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Systematic Review

Health and Thermal Comfort of Dairy Cattle in Compost-Bedded Pack Barns and Other Types of Housing: A Comparative Systematic Review

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Abstract: This systematic review was conducted to describe and discuss the main research findings available in the literature concerning the health and thermal comfort of dairy cattle housed in Compost-Bedded Pack Barn (CBP) systems, in comparison to Free Stall (FS), Tie-Stall (TS), and/or Loose Housing (LH) systems. Searches for peer-reviewed experimental articles in English were performed in the Scopus and Web of Science databases. Forty-three non-duplicated scientific articles were obtained and subjected to a four-stage evaluation process, according to the PRISMA methodology and predefined eligibility criteria. This process resulted in the selection of 13 articles for inclusion. Regarding animal health, the results provide evidence that the incidence of problems such as lameness, limb injuries, and reproductive disorders is lower in CBP systems. However, if bedding management is not effective in ensuring the provision of dry and comfortable surfaces, an increase in somatic cell count (SCC) and prevalence of mastitis incidence (P_{MI}) may occur. For thermal comfort, it was found that the CBP system exhibited higher temperatures during summer and lower temperatures during winter when compared to FS with cross-ventilation in association with evaporative cooling. However, no differences were observed in terms of thermal comfort in spring and autumn. As this is a recent research area, caution should be exercised when extrapolating the results, considering the specificities of each cited study.

Keywords: dairy cows; confinement systems; animal welfare; animal health

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1. Introduction

To ensure food security and the high quality of animal products, modern livestock farming has assumed a more intensive nature characterized by smaller farms, increased use of inputs, and production in collective facilities, typically equipped with artificial thermal conditioning systems and some level of automation [1,2]. Different housing systems can be employed in intensive animal production, provided that the health, proper feeding management, and thermal comfort of the animals are ensured—conditions that are necessary to achieve good productive and reproductive performance [3,4].

Especially for dairy cattle, there is a lot of variation in housing and management conditions (from the thermal environment, sanity, and nutrition) among different locations. Therefore, the animal health and thermal comfort indices achieved can be very different [5–7]. The main housing systems used in intensive dairy production are Tie-Stall (TS), Free Stall with individual stalls (FS), Loose Housing (LH), and Compost-Bedded Pack Barn (CBP). Each system has advantages and limitations related to its use and the management solutions adopted [8–10]. Drawing on the advantages and limitations of each housing system, this review aims to provide insights for stakeholders in the dairy industry. By addressing the multifaceted aspects of intensive livestock farming, including housing systems and adopted thermal conditioning solutions, this paper contributes to the ongoing discourse on balancing productivity with animal welfare in modern agriculture.

The TS system is characterized by the animals' permanence in individual stalls with dividers (side by side), where they are restrained by the neck by means of chains attached to a rail fixed in the upper region of the stall [11,12]. In this system, traditionally used worldwide for small herds and for research purposes, the feed is provided individually and the animals are typically loosed only during milking times [8,13].

The FS is another housing model that emerged in the United States of America in the 1950s and quickly became common in intensive dairy production, mainly due to the lower requirement for bedding to keep the animals clean. In the FS system, the animals remain loose in collective facilities comprising individual areas for rest (individual stalls side by side, with bedding composed of materials such as sand or shredded rubber on a rubber mattress), feeding, and exercise [8,11].

Another system that emerged in the mid-1950s is the LH system, characterized by the presence of a large covered area, in which animals have access to two distinct areas: a soft collective bedding area for resting (normally between 5.0 and 10.0 m^2 $animal^{-1}$) and an area with feeders and drinkers, offering forages and concentrates. While LH systems allow for housing breeds of different sizes and the storage of solid manure, their effectiveness requires intensive management and larger amounts of bedding compared to Tie-Stall (TS) and Free Stall (FS) systems [8,12,14].

Relatively new compared to TS, FS, and LH, the CBP system is a housing system in free-walk facilities with bedding composed of lignocellulosic material, where animals have free access to the bedding and feeding areas [15–17]. The CBP system operates on the concept of composting the bedding material together with the manure deposited by the animals in the collective resting area. This concept differentiates it from other confinement systems for dairy cattle in bedding facilities [18,19]. In the literature, improvements in animal welfare, productivity, health, and longevity, as well as reduced production costs and better disposal of manure produced, are reported as advantages of its use [8,16,20,21].

Regardless of the type of housing used, the production of dairy cattle confined in facilities aims to ensure improvements in their welfare. However, it is essential to evaluate how different housing systems and thermal-environmental management practices used can impact the health and thermal comfort conditions of dairy cattle, as some health and thermal comfort problems of these animals may be associated with the way they are housed and managed [22,23]. Therefore, establishing potential synergies between factors related to the type of housing and management with animal health and thermal comfort is crucial [13]. In this context, this systematic review was designed to describe and discuss the main results available in the literature on the health and thermal comfort of dairy cattle housed in CBP systems in comparison with FS, LH, and/or TS systems. Therefore, it seeks to provide support and contribute to evidence-based decision-making regarding the adoption or not of CBP systems, as there is a recurring question about the improvements that can be achieved in animal health and thermal comfort from the adoption of this system, also considering the different forms of thermal conditioning that can be employed.

2. Materials and Methods

2.1. Search Strategy

To identify the main comparative studies between CBP, FS, LH, and/or TS systems in terms of animal health and thermal comfort, this systematic review was conducted using a Population, Intervention, Comparison, and Outcome (PICO) search strategy [24], following the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [25]. PICO is a methodology used in practice in systematic reviews, being evidence-based [26]. Based on this methodology, the following question was defined: "Does housing in CBP systems promote positive impacts on the health and thermal comfort of dairy cattle, compared to the FS, LH, and/or TS systems?" To answer this question, search, selection, eligibility, and inclusion procedures were carried out, and information of interest from eligible studies was extracted and analyzed [27].

