. These points are described as essential for maintaining the good functionality of the system (Janni et al., 2007; Barberg et al., 2007a).

Table 1 - Quantitative characteristics of compost bedded pack barns located in the subtropical region of Brazil (n = 30).

Parameters	Mean ± SD	Minimum	Maximum	Median
Time of CB usage (mo)	22. 3 ± 13.4	3.0	46.0	21.0
Bedding added - each load (m^3)	27.5 ± 14.7	7.0	60.0	25.0
Price paid for bedding (US$/$m^3$)	4.4 ± 1.5	1.7	8.5	3.9
Barn length (m)	43.5 ± 20.1	19.0	100.0	38.0
Barn width (m)	20.2 ± 7.4	10.0	40.0	17.0
Bedded pack area (m^2)	887.8 ± 551.1	285.0	2800.0	750.0
Sidewall height (m)	4.3 ± 0.8	3.0	5.60	4.30
Ridge height (m)	6.7 ± 1.8	4.0	11.0	6.4
Waterers (number)	3.7 ± 2.6	0.0	12.0	3.0
Resting space per cow (m^2)	14.6 ± 4.1	6.0	21.8	15.2
Feed alley width (m)	2.6 ± 1.8	0.0	6.0	3.4
Feeder space (m/cow)	0.7 ± 0.6	0.0	1.7	0.8
Surface bedded pack temperature. before stirring (°C)	25.2 ± 1.7	20.7	28.8	25.0
Surface bedded pack temperature, after stirring (°C)	26.9 ± 13.6	23.4	31.6	26.3
20-cm deep bedded pack temperature, before stirring (°C)	42.5 ± 6.6	30.7	58.8	43.1
20-cm deep bedded pack temperature, after stirring (°C)	40.7 ± 20.9	32.3	52.3	40.0
Dry matter (%)	48.4 ± 10.1	25.9	67.2	47.9
Organic matter (%)	66.4 ± 14.0	36.9	90.3	65.3
pH	8.7 ± 0.5	6.8	9.3	8.8
Depth (cm)	42.0 ± 14.5	10.5	81.3	36.8
Water retention capacity (W)	75.1 ± 4.9	59.9	83.3	75.0
Carbon:nitrogen ratio (C:N)	5.9 ± 4.5	5.9	25.1	10.5
Density (kg/m^3)	650.5 ± 137.2	445.3	945.9	618.7

Source: Authors' elaboration.

Some building characteristics did not follow usual recommendations. We suggest reasons for this finding include limitations due to retrofitting of the barns and building costs.

These characteristics could make daily management more difficult, and interfere with various housing needs, such as the installation of heat abatement systems. An illustration of this problem is the presence of posts in the bedded pack area, found in 33.3% of the CB evaluated, mostly in the retrofitted barns. Open ridges are recommended because they help with the removal of indoor hot air, and in the current study they were present in only 33.3% of the farms.

Ventilation systems are important to maintain air quality and they help with evaporation of the moisture contained in the bedded pack. Sixty percent of the farms had a ventilation system present in the form of mixing fans. Of these, 83.3% the fans were position in the CB wind tunnel, 11.1% in side of the barn and 5.6% as ceiling fans. Sprinkler systems in the feed alley and in the holding pen were not as common, present in only 30% of the farms. The roof type was of Metal tile in 80% the barns and of fiber cement or cay tile in 20% the barns.

As demonstrated by Shane et al. (2010), different bedding materials have characteristics considered adequate for the composting process, with their use mostly driven by local availability and cost. In the current study, the most commonly used materials were sawdust (70% of the CB evaluated), a mix of sawdust and wood shavings (26.7%), and only wood shavings (3.3%). Initially (when the firsts CB were built) bedding material prices were lower, but with the increased demand, there was also an increase in prices, which explains the variability in the prices of bedding (US$/$m^3$) (Table 1).

