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Physical and environmental characteristics of the compost barn system and its effects on the physical integrity, reproduction and milk production of dairy cattle: a scoping review

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Abstract Compost barn (CB), although recent in Brazil, is increasingly gaining popularity among the intensive breeding systems in the dairy sector. This system promises to offer several advantages to producers and animals: such as providing an environment in which milk production is increased and the physical integrity of cattle is improved, reducing mastitis episodes, and promoting thermal comfort for animals. Another factor that highlights CB concerning other intensive systems is the composting process, generated by the deposition of carbon-rich materials (bedding) with nitrogen sources (urine and feces) from animals. For the full benefits of this composting to be achieved, management, especially of bedding, must be carried out correctly, considering the development requirements of the compost, the use of quality organic material, adequate ventilation, and an ideal rate of animal capacity, so that the generation of heat occurs efficiently. However, there is a general lack of information about the CB system. Hence, there is an increasing need for data surveys of Brazilian regions to compare the diversity of materials used in bedding, assessing energy efficiency and performance over time. Therefore, this bibliographical review addressed the main points of the CB system approach, considering that studies such as this are consistently relevant for rural producers, facilitating decisions regarding the implementation and management of the CB system on their farms.

Keywords: animal welfare, composting, environment

1. Introduction

Technological advances involving infrastructure and new milk production systems have increased in Brazil. Indeed, these intensive systems, characterized by semi-open or fully closed facilities with mechanization and technological modernization, are a growing reality.

A widespread alternative to intensive milk production in the US and Israel is the compost barn (CB) intensive system, which aims to improve breeding conditions, providing a favorable environment for animals, and thus promoting an increase in the productivity (kg/milk) of herds (Astiz et al 2014; Black et al 2013). However, concerning countries in tropical climates, there has been much debate about the best systems for milk production: pasture or confinement in a Free-stall (FS) or CB system.

The CB system has stood out among the production systems in Brazil because it provides dairy farms with a way to reduce initial investments and ease the costs of the thermal and environmental conditioning of animals. However, no single model can be used for all regions due to Brazil's continentality and climatic diversity. There is a need, therefore, to understand the performance of the different regional production systems in Brazil.

Some results report that the CB system provides better conditions for animal welfare in all activities, leveraging herds' productive and sanitary indexes and reducing costs through the possibility of appropriately using the organic waste produced by animals on crops and/or pastures. On the other hand, the concept of welfare is broad and does not only relate to thermal comfort or animal environment. Other functional domains should also be considered, such as behavioral (freedom to express normal behaviors), environmental, health, and affective experience (related to a positive mental state).

Even so, due to the lack of technical information regarding the effects of the CB system on the productive, zootechnical, and bioclimatic data of the Brazilian production conditions system, and also with the growing interest of producers in adopting CB, case studies, comparisons of systems, energy efficiency analysis, and studies of its implementation and performance over time will always be of vital importance to producers considering the adoption of such systems and other management improvements.

To this end, this article addresses the CB system's main points to facilitate rural producers when deciding whether or not to adopt the CB system on their properties.

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2. The compost barn system for dairy cattle breeding

The compost barn (CB) system emerged in the mid-1980s in Virginia, United States (USA), adapted from the loose housing system. Due to the approval and satisfaction of the pioneer producers, other countries, such as Israel, Italy, Holland, Spain, and recently Brazil, started to adopt the system. Table 1 presents studies carried out in different countries. These studies demonstrate the local results and their responses.

Despite the dissemination of the CB system in various countries, Guimarães and Mendonça (2015) report that most studies concerning the efficiency and characterization of the system were carried out in regions with milder (temperate) climates. The system has two different models, one applied in Israel and the other in the USA. The model adopted in North America uses bedding composed of carbon-rich material, usually sawdust, in which the composting process occurs more quickly by producing a large amount of heat, helping to dry the bedding material and consequently improving the quality of the bed.

The American model is characterized by sheds with a food supply track structure, either centrally located or at the side, separated from the compost bed by a concrete wall. Its sizing is ideal for a density of 10 m^2 of bedding/animal (Milani and Souza 2010).