Searches for studies relevant to the topic of interest were conducted in the Scopus (ScP) and Web of Science (WoS) databases, widely recognized as the largest and most reliable repositories of scientific literature data worldwide [28]. The choice of these databases was made because Scopus is a comprehensive platform that accommodates studies published in different databases, and Web of Science only includes studies published in journals indexed by Clarivate Analytics, which are peer-reviewed [29].

Since this study addressed a specific topic, different search terms were used (Table 1), aiming to return a representative set of publications on the topic of interest. Using the different expressions listed in Table 1, searches were conducted in the main repositories of studies from Sc and WoS, with the integration of Boolean operators (AND and OR) to combine words or phrases, as well as wildcard truncation (" ") to denote different expressions. Additionally, the asterisk (*) was employed to include alternative spellings of the words and/or expressions of interest, such as variations between US English and British English.

Table 1. Population, intervention, comparison, and outcome (PICO) of the search term sequence used in this systematic review study.

Acronym	Search Sequence
Population	(cattle OR cow* OR calves OR heifers) AND (dairy OR lactating OR milking)
Intervention	("compost barn*" OR "compost bedded*" OR "compost-bedded pack*" OR "compost-bedded barn*" OR "compost-bedded pack barn*" OR "compost-bedding*" OR "open pack barn*" OR "free-stall*" OR "free stall*" OR freestall* OR "tie-stall*" OR "tie stall*" OR tiestall* OR "loose housing*" OR "loose-housing*")
Comparison	("compost barn*" OR "compost bedded*" OR "compost-bedded pack*" OR "compost-bedded barn*" OR "compost-bedded pack barn*" OR "compost-bedding*" OR "open pack barn*") AND (("free-stall*" OR "free stall*" OR freestall*) OR ("tie-stall*" OR "tie stall*" OR tiestall*) OR ("loose housing*" OR "loose-housing*"))
Outcome	(health OR disease* OR pathology* OR incidence* OR prevalence* OR sanity OR score* OR dirtiness) OR (comfort OR environment OR "heat stress" OR microclimate OR "thermal comfort" OR "thermal environment" OR "thermal stress" OR welfare)

2.2. Inclusion and Exclusion Criteria for Studies

Since this systematic review aimed to select only studies evaluating and/or characterizing the health and thermal comfort of dairy cattle housed in CBP systems, in comparison to FS, LH, and/or TS, only experimental articles written in English, peer-reviewed, and published in any year up to December 2023 were considered. In collaboration with co-authors, a priori inclusion and exclusion criteria were established.

Searches in the ScP and WoS databases returned 30 and 33 studies, respectively. All results (n = 63) were included in a Mendeley® account, using a Google Chrome plugin, from which duplicates were identified and removed. The remaining studies (n = 43) underwent a 4-stage assessment process, in accordance with the PRISMA methodology—Figure 1 [25]:

- First stage: Meta-data assessment, excluding studies that were not published in English, review articles, dissertations, theses, conference proceedings, and book chapters;
- Second stage: Assessment of study titles and abstracts, identifying and excluding studies that did not evaluate CBP systems compared to other intensive housing systems for dairy cattle (FS, LH, and/or TS), or that did not evaluate and/or characterize indicators of animal health and/or thermal comfort in the aforementioned systems;
- Third stage: Qualitative assessment of the filtered studies, using the domains 1 (study eligibility criteria), 2 (study identification and selection), and 3 (data collection and assessment) of the Risk of Bias in Systematic Reviews (ROBIS) tool, in accordance with Whiting et al. [30];

- Fourth stage: Finally, the remaining studies were read in detail, with the aim of assessing whether all of them referred to experimental studies that assessed/characterized the health and/or thermal comfort of dairy cattle housed in CBP systems, compared to FS, TS, and/or LH systems.

