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Systematic Review

Effect of Heat Stress on the Behavior of Lactating Cows Housed in Compost Barns: A Systematic Review

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Abstract: In this study, we performed a systematic review to assess the effect of thermal stress on the behavior of lactating cows housed in compost barns. Peer-reviewed articles written in English that evaluated the effect of heat stress on the behavior of lactating cows raised in compost barns were used in this systematic review. The resulting articles (38) underwent a four-step PRISMA appraisal process and resulted in six articles that fitted our inclusion criteria. Our review highlighted that the temperature and humidity index prevailed among the studies to evaluate thermal comfort. Regarding the behavior, heat stress promoted decreases in feed events and the time that cows spent lying down. In contrast, there was an increase in events of visiting the water trough, the number of steps, agonistic behavior, and dyspnea. In conclusion, heat stress affected the behavior of lactating cows raised in compost barns; however, some care is needed in extrapolating our findings since this is a recent research area and further studies are needed.

Keywords: confined system; cattle; temperature-humidity-index; applied ethology; thermal comfort; zero-grazing system

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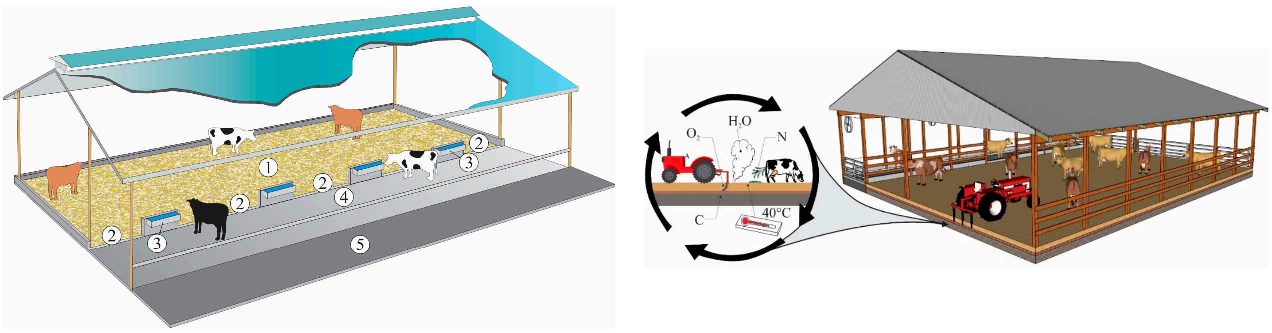
1. Introduction

Heat stress is among the main challenges in the dairy production systems [1–3]. Prolonged harsh periods with extremes in air temperature, for example, heat waves [4,5], will rise in frequency (four or more events per year), intensity (air temperature above 30 °C) and duration (six or more days) [6,7]. The identification and analysis of these climatic phenomena are necessary when aiming for the sustainability of dairy production. Indeed, heat stress has become a significant challenge faced by dairy farmers.

When exposed to challenging environments (for more information about the thermal neutral zone of dairy cows, please see de Castro Júnior et al. [8]), lactating cows' body temperature becomes elevated (>39 °C), stimulating peripheral receptors to transmit nerve impulses to the hypothalamus to release stimuli activating physiological mechanisms to control the thermolysis [9]. These mechanisms promote heat abatement through conduction, convection, radiation, and evaporation [10]. However, as body temperature exceeds the thermal gradient of cows, the expenditure of net energy that would be used for production is increased for the body balance of lactating cows [11]. In addition to production losses, other adverse effects associated with heat stress include decreased fertility [12], health [13], dairy cow behavioral changes [14], and a decrease in the cows' welfare [15]. These factors related to heat stress result in annual economic losses of approximately 2.3 billion USD for the American dairy industry [16].

Animal thermal comfort concerns have expanded in the last 25 years among temperate and tropical climate countries [6,17], as thermal heat load remains a significant problem in production systems, regardless of geographical region. To mitigate the effect of heat stress on dairy cows, confinement systems have emerged as an alternative to pasture-based systems. Among the confinement systems, the compost barn system is a relatively new alternative for dairy farmers [18]. The compost barn system (Figure 1) consists of housing animals in a barn with a resting area covered with an organic compost-bed [19] without stalls or partitions [20]. The main positive points of the use of this system are the improvement in the comfort and welfare of the dairy cows, improvement in milk quality, reduction in hoof problems, increase in reproductive and productive efficiency, low initial construction cost, and better manure management [21]. On the other hand, the compost barn system presents some challenges, such as thermal conditioning and bed management [22]. As the main difficulties of the system highlight seasonal offers of bed materials (especially in the winter), the high cost of bed materials, the use of implements for the revolving of the bed, the use of fans for heat abatement, and the increased use of electricity [21].