The Israeli model differs from the American one by using alternative materials for the bed, composed entirely of manure, making the composting process and the drying of the material more difficult due to the lower amount of carbon and the lower generation of heat. For this model, a density of 15 to 20 m^2 of bedding/animal is recommended, practically 1.5 to 2 times the density of the American system (Klaas et al 2010).

The system structure should consist of bedding of soft and comfortable material (variable according to the region and availability) that can be submitted to the composting process under appropriate conditions of temperature, humidity, and oxygen concentration (Black et al 2013). The physical structure of an animal shed is extremely important for the adopted model's success since well-built facilities provide better conditions of comfort for animals through ventilation and isolation, resulting in higher productivity (Costa and Silva 2014).

The bed area per animal is one of the most important parameters in CB system design because higher densities can increase material compaction and lead to excessive humidity. Studies in various countries show the varied densities used in the CB system, as presented in Table 2.

The main innovative factor of the CB system is the possibility of constant "composting" during the breeding cycles of animals on a property. According to Epstein (2011), the composting process is defined as the biological decomposition of waste into stabilized organic matter, influenced by aeration, humidity, temperature, pH, particle size, and a Carbon/Nitrogen ratio that can affect the quality of the process.

Table 1 Research conducted on CB in various countries worldwide.

Country	Authors
USA	Black et al (2013)
Canada	Leblanc & Anderson (2013)
Israel	Klaas et al (2010)
Netherlands	Galama (2014)
Austria	Ofner-Schröck et al (2015)
	Burgstaller et al (2016)
Switzerland	Ghielmetti et al (2017)
Italy	Leso et al (2013)
Brazil	Fávero et al (2015)
Japan	Saishu et al (2015)

Table 2 Density studies for animals raised in the CB system, in various countries.

Area	Country	Author
- 9,0 m^2/cow	USA	Black et al (2013)
-15 m^2 of bed area/cow	Israel	Klaas et al (2010)
-12 a 15 m^2/cow	Netherlands	Galama (2014)
-6,8 m^2/cow	Italy	Leso et al (2013)
-11 a 19 m^2/cow	Brazil	Fávero et al (2015)

3. The composting

Composting in a CB system shed combines a carbon source (bedding) with a material rich in nitrogen (feces/urine). This material needs to be regularly turned so that air infiltration occurs and the humidity level is adequately maintained, facilitating the decomposition process of organic matter (Black et al 2013). The composting process occurs in three distinct phases: the first generates the so-called raw or immature compost, being the phase that involves the release of heat, water vapor, and carbon dioxide (CO_2); the second phase is the period in which the so-called bio-stabilization occurs; and the third phase is when humification, accompanied by the mineralization of certain components of organic matter is achieved (D'Almeida and Vilhena 2000). The product resulting from the composting process is called an organic compound or organic fertilizer. It has a direct application as an organic soil improver, with numerous agricultural uses.

During composting, the increase in material temperature is known as the thermophilic phase, which lasts approximately 5 to 60 days. The biochemical oxidation reactions increase the medium's temperature from 40 to 65 °C. The next phase, called maturation, lasting 60 to 90 days, occurs when the material loses heat to the medium, presenting a temperature range of between 35 and 45 ºC, with the process of humifying the organic material and mineralizing the remaining Carbon (Matos 2014). However, humidification occurs in the composting of windrows and only occurs in the CB system if the material is removed and allowed to rest.

The efficiency of composting is proven by the temperature and humidity of the bed, where microorganisms capable of degrading the compost material produce heat and, with high temperatures, determine the highest efficiency and quantity of beneficial bacteria.

For efficient composting, the temperature and humidity values of the bed must be between 43 and 65 °C and between 40 and 65%.

4. The bed

Not only is the efficient composting process presented in the literature an advantage of the system, but several other beneficial factors are also reported.