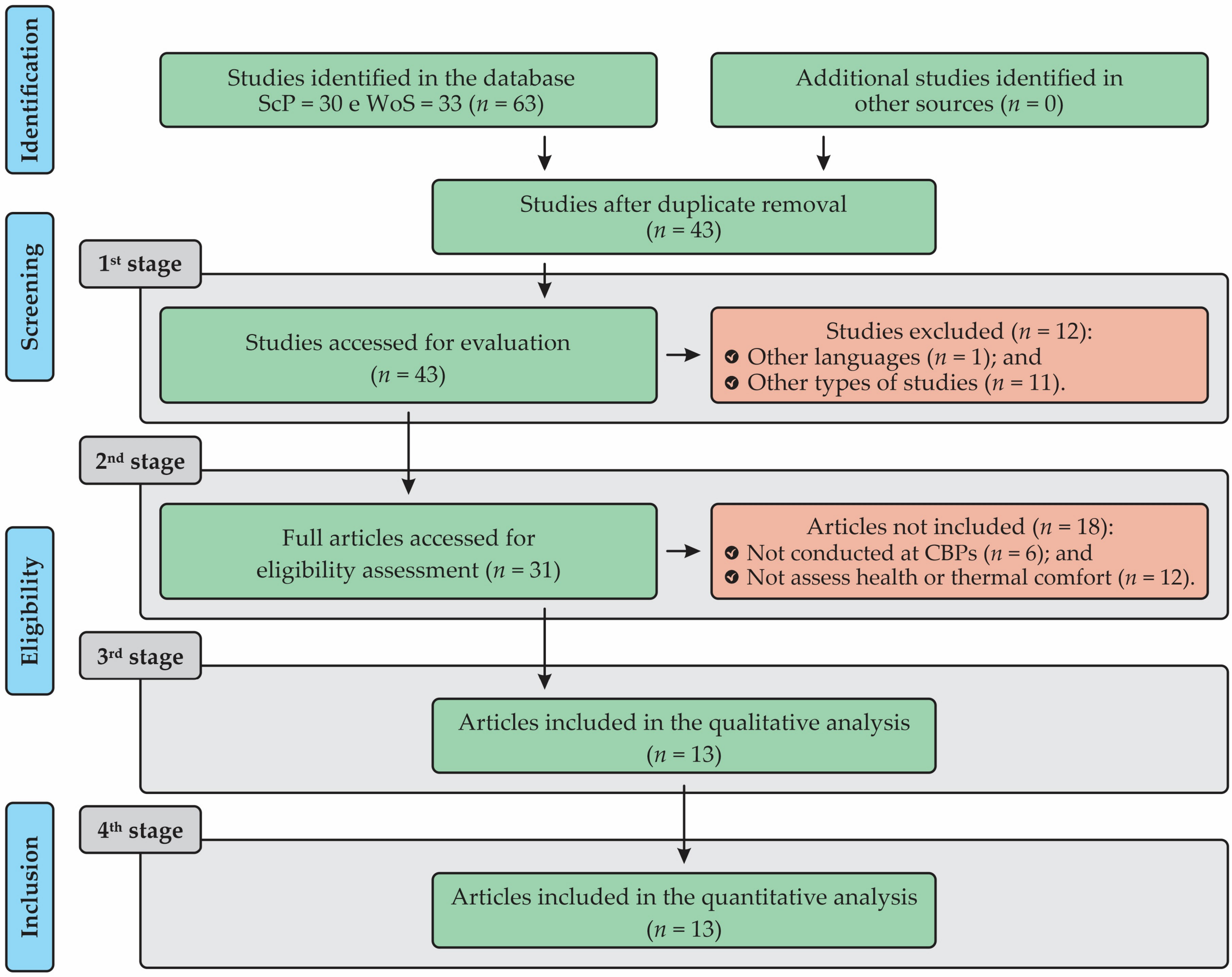

Figure 1. Flowchart of selection, indicating the total number of studies identified and filtered at each stage of the systematic review process. Source: Adapted from Moher et al. [25].

To provide a comprehensive overview of the literature on the topic, no additional restrictions, such as sample size, facility and/or farm size, or journal quality, were imposed. However, it was not possible to determine the extent to which the systematic exclusions affected the results obtained in the study.

2.3. Data Extraction

Two investigators (C.E.A.O. and F.C.S.) independently selected the full texts of the included articles. To organize the information of interest about the studies, Microsoft Excel®, version 2404, was used to create a spreadsheet containing the following information: authorship, publication year, journal, country and/or region where the study was conducted, local climate classification, evaluated systems, characteristics of evaluation systems, number and types of facilities for each system, breed and number of animals housed in each facility, indicators of animal health and/or thermal comfort used, and main results achieved. Interobserver reliability for data extraction was tested for all categories (except authorship and publication year), with 100% agreement obtained.

For the purpose of bibliometric analysis, the R Bibliometrix package, version 0.3.0, was used [31,32]. With this package, the intellectual structure of scientific domains was determined through multiple correspondence analyses of article titles, abstracts, and keywords [26]. To assess the appropriateness of the search terms and expressions used, a word cloud was created containing the 25 most cited words in the abstracts (frequency > 10%). Additionally, the R Bibliometrix package was used to obtain the co-occurrence network and link between the most used words in the abstracts of the 14 articles [33]. In the co-occurrence network, the size of the circle and the label of the words was a function of the number of times the term was used in the abstracts of the articles (which defines its weight), and the links between circles indicated the relationship between areas of knowledge, with closer circles having a stronger relationship [26].

3. Results and Discussion

3.1. Overview of Included Studies

This study was designed to describe and discuss the main results available in the literature on the health and thermal comfort of dairy cattle housed in CBS systems, compared to FS, LH, and/or TS systems. Through a search of the ScP and WoS databases, 43 non-duplicated studies were found on the topic of interest (Figure 1). In 1st stage of the screening process, 12 studies were excluded from the study because they did not meet the eligibility criteria: 1 study was written in a language other than English (Portuguese); 8 studies were literature reviews; 2 studies were published in conference proceedings; and 1 study was published as a book chapter. Among the remaining 31 studies (n = 31), 18 did not meet the eligibility criteria defined in 2nd stage and were excluded: 6 were not conducted in CBP systems or, when they were, did not compare with other housing systems (FS, TS, or LH); and 12 did not evaluate indicators of health and/or thermal comfort of the housed animals. Finally, 13 articles met the eligibility criteria and, therefore, were selected to compose the results of the systematic review.

Table 2 provides detailed information on the selected studies, including the authors, region, and country where they were conducted, types of facilities used, and the main objective of the study. The selected articles were published between 2011 and 2023 and conducted in different countries: Austria (n = 1); Brazil (n = 3); Spain (n = 2); United States of America (n = 3); Italy (n = 2); and Poland (n = 1). One study was conducted in six different European countries (Austria, Germany, Italy, Netherlands, Slovenia, and Sweden). The studies did not use the same methodology; therefore, a meta-analysis was not performed.

An analysis of the word cloud generated from the article abstracts (Figure 2) revealed that six words appeared with a frequency greater than 50% in the article abstracts: systems (97%); compost barn (92%); cattle (88%); dairy (88%); barns (69%); and free stall (63%). The frequency of the remaining words included ranged from 10 to 49%, with emphasis on some words related to animal health and thermal comfort: lameness (49%); prevalence (39%); health (26%); score (24%); and thermal-comfort (17%). From the co-occurrence network (Figure 3), it was observed that the words that appeared with the highest frequency in the word cloud also had larger circles and more connections, indicating that they were explored in more articles.