Variability was also observed on the overall dimensions of the CB, mainly due to the adaptations that were performed, as previously mentioned. The average bedded pack area was 887.8 ± 551.1 m^2, with resting area space of 14.6 ± 4.1 m^2/animal (Table 1). These areas are larger than those reported in a study done in Virginia (9.3 m^2/animal) and Minnesota (7.4 m^2/animal) (Janni et al., 2007). However, the values found were more similar to Israeli systems, with resting area space of 15 m^2/animal (Klass et al. 2010). Some CB had a very low stocking rate, which allows the addition of more animals without compromising cow comfort and the composting process.

3.2 Management of the CB

In this research, 60% of the compost barns were used to the category of lactating cows and 40% used to lactating cows and pre-partum cows. In all, 63.3% the farmers uses the compost barn the entire year. The bedded pack material in 70% the CB was sawdust, in 3.3%

was wood shavings, and in 26.7% it was a mixture of sawdust and wood shavings. In its turn, bedded pack management practices varied according to the routine and labor availability of each farm.

The initial bedded pack depth in 53.3% the CB it was greater than 30 cm, in 40% between 20 to 30 cm, and in 6.7% it was less than 20 cm. The measured bedded pack depth at time of visit it was between 20 to 30 cm in 30% the CB, between 30 to 40 cm in 20% and it was greater than 40 cm in 50% the CB. This difference was identified because some farmers add new bedding material without removing an old bedding. The incorporation of oxygen into the bedded pack is essential to keep the composting system active (Bewley et al., 2012). According to Barberg et al. (2007), composting occurs when the bedding is stir at least twice a day. In this research, 53.3 of the beds performed the management recommended by Barberg et al. (2007) and another portion of 3.3 CB performed three times a day. Stirring of the bedding was mostly done twice a day during milking time. However, in CB that did not have high stocking rates, or did not use the bedded pack full time, the stirring was performed once daily (40%) and another portion of 3.3 of the CB has the bedding stirring every two days.

The cultivator was used in 93.3% of the CB to stir the bedded pack, the chisel plow in 3.3% and rototiller in 3.3%, but the depth of stirring was influenced by the height of the pack. In most of the farms (60%), the depth of stirring was between 20 and 30 cm, reaching depths greater than 30 cm in 36.7% of the farms and less than 20 cm in 3.3% of the farms. Additionally, it was possible to verify the presence of soil in the bedding packs of shorter depth. Janni et al. (2007) reported values between 30 and 50 cm, with variation depending on the composting process and the frequency of bedding replacement of each farm. Those authors also stated that a minimum depth of 30 cm is preferred, in order to prevent the incorporation of soil during the stirring process, which may interfere with the composting process.

Addition of new bedding was performed monthly in 56.7% of the CB. In the remaining farms (43.3%), bedding addition occurred every 2 to 6 months, depending on the intensity of their use and their conditions, similar to practices described by Barberg et al. (2007a), where replacement was done by layers 5 to 10 cm thick, between 2 and 5 wk apart. The criteria used to perform bedded pack replacement in 63.3% the barns were visual and physical evaluation of the pack, in 20% was animal dirtiness and visual and physical evaluation of the pack, in 10% only the moisture, and in 6.7% the barns were visual and physical evaluation of the pack and moisture.

3.3 Bedding characteristics and environmental variables

The bedding characteristics are available in Table 1. The mean DM content of the bedded pack was 48.4 ± 10.1%, thus within the standards cited by NRAES 54 (1992), between 40 and 65%. However, the mean value for deeper temperature at 20 cm, prior to stirring, was 42.5 ± 6.6°C. This is considered not appropriate according to Janni et al. (2007), who reported ideal temperatures between 54 to 65 ºC. However, the lower temperatures would be considered acceptable according to Petzen et al. (2009), who reported values close to 43 °C. Thus, considering the recommendations by Janni et al. (2007), only one farm would fit the established parameters; when considering the recommendations by Petzen et al. (2009), 50% of the CB in the current study had adequate bedded pack temperature. The lower pack temperature seems more appropriate, since many of the farms evaluated had bedded packs with visual characteristics desirable for the maintenance of composting process (Bewley et al., 2012). The bedded pack surface temperature (25.2 °C, Table 1) was close to the average indoor temperature of the CB (27.6 °C, found in this search). in this context, it is important to highlight that 90% the farmers not usually measured the surface temperature or indoor temperature of the pack.