(**a**) (**b**)

Figure 1. Schematic representations of a compost barn system. (**a**) 1—rest area with organic compost-bed; 2—free passage area; 3—water trough; 4—feeding area; 5—feeder. (**b**) Bed turning management. Figures adapted with permission from Ref. [23] (in Portuguese: compost barn como alternativa para a pecuária leiteira), 2020, Flávio Alves Damasceno.

One approach for thermal environment control in compost barns consists of the thermal conditioning of the facility, which can be natural or artificial. However, it is important to highlight that the compost barn has two structure forms, (1) a system with open sides and (2) s system with closed sides. Therefore, the inside cooling efficiency is directly influenced by the structure of the barn [24]. Thus, evaluating the effects of thermal conditions on dairy cattle facilities is necessary [25]. This can be explained because the housing structure has the potential to reduce or increase indoor climatic conditions [26,27] and consequently, a better or worse environment induces behavioral changes in dairy cows. In summary, the behavior of cows is expressed in values that reflect the time of their activities. In comfort conditions, cows lie down for an average of 10–12 h/day, and a reduction in this behavior can be related to welfare problems [28], lameness [29] and metritis [30]. In contrast, cows in heat stress decrease dry matter intake (approximately 50%; Herbut et al. [31]), are prone to reduce resting time lying down [32] and consequently increase the probability of standing up [33]. This change in posture may be related to aiding body heat abatement [34].

The change in behavior is the cow's first reaction to the challenging environment (e.g., heat stress). However, the influence of environmental variables on the behaviors of lactating cows raised in compost barns has been explored in few studies. Although several studies have evaluated the effects of heat stress on confined dairy cows, these studies have focused on evaluations in free-stall barns. To our knowledge, no systematic review has been performed to evaluate the influence of heat stress on the behavior of lactating cows raised in compost barns. The knowledge of behavioral strategies of dairy cows within compost barn systems can help us to understand the cows' thermodynamics in these systems. So, we aimed to perform a systematic review to identify the effect of heat stress on the behavior of lactating cows raised in a compost barn system.

2. Materials and Methods

2.1. Literature Survey Strategies

This systematic review followed the standard guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA; Moher et al. [35]). The systematic searches (Table 1) were performed in the Web of Science (WoS) and Scopus (ScP) databases with the integration of Boolean operators (e.g., AND, OR, NOT) to string together words or phrases, as well as wildcard truncations (denoted as " ") to designate a range of possible word forms. We consider WoS and ScP to be the best resources available as ScP is a more comprehensive platform that hosts different databases and WoS due to its status as a human-curated database with structured and detailed entries that provide results from journals indexed by Clarivate Analytics, filtering out peer-reviewed literature. Thus, we adopted a more comprehensive platform and another with greater filtering power so that there was no risk of articles from well-known journals with a high impact factor being underrepresented in our results. We restricted our literature screening to only two search engines (WoS and ScP), as different search engines employ different criteria and weights to generate search results. Additionally, search terms require changing across different databases; certain search engines are automatically responsible for similar terms, while others are not. Therefore, it becomes difficult to integrate reference lists that were generated based on unique algorithms.

Table 1. Search term strings used for the final searches in the systematic review.

Acronym	Search String
Population	(cattle OR cow OR milking OR lactating OR "lactating cows" OR dairy OR "dairy cow" OR "dairy cattle")
Interventions	("confined system" OR "confinement system" OR "compost-bedded pack barn" OR "compost barn" OR "compost-bedded pack barn system")
Outcome	(climate OR heat OR "heat stress" OR "thermal comfort" OR temperature OR "relative humidity" OR "temperature humidity index" OR THI) AND (behavior OR behaviour OR "lying rest" OR feeding OR "standing rest" OR walking OR "water intake")