Table 2. Characterization of the 13 experimental studies that evaluated animal health and thermal comfort in Compost-Bedded Pack Barn (CBP), compared to Free Stall with individual stalls (FS), Loose Housing (LH) and/or Tie Stall (TS) systems.

			Study Details		
Reference	**Local**	**Facilities Type**	**Animals/EU**	**Breed**	**Objective**
Lobeck et al. [20]	Minnesota and South Dakota (USA)	6 CBP [1] 6 FS-NV [1] 6 FS-CV [2]	78.8 ± 32.4 126.7 ± 79.6 139.6 ± 63.4	Holstein and Jersey–Holstein crossbreds	To describe animal welfare in CBP and FS-CV facilities, compared to FS-NV facilities, using outcome-based measures (locomotion, body condition, hygiene, foot lesions, respiratory rates, slaughter, mortality, and prevalence of mastitis infection)
Lobeck et al. [34] [3]	Minnesota and South Dakota (USA)	6 CBP [1] 6 FS-NV [1] 6 FS-CV [2]	78.8 ± 32.4 126.7 ± 79.6 139.6 ± 63.4	Holstein and Jersey–Holstein crossbreds	To describe different housing systems for dairy cattle (CBP, FS-CV, and FS-NV), and to evaluate air temperature, relative humidity, air velocity, and air quality (ammonia and hydrogen sulfide), as well as light intensity
Astiz et al. [35]	SP [4]	1 CBP [1] 1 LH [1]	180 [5] 110 [5]	Holstein	To analyze the potential effects of using CBP systems, compared to LH systems, during the dry period on the health (udder and uterus), reproductive performance, and productive performance during the following lactation of cows with more than 2 calfs
Eckelkamp et al. [36]	Kentucky (USA)	8 CBP [1] 7 FS [1]	178 ± 108 84 ± 37	NS	To evaluate the differences between CBP and FS systems for mastitis indicators (clinical mastitis, SCC, high SCC, and SCC in bulk tanks), locomotion, hygiene, and foot scores
Burgstaller et al. [37]	AT [6]	5 CBP [1] 5 FS [1]	20–41 20–39	Fleckvieh and Holstein	To evaluate the prevalence of lameness and the prevalence and type of foot lesions in cows kept in CBP systems, and to compare these results with data from cows kept in other conventional housing systems (FS)
Costa et al. [38] [7]	Paraná (BR)	12 CBP [1] 23 FS [1]	56–173 207–376	Holstein	To compare the prevalence of lameness and lesions in the hocks and knees of confined dairy cattle in CBP, FS, or a combination of these two systems, in southern Brazil
Leso et al. [39]	Mantua and Cremona (IT)	10 CBP [1] 10 FS-M [1,8] 10 FS-S [1,9]	112.0 ± 56.6 147.0 ± 102.3 143.0 ± 83.9	Holstein	To evaluate and compare the performance of dairy cows housed in CBP and FS systems, with a primary focus on herd longevity
Bran et al. [40]	Paraná (BR)	12 CBP [1] 38 FS [1]	104.3 ± 62.9 327.7 ± 201.0	Holstein and others	To study the factors at the cow, barn, and herd levels associated with lameness in lactating dairy cows housed in CBP and FS systems in southern Brazil
Biasato et al. [41]	Cuneo (IT)	1 CBP [1] 1 FS [1]	11 11	Fleckvieh	To develop and describe a CBP system for dairy cattle housing, evaluate and compare the health and welfare of cows housed in CBP versus those kept in a conventional system (FS), and characterize the quality of milk and three local traditional products from northwestern Italy
Fernández et al. [42]	Catalonia (SP)	2 CBP [1] 2 FS [1] 2 LH [1]	73–105 [10] 95–96 [10] 88–9 [10]	Holstein	To examine the comfort and behavior of lactating dairy cows housed in three different types of housing systems on the same farm: CBP, FS, and LH
Kogima et al. [43] [11]	Santa Catarina (BR)	17 CBP [1] 17 FS [1]	52.2 ± 23.5 82.0 ± 57.0	NS	To evaluate the impact of different dairy cattle production systems (CBP, FS, and grazing) on animal welfare using the Welfare Quality® protocol

Table 2. *Cont.*

			Study Details		
Reference	**Local**	**Facilities Type**	**Animals/EU**	**Breed**	**Objective**
Witkowska and Ponieważ [9]	PL [6]	1 CBP [1] 1 FS-SR [1,12] 1 FS-SC [1,13] 1 TS [1]	120 (in each system)	Polish Holstein-Friesian	To evaluate the impact of different housing systems (CBP, FS-SR, FS-SC, and TS) on the prevalence of diseases and productive life of dairy cows
Emanuelson et al. [44]	AT, DE, IT, NL, SI and SE	16 CBP [1,14] 16 FS [1,14]	14–175 [15] 28–156 [15]	Holstein and others	To evaluate the health of dairy cattle housed in CBP and FS systems based on health indicators (CCS, high CCS, elevated CCS, ketosis risk, prolonged calving intervals, dystocia, and stillbirths) and other characteristics (lifespan, productive life, parity at herd exit, first-calving risk, calf mortality)