The pack organic matter (OM) directly influences the availability of carbon, i.e., the more OM the greater the availability of carbon for the microorganisms to use (Changirath et al., 2011). In the present study, the mean OM of 66.4% was considered low, which may have influenced the C:N ratio. The C:N ratio had modest values, with a mean of 5.9:1, lower than the 15:1 ratio reported by Janni et al. (2007). The maximum composting process occurs when this ratio is between 25 and 30:1 (NRAES-54, 1992). The microorganisms present in the bedded pack need C as a source of energy, and N as a source of protein for their metabolism. The concentrations of C and N are directly related to the stocking rate, which will determine the incorporation of feces and urine (N sources), and the frequency of bedded pack replenishment (C source) to keep the composting process constant.

The pH of the bedded pack averaged 8.7 (Table 1), close to 8.4 and 8.9 reported by Janni et al. (2007) and Fávero et al. (2015), respectively. These elevated pH values can be attributed to the prolonged time of bedded pack utilization (Table 1), which may lead to higher N uptake in the environment, increasing the pH. During the initial stages of decomposition (Changirath et al., 2011), organic acids are formed. With a continuous composting process, the acids become neutralized and the mature compost generally has pH between 6.0 and 8.0.

The water retention capacity (W) is directly related to the bedding material particle size, where smaller particles have a higher W, but they also promote less aeration in the bedded pack, affecting the composting process (Damasceno, 2012). This fact was tested by Changirath et al. (2011), who also reported increasing W with decreasing particle size. In the present study, bedding materials had 75.1% W, with low variation, which can be attributed to the fact that most of the bedded packs were composed of the same material. The mean density in the present study was 650.5 kg/m^3, with some variability among the CB. Density results between 372.7 and 526.2 kg/m^3 were found by Fávero et al. (2015) on a small study of 3 CB in Brazil. The density is influenced by the daily management of the bedded pack, which interfere in the composting process and consequently in moisture evaporation and porosity of the bedding. Damasceno (2012) found a lower porosity when the bedding density was high.

The particle size in the bedded packs had the following mean distribution: 32.7, 18.4, 16.1 and 29.1%, in 9.75, 4.75, 2 mm sieves and bottom pan, respectively. The particle size distribution has a great influence on the composting process, in which very large particles have a smaller surface area, and a lower amount of carbon to be used by the microorganisms. In contrast, very small particles increase the chances of pack compaction, which can lead to lack of oxygen and affect the composting process (NRAES-54, 1992). Ideally, materials with heterogeneous particle sizes should be used, with a more even distribution among their particle sizes.

This study was conducted in the summer of 2017, when well distributed rainfalls were observed (data not shown). The air temperatures obtained were on average 29.3 °C, with a maximum of 32.3°C (Table 2). These values were lower than those measured inside the CB, which reached a maximum value of 31 °C, and average of 28.4°C. These numbers show that in spite of the animal concentration inside the CB, which naturally produces heat, in addition to the heat from the composting process, temperatures inside the barns were milder than the outside (Table 2). The difference between internal and external temperatures in the CB was more significant when considering the black globe temperature, which takes into account solar radiation and ventilation. A difference of almost 8 °C was observed between indoor and outdoor temperatures, which may be caused mainly by the strong solar radiation present at that time, directly affecting the black globe thermometer. The black globe thermometer simulates the interception of this radiation by the animals' bodies, which could increase the ambient temperature and reflect directly on the comfort and well-being of the animals.

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Table 2 - Environmental characteristics inside and outside compost bedded pack barns located in the subtropical region of Brazil (n = 30).