2.2. Eligibility Criteria

We selected studies reporting on the effects of microclimate variables and thermal comfort indicators on the behavior of lactating cows raised in compost barns. Thus, we considered studies that described the method of behavioral assessment, studies that described in detail the behaviors analyzed and studies that reported behavioral changes related to the effects of heat stress. For this, experimental peer-reviewed articles written in English and published in any year up until January 2023 were systematically reviewed. Inclusion and exclusion criteria were determined a priori. The WoS search returned 20 results, while the ScP search returned 18 results. All results (n = 38) were included in the Mendeley® software. Results were automatically searched for duplicates using Mendeley®, all duplicates were excluded, and the remaining studies were selected based on a four-step screening and assessment process (Figure 1). Step 1: Studies written in languages other than English, review articles, theses, dissertations, book chapters, and conference papers were removed (where peer-review is uncertain). The remaining studies were screened to filter out irrelevant results (e.g., animals other than lactating cows). Step 2: Titles and abstracts were assessed to identify and remove studies that did not use lactating cows (e.g., studies that dealt with dry cows and heifers), compost barn systems (e.g., studies that evaluated cows in free-stall barns, tie-stall barns, or loose housing) and heat stress (e.g., studies that evaluated cold heat stress). Step 3: The remaining studies were analyzed and identified from their titles and abstracts and studies that evaluated the behavior of lactating cows in a compost barn system were selected using the sourced from domains 1 (study eligibility criteria), 2 (identification and selection of studies) and 3 (data collection and study appraisal) of ROBIS (risk of bias in systematic reviews, [36]) to be evaluated in step 4. Step 4: Finally, the full set of studies were read in detail, and studies that did not address the effects of heat stress on the behavior of lactating cows in a compost barn system were excluded (e.g., studies that evaluated the behavior of lactating cows but did not show a relationship with heat stress). The remaining studies (n = 7) were included in the systematic review. However, to provide a comprehensive overview of the literature, no additional restrictions were placed upon the publication year, sample size, or journal quality.

2.3. Data Extraction and Manipulation

A Microsoft Excel spreadsheet was built from the extracted information: study identification, author, year of publication, journal of publication, country, region, classification of Köppen, number of farms, number of animals, breed, parity, heat stress indicator, behavioral verification method, types of behaviors evaluated, ventilation system and results.

3. Results and Discussion

3.1. Overview of Included Studies

The initial database search retrieved 38 research articles (Figure 2). After removing duplicate reports, 28 article titles and abstracts were selected, of which 13 were excluded due to not matching our eligibility criteria. Subsequently, 15 papers were reviewed in detail, and we identified seven studies that matched our eligibility criteria. The publication years of the studies included in this review ranged from 2007 to 2022. This shows that the compost barn is a recent confinement system when compared to free-stall and tie-stall barn systems. A bibliometric study performed by Silva et al. [21] also identified that studies involving compost barns started in 2007. The studies were carried out in Brazil (n = 6) and the United States (n = 1), and the main characteristics considered for the experimental trials, including the method used for behavioral analysis, the source of data, and the main findings are shown in Table 2.

3.2. Herd Characteristics

Holstein and Jersey were identified as the main breeds in the herds (Table 3). These breeds are prevalent in confinement systems because of their productivity [20]. In a study on six farms using the compost barn system in Europe, Emanuelson et al. [37] observed the predominance of the Holstein breed among the farms. However, several studies reported the use of different dairy cattle breeds and crossbreeds (Montbéliarde, Viking Rede, Normande, crossbred Holstein x Simmental cows, cows and crossbred Jersey x Holstein cows) raised in a compost barn [38–44]. The average herd size (49 cows) was similar to those found in Brazil (49 cows; Nogara et al. [44]) and Italy (58.8 cows; Leso et al. [45]), and the maximum number of animals (177 cows) was identical to those found in Kentucky (178 cows; Eckelkamp et al. [46]) and Brazil (180 cows; De Oliveira et al. [47]).