[1] Facility provided with natural and/or mechanical ventilation with positive pressure; [2] Facility provided with mechanical ventilation with negative pressure; [3] Study conducted simultaneously with the study conducted by Lobeck et al. [20]; [4] Study conducted in the region of eastern Spain; [5] Maximum number of animals housed during the experimental period (density of 10.3 and 10.5 $m^2 \cdot cow^{-1}$ in CBP and LH systems, respectively); [6] More details about the region in which it was conducted were not specified; [7] The results from farms using a combination of CBP and FS systems were not used in this review because they were not separated by system; [8] FS systems that used rubber mattresses; [9] FS systems that used straw bedding; [10] The number of animals housed can vary between facilities; [11] Grazing systems were also evaluated, but they were not included in this systematic review because of the proposed objective; [12] Free Stall barn with a slatted floor scraped by robots; [13] Free Stall barn with a self-cleaning floor; [14] Number of systems varies by country; [15] The number of animals varies by facility and country; AT—Austria; BR—Brazil; CBP—Compost-Bedded Pack Barn; DE—Germany; SP—Spain; EU—experimental unit; FS—Free Stall; FS-CV—Free Stall systems with negative pressure mechanical ventilation; FS-NV—Free Stall systems with natural and/or positive pressure mechanical ventilation; FS-SC—Free Stall systems with a self-cleaning floor; FS-SR—Free Stall systems barn with a slatted floor scraped by robots; IT—Italy; LH—Loose Housing; NS—not specified; NL—Netherlands; PL—Poland; SCC—somatic cell count; SE—Sweden; SI—Slovenia; TS—Tie Stall; USA—United States of America.

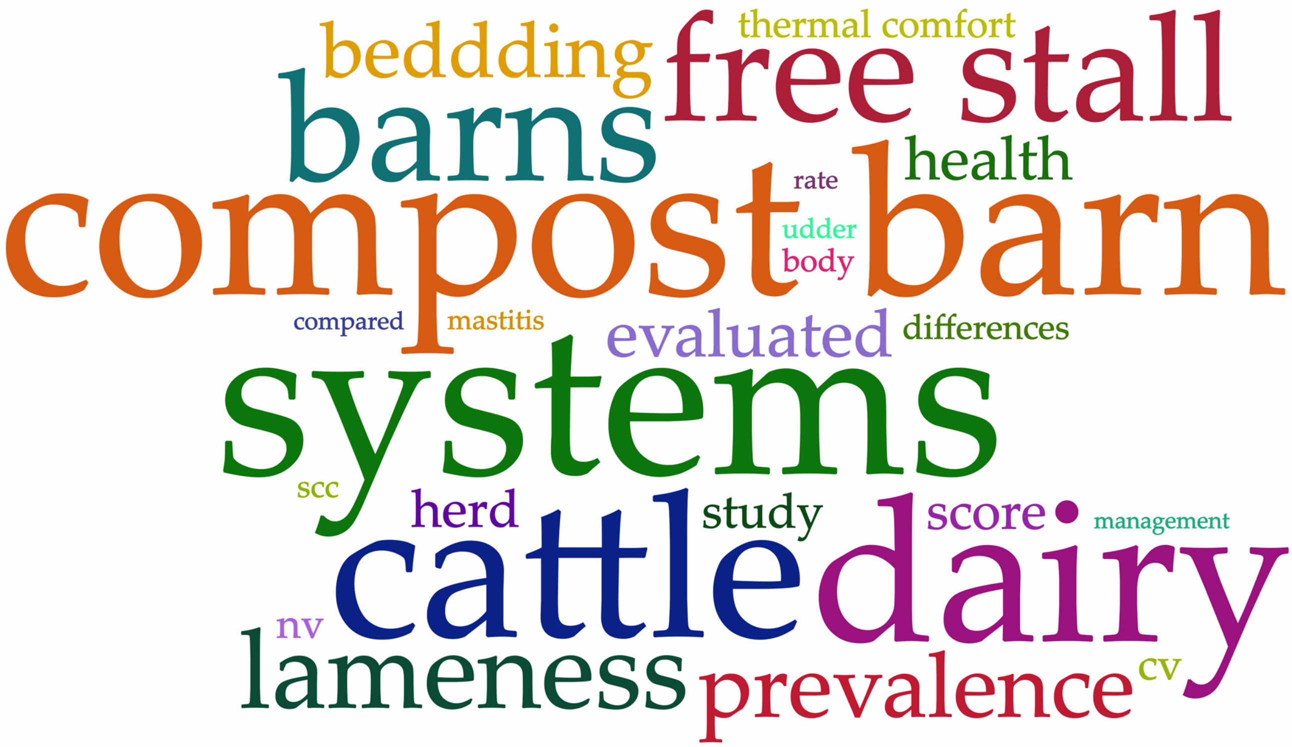

Figure 2. Word cloud generated from the 25 most used words in the abstracts of the experimental articles included in the systematic review. Bigger words were used more frequently. CV—systems with negative pressure mechanical ventilation; NV—systems with natural and/or positive pressure mechanical ventilation; SCC—somatic cell count.