One of the main aspects for maintaining the quality of a bed is aeration because animals tend to compact the composting material while treading on it. Therefore, turning a bed 2 to 3 times a day is essential. The compacted beds with large particles impair decomposition since oxygen levels in composting material reduce, and aerobic microorganisms have difficulty propagating it. Very fine particles also lead to major compaction, causing less oxygen entry into the compound, higher humidity, and problems related to dirt and, consequently, to the welfare of the cows housed.

Suppose the development is done inadequately and inefficiently. In that case, anaerobiosis of the medium occurs, facilitating the proliferation of pathogenic bacteria, especially those causing mastitis. The "activity" of the bed remains superficial, losing the ability to maintain the high temperatures required during the process. In addition to bed temperature problems with inadequate handling, the air quality inside a shed is also impaired by increasing methane, organic acids, and hydrogen sulfide levels.

One possible alternative was using palm straw as bedding material, which resulted in a significant cost reduction in CB systems (Elashhab et al 2019).

In addition to the quality of organic matter used and its handling (allowing for proper composting), the provision of a space that allows all animals to lie down at the same time, and to move freely to the troughs and feeders, is fundamental (i.e., the adequacy of animal density/m^2 is maintained). Therefore, the success of a CB system is multi-factorial: it depends on the size of the herd, the climatic conditions of the region, the material of the bed, the depth of the bed, the management or number of layers turned per day (aeration) and the compaction.

5. The effect of the environment on the compost barn system

The CB system divides the production environment into the solid medium (bed) and the surroundings' gaseous medium (air). These two microenvironments form the production environment to which the cows will be exposed. Therefore, they must be considered for the characterization of the bioclimatic effect. Several factors can influence the efficiency of a CB system, the chief among them being the internal environmental conditions of an installation. Regardless of the production system adopted, animals must be housed in an environment within their thermo-neutral range (comfort zone limit for the species).

In the context of the animal environment, meteorological variables, such as temperature and relative humidity of the air, complemented by the temperature and characteristics of the bed, should be considered. A correlation between these two environments in the same production system becomes necessary.

The durability of a bed is closely linked to the season, as the relative humidity (RH) levels decrease to acceptable standards during the summer, increasing the bed duration in a system. Therefore, it is believed that for each country where the CB system is implemented, there is a need for studies related to the regional climate. In this case, the importance of defining bed conditions and recommendations for the different Brazilian regions is verified.

In an association between the air environment and bed quality, Bewley et al (2012) demonstrated that colder environmental temperatures associated with the northern U.S.A. are detrimental to the establishment of a composting process. For Lobeck et al (2012), when compost humidity is high, applying a new layer of material or decreasing the capacity rate of the house is recommended.

Ventilation is a key ally to the process of composting a bed and the maintenance of ideal conditions of comfort for animals. Concerning natural ventilation, it can be beneficial if the orientation of the installation is directed to the region's prevailing winds. However, if there is no ideal natural ventilation, ventilators (mechanical ventilation), classified as high volume and low rotation (HVLS) and low volume and high rotation (LVHS), should be used.

The artificial ventilation in the CB system with open sheds should be 3m/s (Black et al 2013). This value will allow a higher drying rate of the material, favoring the whole composting process. Shane et al (2010) stated that to improve the efficiency of the use of fans, installing them on a bed with an angulation of 15° to 30° will promote better gas circulation.

6. Behavior and physical and animal integrity in the compost barn system

Many factors can affect the environment of dairy cows. Thermal stress, physical integrity, and health are the main factors causing behavioral changes, productive and reproductive losses within a herd, and economic loss.

6.1. Behavior

Regarding animal behavior, the CB system incorporates factors that positively affect dairy cows, allowing them to interact with animals of the same species and human beings. The objective of the CB system is to allow animals to have freedom of movement, with cows being able to perform natural movements associated with lying down and getting up without injury.

The lactation phase of animals is also a predisposing factor to the type of behavior. Pilatti et al (2019) demonstrated that multiparous cows more frequently exhibited behaviors considered negative (such as pushing) than primiparous, with the afternoon being the peak time. Based on what has been reported, it can be affirmed that animals raised in the CB system lie down longer than in other production systems.