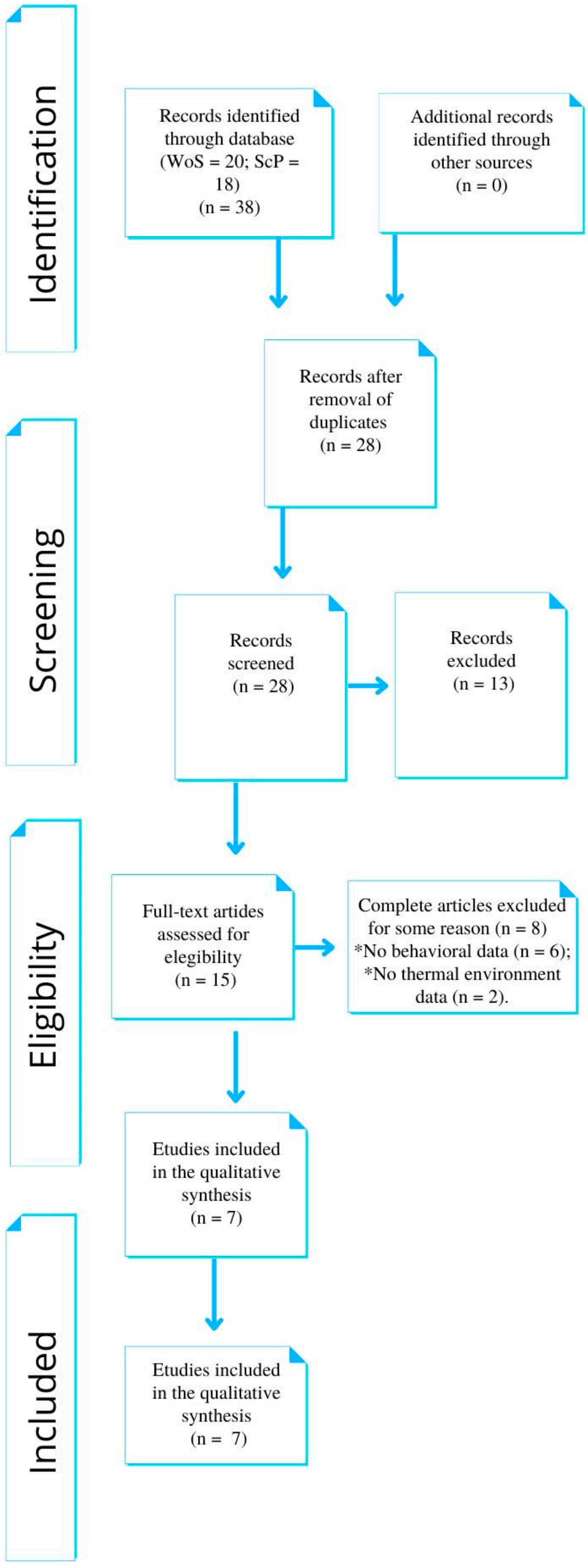


Figure 2. Flowchart following PRISMA guidelines (Moher et al. [35]) showing the total number of publications identified and the number of publications filtered at each stage of the selection process from the systematic review.

Table 2. Characterization of the studies included in the systematic review.

Reference	Country	Breed	Cows (n)	DO [1]	HIS [2]	MBV [3]	CC [4]	VS [5]	MF [6]
Endres and Barberg. [48]	Minnesota/US	Holstein and other breeds (not specified)	147	Nulliparous and multiparous	THI [7]	Automatic and visual	Non-informed	Not informed	Increased THI interfered with the lying rest of dairy cows. Cows remained to lie for 12.7 h/d when THI was <72. In contrast, when THI was ≥72, the cows remained at 7.9 h/d. Furthermore, cows increased the number of steps as THI increased from 71.6 steps/h with THI < 72 to 120.8 with THI ≥ 72.
Vieira et al. [49]	Paraná/BR	Holstein and Jersey	18	Nulliparous and multiparous	THI [7]	Visual	The CB [8] was situated in a north–south direction. The confinement was 24.4 m wide, 31.4 m long, and 8 m high. The roof was made of galvanized tiles. The pen had eight fans with low volume and high speed. The fans were installed 3.5 m from the litter at an angle of 30°. The capacity ratio ranged from 12.35 to 17.02 m^2/animal.	Natural and mechanical ventilation (fans)	Multiparous cows fed at the coolest hours of the day (8 a.m. and 8 p.m.), while nulliparous cows fed at the hottest times (after 9 a.m. until ~3 p.m.). In addition, multiparous cows were more prone to walk at the hottest times of the day. In contrast, multiparous cows were more probable to lie down and rest at the hottest times of the day in the bedding area where there was higher wind flow.
Pilatti et al. [50]	Paraná/BR	Holstein and Jersey	10	Nulliparous and multiparous	THI [7]	Visual	The CB [8] was situated in an east–west direction. It was 45 m long and 20 m wide. The bedding area was 576 m^2 (16.4 m^2/animal). The confinement had seven fans with six blades and an airflow capacity of 34,000 m^3/h.	Natural and mechanical ventilation (fans)	Nulliparous cows were more likely to walk between 09:20 a.m. (maximum THI = 78), 11:20 a.m. (maximum THI = 81) and 3:20 p.m. (maximum THI = 81). Additionally, at the hottest times of the day, the nulliparous cows showed the highest number of visit to the troughs, which was not observed in multiparous cows.