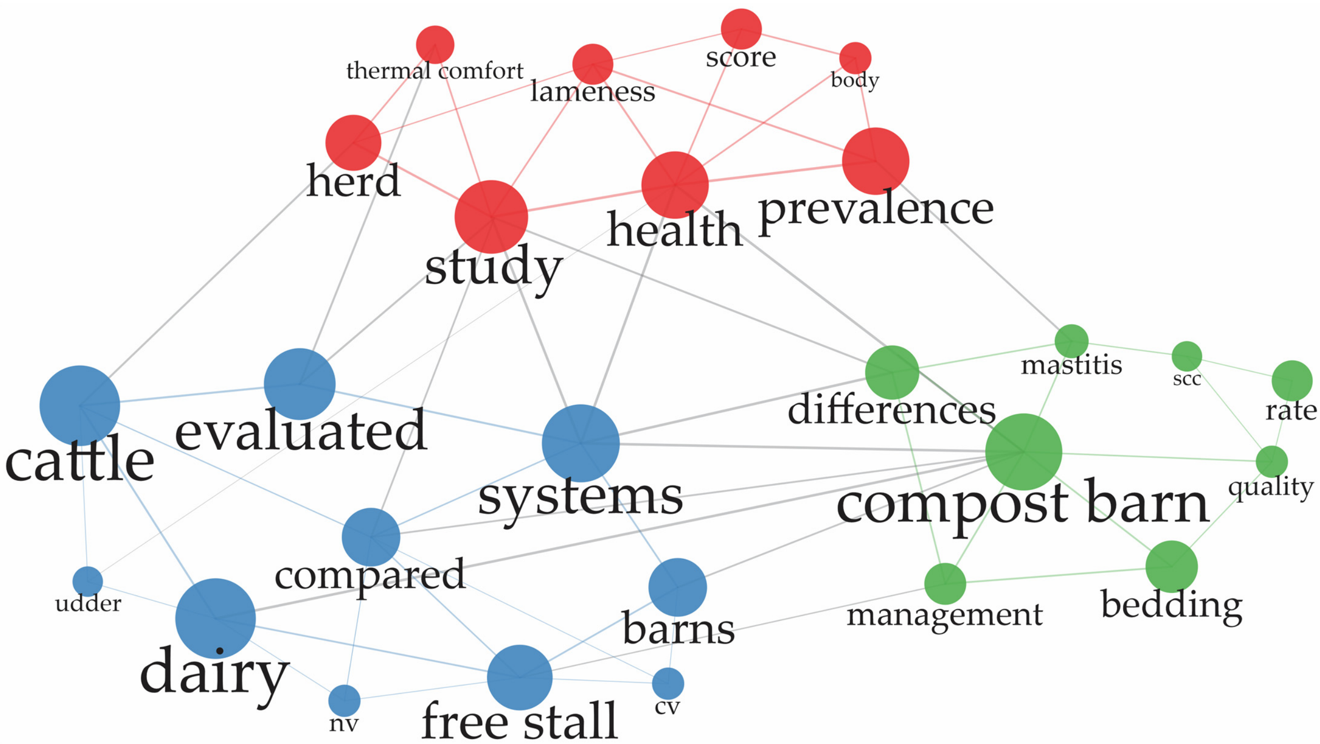

Figure 3. Word network of co-occurrences in the abstracts of the articles included in this systematic review study. The size of the labels and circles is determined by the frequency of the word, and the lines illustrate the relationship between the areas of knowledge; words that are closer have a stronger relationship.

Out of the studies selected for this systematic review, nine compared CBP systems with one of the other systems (eight studies compared with FS; and one study compared with LH), and four studies compared CBP systems with more than one of the systems (one study compared with FS and with the combination of CBP+FS systems; one study compared with FS and LH systems; one study compared with TS and FS systems; and one study compared with FS and semi-intensive grazing). Since the primary objective of this study was to analyze indicators of animal health and thermal comfort in CBPs, compared to other cattle housing models, the results obtained from the comparison with grazing systems were not considered. For the two studies in which this was performed [38,43], only the results depicting the comparisons between CBP and FS systems, individually, were considered.

Regarding the evaluations performed, 12 studies (92.3%) examined animal health indicators, while 3 studies (23.1%) evaluated thermal housing indicators. The results obtained in these studies, including the effect of housing in CBPs compared to other systems, are listed in Table 3.

3.2. Animal Health

Various animal health indicators were used to assess CBP systems compared to FS, LH, and/or TS systems, with lameness being the most reported indicator, including prevalences of clinical lameness ($PL_{Clin.}$, n = 8) and severe lameness ($PL_{Sev.}$, n = 7). Lameness is a multifactorial problem frequently used as an animal health indicator in dairy production systems. It is still a major concern for animal welfare in the global dairy industry [40,45–47].

Of the eight studies evaluating $PL_{Clin.}$ in CBP systems, compared to FS, LH, and/or TS systems, five indicated that $PL_{Clin.}$ was statistically lower in cattle housed in CBP systems [9,20,38,40,43] (Table 3). In other studies, CBP and FS had statistically similar results, but $PL_{Clin.}$ was higher in CBP when compared to LH [36,37,42]—Table 3. Similar results were obtained for $PL_{Sev.}$, with animals housed in CBP systems showing statistically lower (n = 3) or equal (n = 4) indices than those obtained in FS, LH, or TS systems (Table 3). In studies where no statistical difference in $PL_{Clin.}$ and $PL_{Sev.}$ was observed between systems, the discrepancy may be, in part, due to the multiple factors associated with this problem and/or differences between housing systems and management practices [40].

The occurrence of lameness in dairy cows is not a single condition, as it can be indicative of a wide range of different diseases. The main causes of lameness are disruption lesions, such as sole ulcers, white line disease, and infections affecting the animal's hooves, such as interdigital dermatitis, interdigital necrobacillosis, etc. [47]. Therefore, the lower incidences of lameness in CBP systems may be attributed to a reduction in the prevalence of these types of lesions and diseases, as depicted in some studies for hoof lesions ($P_{Hoof\text{-}L}$), heel horn erosion (P_{HHE}), white line disease (P_{WLD}), interdigital hyperplasia (P_{IH}), and chronic laminitis (P_{CL}) [9,37,41]—Table 3.