Environmental parameters	Mean ± SD[A]	Minimum	Maximum
Indoor temperature (°C)[B]	27.6 ± 2.6	21.9	30.1
Outdoor temperature (°C)[B]	28.4 ± 2.9	21.2	32.3
Indoor black globe temperature (°C)[B]	27.5 ± 2.5	21.9	30.9
Outdoor black globe temperature (°C)[C]	35.3 ± 5.7	22.0	43.8
Relative humidity (%), indoors[B]	66.2 ± 11.5	43.1	92.3
Relative humidity (%), outdoors[C]	52.8 ± 11.4	26.3	84.8
Temperature and humidity index (THI), indoors[B]	76.5 ± 3.0	70.6	80.3
Temperature and humidity index (THI), outdoors[C]	76.3± 3.2	69.3	80.6
Black globe temperature and humidity index (BGTHI), indoors[B]	76.4± 2.9	70.3	81.0
Black globe temperature and humidity index (BGTHI), outdoors[C]	83.1 ± 5.6	70.2	91.5

[A]SD: standard deviation; [B]inside the compost barns; [C]outside the compost barns.
Source: Authors' elaboration.

The temperature and humidity index (THI) was calculated based on the weather data collected (Table 2). This indicator combines humidity and temperature and it is used to have an idea about the thermal sensation animals are experiencing. High producing dairy cows, especially those of the Holstein breed, may begin to show signs of heat stress with a THI of 68 (Bernabucci et al., 2010). The average THI in the present study was much more elevated, with an average of 76.5 ± 3.0. In this condition they are panting, with high sweating and increased rectal temperature. There may also be severe depression in food consumption, in an attempt to minimize the production of endogenous heat (Bernabucci et al., 2010). Another index evaluated was the Black Globe Temperature and Humidity Index (BGTHI) proposed by Buffington et al. (1981), which better represents the influence of the environment on animals, since it considers the effects of direct and indirect radiation and ventilation. We used the BGTHI to describe the internal environment provided by the installations (solar orientation, barn height, type of cover, etc.) and, mainly, the ventilation system used in the barn. It is not possible to ensure that the BGTHI values are indicators of thermal comfort. However, a numerical difference was observed for these values indoor and outdoor of the CB facilities, with 76.4 and 83.1 respectively (Table 2). This difference may be caused by the ventilation, which decreases the indoor values of BGTHI, besides the thermal conditioning provided by the building, which attenuates the effect of the indoor radiant heat load. Mota et al. (2019) observed an effect of the daytime on the increase in BGTHI, especially in the afternoon as a result of the increase in air temperature. The same authors suggest that they are aspects of greater difficulty of control.

3.4 Respiratory rate and skin temperature

We measured the respiratory rate of 1020 lactating cows in the current study. It ranged from 39 to 116 breaths/min. We found that 53.3% of the animals had respiratory rate greater than 60 breaths/min. However, if only animals with a frequency between 40 and 80 breaths/min were selected, we classified 93.7% of the animals within a range of low to medium stress (Silanikove, 2000). Values between 40 and 60 breaths/min represent low stress level, 60 to 80 medium stress, 80 to 120 high and over 150 breaths/min, severe stress (Silanikove, 2000). In these regions during the hottest times of the day (maximums up to 35.9 °C and THI of 83 at 15h00), cows crowd into areas with mixing fans blowing on them and they are panting. This stress pattern may be trigger disputes over resources such as ventilation, water and space (Pilatti et al., 2018).

The skin surface temperature averaged 31.4 °C, with a maximum of 36 °C and a minimum of 23.5 °C (n = 1,118 lactating cows). This finding may be related to the animals not being under direct solar radiation. Changes in room temperature affect body temperature, by increasing rectal temperature, respiratory rate, surface temperature, and activate thermoregulatory responses to maintain thermostability (Pilatti et al., 2018; Mota et al., 2019).