Table 2. *Cont.*

Reference	Country	Breed	Cows (n)	DO [1]	HIS [2]	MBV [3]	CC [4]	VS [5]	MF [6]
Pilatti et al. [51]	Paraná/BR	Holstein and Jersey	12	Nulliparous and multiparous	THI [7]	Visual	O CB [8] was situated in an east–west direction. It was 45 m long and 20 m wide. Bedded area was 576 m^2 (16.4 m^2/animal). The confinement had seven fans with six blades and an airflow capacity of 34,000 m^3/h.	Natural and mechanical ventilation (fans)	Multiparous cows showed a higher probability of agonistic behaviors (pushing, hitting, and chasing) and a higher probability of dyspnea as air temperature increased. At the hottest times of the day (maxima up to 35.9 °C and a UTI of 83 at 3:00 p.m.) multiparous cows competed more for ventilated areas, showing dominance behavior. On the other hand, the authors also observed a greater probability of cows to ruminate standing up as the temperature increased. Resting lying down was more likely between 09:20 and 11:20 a.m., while feeding was more likely at 08:00 a.m.
Yameogo et al. [52]	Minas Gerais/BR	Holstein and Jersey	85	Nulliparous and multiparous	THI [7]	Visual and video recording	O CB [8] was situated in a northwest–southeast direction. The housing enclosure was 55 m long and 26.8 m wide. The litter area was 880 m^2 (10.35 m^2/animal). The roof was made of galvanized tiles. On the sides there were blue polyethylene curtains. Inside the facility, there were five deflectors. The confinement had an evaporative cooling system with five cellulose fiber panels.	Wind tunnel	Cows decreased time lying down as THI increased. Standing behavior increased with increasing THI. Feeding behavior was affected by THI.
Peixoto et al. [53]	Ceará/BR	Not informed	20	Not informed	Air temperature and relative humidity	Visual	O CB [8] was located in an east–west direction. The barn had a litter area of 540 m^2 (27 m^2/animal) and 4.5 m of headroom. The roof was made of galvanized tiles.	Natural and mechanical ventilation (fans)	Animal discomfort was observed during the region's dry period, reflecting greater behavioral changes. Cows spent more time lying down in areas where the airflow was higher due to artificial ventilation and bedding temperature was lower. While during the rainy season, cows spent more time feeding and resting lying down.

Table 2. *Cont.*

Reference	Country	Breed	Cows (n)	DO [1]	HIS [2]	MBV [3]	CC [4]	VS [5]	MF [6]
Laurindo et al. [54]	Minas Gerais/BR	Girolando	51	Not informed	THI [7]	Automatic and visual	The CB had a bed area of 15.7 × 54.0 m and a total area of 23.0 × 54.0 m. The foot-right of the CB was 4.8 m. The CB had two ventilators (HVLS).	Natural and mechanical ventilation (Fans)	Cows spent less time lying down and more time standing when THI was >70.

[1] DO—delivery order; [2] HSI—heat stress indicators; [3] MBV—methodologies of behavioral verifications; [4] CC—constructive characteristics; [5] VS—ventilation systems; [6] MD—main findings; [7] THI—temperature–humidity index; [8] CB—compost barn.