In CBPs, cows spend less time standing on concrete and have no restrictions on movement, as is the case in FS and TS systems [20]. Moreover, CBPs provide a surface for lying down composed of organic bedding, which is softer than sand and other materials typically used in FS. This characteristic can help reduce friction with the animals' feet [20,36]. As a consequence, it is possible to reduce the prevalence of lameness and lesions in the hocks and knees [20,38,41] (Table 3). Therefore, the lower prevalence of hoof, hock, and knee problems in dairy cattle housed in CBP systems, compared to FS and TS systems, is a function of the organic material present in the bedding, as these lesions are closely associated with the relative hardness and abrasiveness of the floor material [48]. These results suggest that, when managed properly to avoid excessive moisture in the bedding, the use of CBP systems can be advantageous in reducing the occurrence of lameness, a condition that could compromise not only the animals' health but also their productive and reproductive performance [6,8,49].

Table 3. Characterization of animal health and thermal comfort in Compost-Bedded Pack Barn (CBP) systems, compared to Free Stall (FS), Loose Housing (LH), and/or Tie Stall (TS) systems, according to the results obtained in the studies included in this systematic review.

Reference	Indicator	Result Achieved [1]				Effect [2]		
		CBP	FS	LH	TS	CBP × FS	CBP × LH	CBP × TS
Lobeck et al. [20]	Respiration rate (RR, in breaths min^{-1}) [3]	58.4	59.3 (NV) and 57.5 (CV)			=		
	Prevalence of clinical lameness ($PL_{Clin.}$, in %) [4,5]	4.4	15.9 (NV) and 13.1 (CV)			+		
	Prevalence of severe lameness ($PL_{Sev.}$, in %) [4,6]	0.8	1.4 (NV) and 1.0 (CV)			=		
	Prevalence of hock lesion (P_{HL}, in %) [7,8]	3.8	23.9 (NV) and 31.2 (CV)			+		
	Prevalence of severe hock lesion ($P_{HL\text{-}Sev.}$, in %) [7,9]	1.0	6.3 (NV) and 6.5 (CV)			+		
	Prevalence of mastitis infection (P_{MI}, in %) [10]	33.4	26.8 (NV) and 26.8 (CV)			=		
	Prevalence of mortality (P_{Mo}, in %)	5.1	5.0 (NV) and 5.8 (CV)			=		
	Hygiene score (HS, in scores from 0 to 5) [11]	3.2	2.8 (NV) and 2.8 (CV)			–		
	Body condition score (BCS, in scores from 1 to 5) [12]	2.9	3.0 (NV) and 3.0 (CV)			=		
Lobeck et al. [34]	Dry-bulb air temperature in winter ($t_{db\text{-}Winter}$, in °C)	–3.7	–1.4 (NV) and 3.9 (CV)			=/–		
	Dry-bulb air temperature in spring ($t_{db\text{-}Spring}$, in °C)	11.8	12.2 (NV) and 12.2 (CV)			=		
	Dry-bulb air temperature in summer ($t_{db\text{-}Summer}$, in °C)	20.7	20.8 (NV) and 19.6 (CV)			=		
	Dry-bulb air temperature in fall ($t_{db\text{-}Fall}$, in °C)	5.0	6.4 (NV) and 8.2 (CV)			=/–		
	Temperature and humidity index in summer (THI_{Summer}) [13]	68.0	68.4 (NV) and 65.9 (CV)			=/–		
Astiz et al. [35]	Prevalence of mastitis infection (P_{MI}, in %) [10,14]	22.1		35.0			+	
	Prevalence of purulent vaginal discharge (P_{PVD}, in %)	7.2		10.0			+	
	Prevalence of cytological endometritis (P_{CE}, in %)	27.2		26.9			+	
	Prevalence of mortality (P_{Mo}, in %)	3.9		5.0			+	
	Somatic cell count (SCC, in ×1000 cells mL^{-1})	96.1		139.5			+	
Eckelkamp et al. [36]	Bedding surface temperature ($t_{B\text{-}Sur.}$, in °C)	17.8	16.1			=		
	Prevalence of hock lesion (P_{HL}, in %) [7,8]	0.0	0.0			=		
	Prevalence of mild lameness (PL_{Mildly}, in %) [4,15]	33.3	30.4			=		
	Prevalence of clinical lameness ($PL_{Clin.}$, in %) [4,5]	39.2	40.8			=		
	Prevalence of severe lameness ($PL_{Sev.}$, in %) [4,6]	10.7	13.3			=		
	Prevalence of mastitis infection (P_{MI}, in %) [10]	22.0	19.0			=		
	Prevalence of clinical mastitis ($P_{M\text{-}Clin.}$, in %) [16]	1.2	1.2			=		
	Hygiene score (HS, in scores from 0 to 5) [11]	2.2	2.3			=		
	Somatic cell count (SCC, in ×1000 cells mL^{-1})	242	229			–		
Burgstaller et al. [37]	Prevalence of mild lameness (PL_{Mildly}, in %) [4,15]	13.7	9.9			=		
	Prevalence of clinical lameness ($PL_{Clin.}$, in %) [4,5]	3.9	4.7			=		
	Prevalence of severe lameness ($PL_{Sev.}$, in %) [4,6]	1.1	0.3			=		
	Prevalence of heel horn erosion (P_{HHE}, in %)	26.9	59.5			+		
Burgstaller et al. [37]	Prevalence of white line disease (P_{WLD}, in %)	20.4	46.6			+		
	Prevalence of interdigital hyperplasia (P_{IH}, in %)	0.2	3.1			+		
	Prevalence of chronic laminitis (P_{CL}, in %) [17]	6.5	15.9			+		
Costa et al. [38]	Prevalence of clinical lameness ($PL_{Clin.}$, in %) [4,5]	31.9	43.2			+		
	Prevalence of severe lameness ($PL_{Sev.}$, in %) [4,6]	14.2	22.2			+		
	Prevalence of hock lesion (P_{HL}, in %) [7,8]	0.5	9.9			+		
	Prevalence of knee lesion (P_{KL}, in %) [18]	<1.0 [19]	7.4			+		
	Hygiene score (HS, in scores from 0 to 3) [20]	NS [21]	NS [21]			=		
	Body condition score (BCS, in scores from 1 to 5) [12]	NS [22]	NS [22]			=		