6.2. Physical Integrity

Regarding the physical integrity (claudication and dirt) and milk quality of animals raised in the CB system, the system leads to a decrease in udder dirt, ensuring a lower incidence of mastitis, a decreased CCS count, and better-quality milk, provided that management in pre- and post-milking is adequate.

6.2.1. Dirt

Lobeck et al (2012) compared three closed dairy farming systems (FS with natural ventilation-NV, FS with cross ventilation-CV, and the CB system). An experiment was conducted in 18 commercial dairy farms, 6 for each type of housing, in Minnesota and eastern South Dakota. The authors observed that the animals in the CB system obtained a higher hygiene score when compared to FS (CV and NV). This result was justified because the experiment was conducted during the cold period and had difficulty managing the compound bedding. The hygiene score for the CB system was 3.18, and for the NV and CV systems, it was 2.83 and 2.77, respectively.

Black et al (2013) found that environmental and bed temperature variables and their interaction with environmental humidity significantly affect the hygiene of the average herd in CB systems. The same authors cited that cold and humid environmental conditions, which decrease the drying rate of bedding and increase its humidity, are associated with high rates of dirt, while the increase in material temperature (bedding) reduces the average rates of dirt in a herd.

Fávero et al (2015) identified compost bed characteristics associated with epidemiological indices of mastitis, the cleanliness of cows, and the concentration of selected bacterial populations found in bulk tank milk. The authors also monitored the occurrence of environmental mastitis outbreaks and described the pathogen profile isolated from cases of mastitis in cows housed in the CB system. They identified that environmental coliforms spp. and streptococci spp. were the most frequent pathogens isolated from clinical cases of mastitis.

In their study with 42 CB system sheds, Black et al (2014) identified several isolated pathogens, among them, Coliforms, Escherichia coli, Streptococcus, Staphylococcus, and Bacillus spp, with bacterial counts of 6.3±0.6, 6.0±0.6, 7.2±0.7, 7.9±0.5 and 7.6±0.5 log10 uf/g of dry matter, respectively.

In a study conducted in Italy, Biasato et al (2019) compared two systems of dairy cow breeding, the FS and CB systems. Regarding the quality of milk, the animals raised in the CB system showed better results, proven by the higher percentage of the fat content of the milk (FB 3.54 ± 0.12 % x CB 4.04 ± 0.11%) and the coliforms in the cheese produced (FB 32,500 x CB 20,000 UFC/ml) ($p<0.05$).

The conditions provided by CB system bedding are very favorable for the bacteria causing mastitis to thrive. According to Black et al (2014), it is a dangerous environment for an animal’s udder health. However, studies reported by several authors suggest that the udder health of animals can be controlled as long as adequate system management is maintained (Lobeck et al 2012; Black et al 2014).

Albino et al (2017) found only moderate degree correlations, indicating it to be an inefficient tool to estimate bacterial populations in such sites to correlate the hygiene scores of animals with a CSF count in the teat and milk samples of animals reared under the CB system.

Based on what has been reported so far, it can be stated that the milk quality, in terms of CCS and CBT values, of the animals in CB systems was better than in other intensive production systems (Free-stall).

6.2.2. Claudication

Another alteration that affects the health and welfare of a herd is claudication. The CB system decreases the instance of disease because it allows for greater animal movement on soft surfaces, thereby minimizing the wear of hooves.

Burgstaller et al (2016), in a study in Austria, evaluated the prevalence of claudication and foot lesions in animals kept on five farms using CB and five farms using FS. The authors reported low claudication prevalence in both systems (18.7% CB and 14.9% FS did not present significant differences). However, the animals housed in CB systems showed a significantly lower instance of white line disease (20.4% CB and 46.6% FS), which causes claudication.

Adams et al (2016), in a study conducted on 191 dairy farms that have the CB system, showed that about 90.4% of the animals had a locomotion score of 1, considered good, 6.9% had a score of 2, mild to moderate, and 2.7% of the animals scored 3, considered severe.