3.3. Thermal Stress Indicators

The leading indicator of thermal comfort used in the studies (n = 6) was the temperature and humidity index (THI). Only one study used air temperature as an indicator of thermal stress. The equations that studies used to evaluate the THI are described in Table 3. The THI emerged in 1959 to assess thermal discomfort in humans [55]. This concept was later extended to farm animals, and since then, several researchers have considered the THI a standard method to assess heat stress in dairy cows [56,57]. The THI is the most common thermal comfort indicator used because it considers air temperature and relative humidity, which are variables easily measured. Yan et al. [58] investigated nine thermal indices related to dairy cows, including THI, black globe temperature index, equivalent temperature index, effective temperature for dairy cows, respiratory rate predictor, temperature–humidity adjusted, heat load index, comprehensive climate index and the equivalent temperature index for cattle. The authors concluded that most heat indices could not accurately predict heat stress in confined lactating dairy cows. In addition, Yan et al. [58] identified that the THI, black globe temperature index, temperature–humidity adjusted, comprehensive climate index and equivalent temperature index for cattle were closer to the actual heat stress conditions during the experimental period [58]. In another study, Wang et al. [59], when reviewing 16 heat stress indices for dairy cows, the authors concluded that there was significant variation across the different breeds, access to shade, the cooling system, the physiological responses of dairy cows and the other climatic variables. The authors also reported that heat stress indices must carefully choose different production contexts. Among the 16 indices observed, they identified that the black globe temperature and humidity index, global climate index, respiratory rate index and the adjusted temperature–humidity index performed best among those studied [59]. However, it is worth noting that different climatic conditions involve equations to determine the THI [60]. Thus, indices with higher humidity weights are more suitable in humid climates, while in semi-arid environments, indices with more emphasis on ambient temperatures are recommended [60]. THI is a general and indirect indicator that does not consider individual cows. Thus, its results may be inadequate to meet livestock needs [61]. Therefore, associating the THI with behavioral and physiological parameters is more adequate to assess whether cows are in heat stress. This is because there are differences between the breeds of dairy cows, as well as age and their milk production, in addition to the geographical location of the barn and the types of housing, thus making it difficult for conclusive analyses and future comparisons [62].

Table 3. Temperature humidity index (THI) equations that were used in the studies included in this review to determine the thermal environment for lactating cows raised in a compost barn system.

Reference	THI Equations	Indicators of Stress	Studies
West et al. [63]	THI = td − (0.55 − 0.55RH) (td − 58)	Not informed	[48]
Hahn. [64]	THI = Ta + (0.36 × Tdp) + 41.5	Normal 74; alert 75–78; danger 79–83; emergency 84	[49–52]
Mader et al. [65]	THI = (0.8 × Tdb) + [(RH/100) × (Tdb − 14.3)] + 46.4	Normal 69; alert 70–74; danger 75–79; emergency 80–84	[53]
Thom. [56]	THI = Ta + 0.36 × (Tdp) + 41.5	Normal 69; alert 70–75; danger 75–79; emergency 80	[54]

THI—temperature-humidity index; Tdp—dew-point temperature; RH—relative humidity; Tdb—air temperature.

3.4. Behavior

Behavioral changes are the animals' first response to heat stress [66]. The main behavioral changes reported are shown in Figure 3. Overall, cows decrease their time spent lying down and decrease their feeding events; in contrast, they increase their walking behavior and water trough visits.

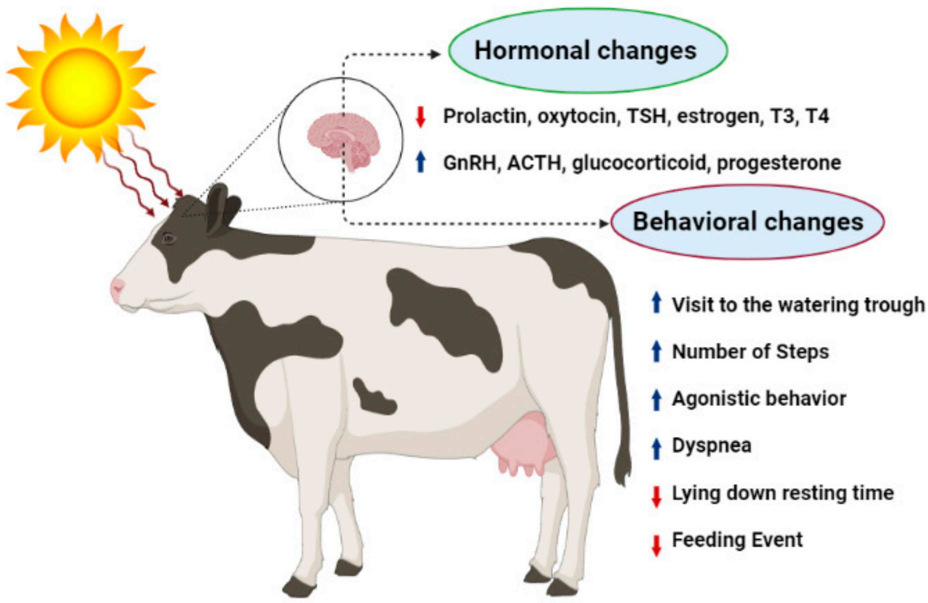


Figure 3. Main findings of the studies included in this review (n = 7) on the effects of heat stress on the behavior of lactating cows raised in compost barns.