3.5 Scores of locomotion, hygiene, hock lesions and body condition score

All scoring was performed by a single trained observer and included between 995 and 1,020 animals across the 30 CB farms evaluated. The representation the frequencies of cow cleanliness, locomotion score, hock lesions and body condition score are available in Figure 1. The majority (74.4%) of cows evaluated for locomotion (n = 995 cows) were classified as score 1 whereas 21.1% of cows scored 2 or only imperfect locomotion. The prevalence of lameness (score = 3) was 2.4%, and severe lameness (score ≥ 4) was 2.1%. These values were

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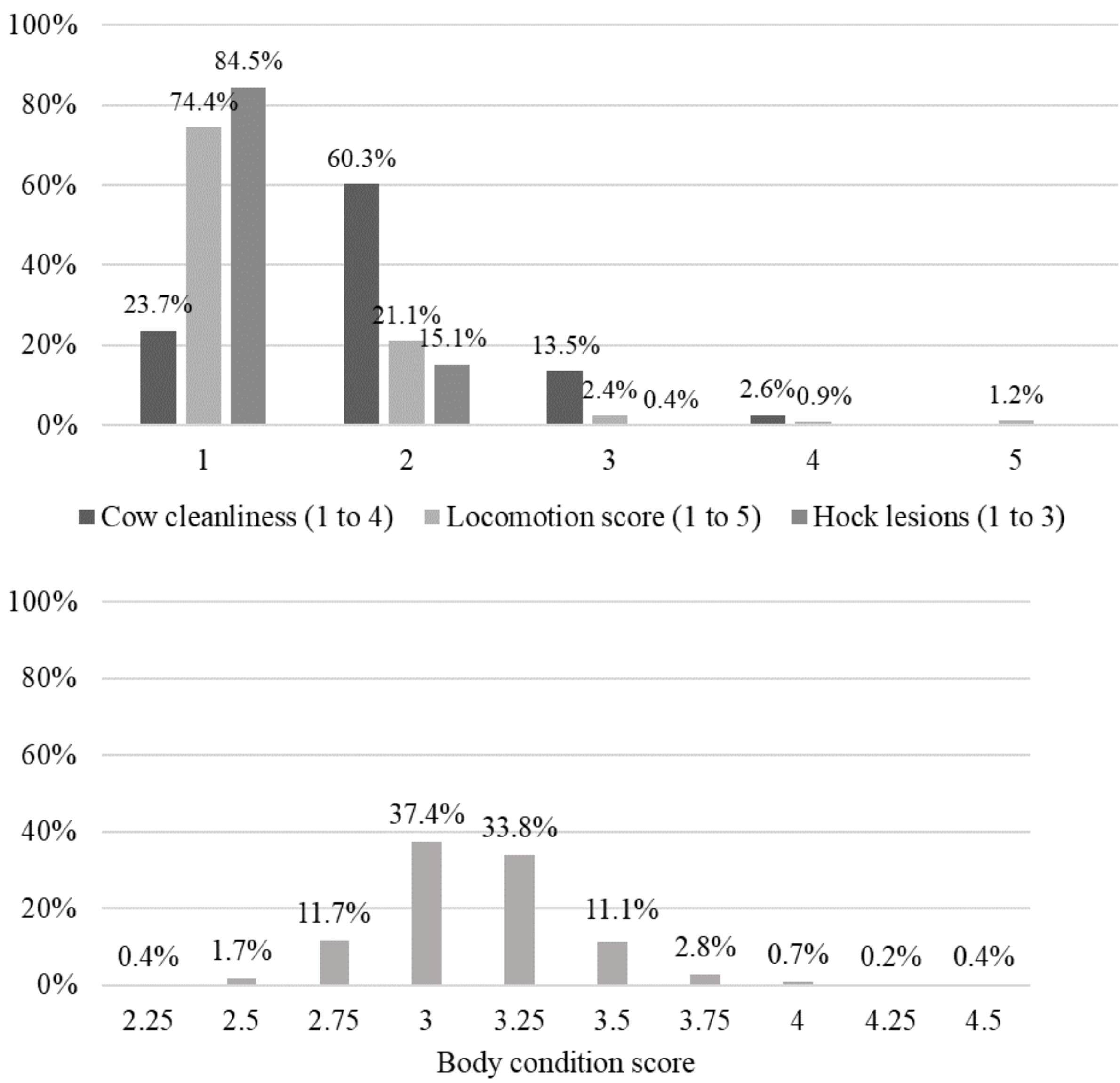
lower than those reported by Costa et al. (2018), who reported severe lameness of 14.2% on CB in Parana State, Brazil. The lower prevalence of lameness reported in the current study may be related to the production system used by most farms before migrating to the CB; 96.6% of farms previously used a grazing system, with supplementation of concentrate 2 to 3 times per day.