In Brazil, Costa et al (2017), in a study of 50 farms in Paraná (Brazil), compared the prevalence of claudication and hock lesions in animals living in FS, CB, and a combination of the two systems. The results indicated a lower overall prevalence of claudication in farms with the CB system (14.2%) compared to farms with FS and those with systems composed of FS + CB, presenting 22%. The same pattern was found for hock lesions, where the prevalence was 0.5%, 9.9%, and 5.7% for farms with CB, FS, and FS + CB systems, respectively.

Lobeck et al (2011), in a US study, found that the prevalence of claudication episodes and the percentage of hock lesions and severe hock lesions were lower in herds housed in the CB system (4.4; 3.8 and 0.8%, respectively) than in the FS system with cross ventilation (15.9; 31.2 and 6.5%, respectively) and in the FS system with natural ventilation (13.1, 23.9 and 6.3%, respectively).

Ofner-Schröck et al (2015), in a study in Austria, found a lower prevalence of claudication episodes in the CB system (25.4%) compared to the FS system (45.7%). However, in contrast, Burgstaller et al (2016) found no significant differences in claudication prevalence among cows housed in the CB and FS systems (18.7% vs. 14.9%).

Overall, the results reported in the literature suggest that the CB system, compared to the FS system, has the potential to improve the health of the feet and legs of animals. However, the results reported are not completely consistent, as large variations can influence the prevalence of claudication and hock lesions.

According to Shane et al (2010), bedding material may be an important source of this variation. The authors compared several bedding materials (sawdust, corn ears, wood chips, sawdust mix, soybean straw, and sawdust mix and soybean straw and sawdust mix) in the CB system and found considerable differences in the prevalence of shank lesions among different types of bedding materials. The material with the lowest prevalence of shank lesions was wood chips and sawdust (0%), while soybean straw had the highest prevalence (46.9%). These results suggest that the choice of the type of bedding material may affect the prevalence of shank lesions and potential claudication.

6.3. The productive performance of animals in the compost barn system

Astiz et al (2014), working with 423 lactating cows in Spain, randomly distributed in the dry period in a group with animals housed in the CB system (n=242) and another group with animals housed in a loose housing system with straw bedding (n=181), reported that the animals in the first system had a higher milk production/day (38.38 *vs.* 36.70 L/d), (P = 0.022).

Black et al (2013), in a field survey of 42 farms and 47 CB system facilities located in Kentucky, USA, found that the average daily milk production increased on farms that started using the CB system compared to milk production before the system was installed (30.7 ± 0.3 *vs.* 29.3 ± 0.3 L/d, respectively), ($P < 0.05$).

Black et al 2013 cite that the effect of the CB system on milk production may be uncertain since other variables may be involved, such as changes in animal management, which could contribute to this increase in production.

Regarding the reproductive part of a herd, introducing the CB system provides positive effects. Astiz et al (2014), in previously mentioned research, found no significant difference in pregnancy rates after the first insemination, metritis, and cytological endometritis, and in the mortality/slaughter rate between groups.

Every improvement in the reproductive part of a dairy farm is associated with economic and zootechnical gains for the producer. The fact that a system provides early pregnancy, increasing the efficiency of the productive life of cows, is one of the great benefits of this production system.

7. Final considerations

It should be considered that, due to the recent implementation of the compost barn system in Brazil, there is a lack of and growing need for scientific, comparative, and published data regarding the different animal production systems in use within the widely diverse regions of the country. It should also be considered that, due to the climatic variability in Brazil, adopting a standard compost barn model is impossible. Furthermore, there is a need for more in-depth research on the different types of bedding and their management, studying energy efficiency and performance over time. This article aimed to facilitate rural farmers making decisions about the best system model for their property, considering both technical and economic aspects. It has been noted that information from the national reality is fundamental for greater assertiveness in this respect. On the other hand, considering results from abroad, which do not always reflect the Brazilian reality due to the inherent characteristics of each country and the rural technology adopted on its dairy farms, should be avoided.

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Ethical considerations

Not applicable.

Conflict of Interest

The authors report no conflicts of interest. The authors themselves are responsible for the content and writing of the paper.

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