Of the seven studies included in this review, four reported a decrease in feeding events. However, among the studies evaluated, no study reported whether there was a reduction in dry matter intake (DMI) or production losses in the animals. However, increases in air temperature negatively impact the appetite center of the hypothalamus, reducing the DMI of dairy cows [67]. The reduction in the DMI of lactating cows begins at air temperatures between 25 and 26 °C [68]. The feed intake of cows results in the production of metabolic heat generated during rumination and feed digestion. These metabolic processes increase the body temperature of lactating cows [69].

A reduction in the DMI by heat-stressed cows was observed after two days of heat stress exposure [63]. Heat stress reduced the DMI by 28–34% [70] and reached up to 40% when the air temperature exceeded 40 °C [68]. In this context, it would be interesting to analyze the cumulative heat load in animal responses over several consecutive days. Heinicke et al. [71] determined a heat-load threshold (THI 67) that led to changes in different activity traits in high-yielding cows during lactation. Furthermore, this study demonstrated that heat-load duration and accumulation should be considered when assessing the heat load in lactating cows. As lactating cows show a time delay in their response to heat stress [15], and according to [72], the time average was explained over three days. Thus, the daily heat-load duration can assist in assessing the time a lactating cow needs to recover from heat stress [71].

The behavior of high-production cows (milk production of more than 30 kg/day) was altered when the THI was greater than 68 [60]. In a recent study, the author of [14] observed that mild heat stress (THI = 73) altered the feeding behavior of lactating cows housed in tie-stall barn systems. Among the behavioral changes, decreased rumination and decreased bolus were observed. Decreased rumination affects rumen health, saliva production and the DMI of lactating cows [73,74]. The reduction in the DMI of lactating cows limits the amount of nutrients to the mammary glands (MGs). Reducing nutrients to the MGs due to heat stress can reduce milk production from 25 [75] to 40% [76]. In a study conducted over 10 years (from 2008 to 2018) in the US, it was observed that cows under heat stress conditions had reduced milk production by 21% during lactation [77].

Heat stress influences the time that cows spend resting. In confined systems, dairy cows spent an average of 10 to 12 h lying down per day [28]. In this same period, three to four hours corresponds to the time cows sleep in average periods of three to five minutes [78]. Endres and Barberg [48] first observed the behavior of dairy cows housed in compost barns. The authors observed an average total rest time of 12.7 h/day when the THI was less than 72. When the THI was above 72, the cows lay down for 7.9 h/day. In another study, the average daily rest time for cows housed in a free-stall system ranged from 6.6 to 14 h/day. However, as the THI increased (THI above 70), the time spent lying decreased (range: 9–10.5 h/day) [79]. Consequently, the reduction in resting time may result in productivity [80,81] and welfare problems [15].

Cows subjected to heat stress change their posture; i.e., they reduce their time spent lying down and consequently spend more time standing up. When the THI was above 70, the cows spend less time lying down and increased their time standing [81]. Thus, cows will seek cooler places in the feedlot, such as the feeding corridor, which usually has a cooling system [53]. This change in posture in lactating cow reduces heat absorption through long wave radiation arising from the bedding, facilitating the circulation of cooler air and aiding heat dissipation through convection. However, increased standing time interferes with the longevity of lactating cows. Cows exposed to heat stress showed an 18.6% increase in hoof problems [82]; the increase in hoof diseases may be related to lameness [83] and hock lesions [84].