Figure 1 - Representation of cow cleanliness (n = 1010), locomotion score (n = 995), hock lesions (n = 1010) (top chart) and body condition score (n = 1020) (bottom chart), expressed in frequency, evaluated in compost barns (n= 30) located in the subtropical region of Brazil.



Source: Authors' elaboration.

We also found a low prevalence of hock lesions (84.5% scored as 1; n = 1,010 cows). A higher occurrence of hock lesions (score ≥2) was reported by Barberg et al. (2007b), who found 25.1% of the cows with hock lesions, 24.1% with hair loss, and 1.0% with swollen hocks. Lobeck et al. (2011) found a lower prevalence of hock lesions (3.8%) in CB systems compared to free stalls and cross-ventilated free stalls (23.9% and 31.2%, respectively). In recent studies, Eckelkamp et al. (2016) compared parameters between CB and free stall systems, and observed no difference in hock lesions between systems, reporting a mean number of hock injuries of 1.0. In addition, Costa et al. (2018) observed 0.5% of prevalence for hock lesions for CB in Southern Brazil. These results might indicate potential improvement in management techniques in both systems over the years.

The same 1,010 animals were evaluated for hygiene, and the most common scores were 1 and 2 (84% of the animals). The overall average score for hygiene in this study was 2.0. This score is lower than reported by Barberg et al. (2007b), with an average score of 2.7 in a study conducted in Minnesota. Higher hygiene scores (average of 3.1) were also found by Shane et al. (2010), who evaluated different materials used as bedding for CB. In contrast, Black et al. (2013) reported mean hygiene score of 2.3, more similar to what was found in the current study.

It can be highlighted that one of the most relevant factors for the maintenance of clean animals is the daily management of the bedded pack, which interferes directly with its moisture content, as well as the different materials used in the bedded pack. An example is the work of Lobeck et al. (2011), in which they compared 3 systems (CB, free stall, and cross-ventilated free stall), and the hygiene scores were 3.18, 2.77 and 2.83, respectively. The authors found an interaction between the season of the year and the dirtiness of the animals, in which the CB system had a higher score in the winter than the other systems, due to the difficulty of maintaining the composting process to the desired standards in the winter.

Regarding the body condition of the animals, about 94% of the animals had scores between 2.75 and 3.5 (n = 1,020 cows). This is an acceptable variation, because animals at different stages of lactation and productive levels were scored. Costa et al. (2018) also reported adequate BCS in most cows housed in 12 CB in Parana State, Brazil.

4. Conclusions

The CB in the subtropical region of Brazil appeared to be a suitable housing systems for dairy cattle. The design of the compost barns varied, because both, new facilities based on

US standards for CB, and adaptations made by dairy farmers to use as CB system were found. Therefore, compromises were made such as less than desirable barn orientation, absence of ridge opening, feed alleys far from the bedded pack area, absence of side curtains, and the presence of posts inside the bedded pack area. However, most of the barns had some ventilation, as well as availability of adequate feed bunk and waterer space. Overall, animals were clean, had few hock lesions, and had good locomotion.

The physical and chemical characteristics of the bedded pack did not meet recommended ideal values for composting. It is suggested that management practices such as the stirring frequency, stocking density, and the presence of ventilation system will influence the quality of the bedded pack. Further research is needed to evaluate these factors, and this study indicates characteristics or issues to start an improvement process on CB usage.

Acknowledgements

The authors thank the National Council of Scientific and Technological Development, CNPQ Universal process no. 428853/2016-1 for financial support. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001. They also thank the dairy farmers for the availability of the structures and the animals to perform the study.

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