As the thermal environment becomes more challenging, the number of steps for lactating cows increases [50]. This behavior in confined systems may be linked to ventilated areas [49] and water demand [50]. In warm regions, water consumption by lactating cows can increase by 10 to 20% during summer [85]. The greater water intake by cattle under heat stress affects the water requirements for evaporative thermolysis and bodily maintenance of dairy cows [86]. McDonald et al. [87], when assessing lactating cows housed in free-stall barns, observed that as THI increased (56.3–81.3), cows ingested more water (112.7 kg/d), spent more time at the trough (54.0 min/day), made more visits to the trough (31 visits/day) and participated in more competitive events at the trough (172 competitions/day). Furthermore, the authors also observed that more productive cows presented more competition for the troughs. This behavior can be explained because high-producing cows ingest more water due to milk production. Thus, lactating cows that have access to the drinker 24 h/day can increase milk production by up to 10% [88], as well as the dominance of multiparous and agonistic behaviors (pushing, butting, and chasing) [52].

Although water is an essential thermoregulatory resource for cows, the more frequent the search for ventilated areas, the greater the animal's thermal discomfort; the ventilation system in the confinement system can promote the dissipation of the animal's heat to the environment when the air is colder than the cow's body temperature. Thus, mechanical ventilation in a confined system can effectively reduce dairy cows' body temperature [89]. However, this process takes three to four days to properly balance the bodily heat loss in cows [15]. It is worth noting that housing is not always sufficient to cool cows in hot climatic conditions [32]. In a European study, Lovarelli et al. [90] investigated the relationship between housing structures and the internal microclimate in eight dairy cow confinements. They observed that the housing characteristics affected the internal microclimate, mainly during summer. Another study evaluated the thermal variability in compost barns in southern Brazil. The authors identified that multiparous cows were allocated to the most ventilated housing regions during the afternoon [49]. Thermal heterogeneity in compost barns was also verified by Damasceno et al. [91]. The authors identified an harmful event in almost all housing regions (temperatures above 26 °C and a relative humidity in specific areas higher than 65%). Oliveira et al. [92] recently identified spatial variability during winter in compost barns. Therefore, this evidence highlights the importance of an appropriate ventilation system throughout the year to reduce the spatial variability of housing [90].

3.5. Study Limitations and Future Directions

The effect of heat stress on the behavior of lactating cows raised in compost barns has been explored in a few studies; thus, as most of the research was conducted in Brazil and the United States, some care is needed in extrapolating our findings. Due to the different methodologies used in the studies to evaluate cow behavior, we could not perform a meta-analysis and, therefore, we did not assess the quality of the studies, which could influence our results. We excluded conference proceedings (articles and abstracts) and book chapters as we could not be sure that these sources had been peer-reviewed. We also excluded literature in languages other than English, as we could not critically evaluate the methods and assess the results. Thus, we cannot determine the extent to which these exclusions affected the conclusions of this review.

Further studies (review and experiments) on the applied ethology for lactating cows housed in compost barns should consider the percentage reduction in the dry matter intake, production losses, the percentage of time cows remain at rest, standing, consuming water, moving, as well as agonistic behaviors. However, lying down behavior should be cautiously assessed due to its relationship with thermoregulatory responses, but there is little literature on this for lactating cows [28]. Furthermore, little data was found in the literature regarding the activities and behaviors of dairy cows under heat stress conditions in a confinement system [93]. Most studies on housing for lactating dairy cows were of the free-stall, tie-stall, and loose-housing models [94]. Few studies have been conducted on compost barns (such as evaluating different breeds, ventilation systems and geographical areas) mainly because it is a relatively new confinement system. This may have hampered data extraction in our study and may serve as the basis for future research.

More precise methods to detect heat stress in feedlot systems are needed. THI does not accurately represent the thermal environment in which dairy cows are embedded, nor does using air temperature alone [95]. Thus, assessing heat stress from physiological assessments may be more adequate and accurate.

4. Conclusions

Heat stress influences the behavior of lactating cows housed in compost barn systems. Our review highlighted that cows in heat stress conditions increased the number of visits to the water trough, number of steps, agonistic behaviors, and dyspnea. In contrast, the cows decrease the feed intake and time spent lying down.

Systematic reviews are an important technique to summarize, evaluate, and interpret evidence on the relationship between the thermal environment and animal behavior. Although the results of this review did not present complete evidence of studies in the area of ethology in lactating cows housed in compost barns, our findings identify the state of the art to support further research. Therefore, we strongly suggest that new studies be carried out to evaluate the behavior of dairy cows raised in compost barns in different thermal environment conditions.

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