Table 3. *Cont.*

Reference	Indicator	Result Achieved [1]				Effect [2]		
		CBP	FS	LH	TS	CBP × FS	CBP × LH	CBP × TS
Leso et al. [39] [23]	Prevalence of mastitis infection (P_{MI}, in %) [10]	32.8	23.2 (M) and 29.6 (S)			−/=		
	Somatic cell count (SCC, in ×1000 cells mL^{-1})	354	259 (M) and 310 (S)			−/=		
Bran et al. [40]	Prevalence of clinical lameness ($PL_{Clin.}$, in %) [4,5]	32.2	44.0			+		
	Prevalence of severe lameness ($PL_{Sev.}$, in %) [4,6]	14.3	23.0			+		
Biasato et al. [41] [24]	Prevalence of hock lesion (P_{HL}, in %) [7,8]	0.0	25.0			+		
	Prevalence of hoof lesions (P_{Hoof-L}, in %)	0.0	5.0			+		
	Prevalence of nasal discharge (P_{ND}, in %)	66.0	16.0			−		
	Prevalence of ocular discharge (P_{OD}, in %)	20.0	32.0			+		
	Prevalence of skin alopecia (P_{SA}, in %)	7.0	16.0			+		
	Hygiene score (HS, in scores from 0 to 5) [11]	2.0	2.2			+		
	Body condition score (BCS, in scores from 1 to 5) [12]	3.0	3.0			=		
	Locomotion score (LS, in scores from 1 to 5) [4]	1.0	1.1			=		
	Fecal score (FaS, in scores from 1 to 5) [25]	1.4	1.4			=		
Fernández et al. [42] [26]	Prevalence of clinical lameness ($PL_{Clin.}$, in %) [27,28]	13.2	15.4	8.4		=	−	
	Prevalence of severe lameness ($PL_{Sev.}$, in %) [27,29]	4.2	0.7	3.4		−	=	
	Prevalence of inflamed coronary bands (P_{ICB}, in %)	19.1	15.2	16.0		−	=	
Kogima et al. [43]	Prevalence of clinical lameness ($PL_{Clin.}$, in %) [4,5]	3.3	8.6			+		
	Prevalence of severe lameness ($PL_{Sev.}$, in %) [4,6]	3.3	6.7			+		
	Prevalence of coughing (P_C, in %)	<0.1 [19]	<0.1 [19]			=		
	Prevalence of nasal discharge (P_{ND}, in %)	46.7	51.9			=		
	Prevalence of ocular discharge (P_{OD}, in %)	6.7	6.7			=		
	Prevalence of purulent vaginal discharge (P_{PVD}, in %)	0.0	2.7			+		
	Prevalence of hampered respiration (P_{HR}, in %)	0.0	0.0			=		
Kogima et al. [43]	Prevalence of diarrhea ($P_{Diar.}$, in %)	6.7	20.0			+		
	Prevalence of downer cows (P_{DC}, in %)	3.9	4.2			=		
	Prevalence of mortality (P_{Mo}, in %)	6.5	9.7			+		
	Prevalence of dystocia ($P_{Dys.}$, in %)	2.2	3.7			=		
Witkowska and Ponieważ [9]	Prevalence of clinical lameness ($PL_{Clin.}$, in %) [4,5]	32.0	41.0 (SR) and 43.0 (SC)		45.0	+		+
	Prevalence of limb contusion (P_{Limb-C}, in %)	29.0	42.0 (SR) and 42.0 (SC)		40.0	+		+
	Prevalence of sprained limb (P_{SL}, in %)	8.0	21.0 (SR) and 28.0 (SC)		9.3	+		=
	Prevalence of footrot ($P_{Footrot}$, in %)	30.0	32.0 (SR) and 32.0 (SC)		26.0	=		−
	Prevalence of sole ulcers (P_{SU}, in %)	29.0	28.0 (SR) and 29.0 (SC)		27.0	=		=
	Prevalence of interdigital hyperplasia (P_{IH}, in %)	1.0	2.0 (SR) and 2.0 (SC)		1.0	=		=
	Prevalence of white line disease (P_{WLD}, in %)	4.0	5.0 (SR) and 5.0 (SC)		6.0	=		+
	Prevalence of heel horn erosion (P_{HHE}, in %)	3.0	3.0 (SR) and 4.0 (SC)		3.0	=		=
	Prevalence of chronic laminitis (P_{CL}, in %)	3.0	1.0 (SR) and 2.0 (SC)		2.0	−/=		=
	Prevalence of mastitis infection (P_{MI}, in %) [10]	17.0	15.0 (SR) and 18.0 (SC)		12.0	=		−
	Prevalence of teat infection (P_{TI}, in %)	8.0	7.0 (SR) and 9.0 (SC)		9.0	=		=
	Prevalence of retained placenta (P_{RP}, in %)	32.0	36.0 (SR) and 35.0 (SC)		38.0	=		+
	Prevalence of parturient paresis (P_{PP}, in %)	13.0	15.0 (SR) and 16.0 (SC)		17.0	=		+
	Prevalence of miscarriage ($P_{Misc.}$, in %)	10.0	9.0 (SR) and 11.0 (SC)		8.0	=		−
	Prevalence of conjunctivitis ($P_{Conj.}$, in %)	3.0	2.0 (SR) and 1.0 (SC)		0.0	=/−		−
	Prevalence of pneumonia ($P_{Pneu.}$, in %)	31.0	40.0 (SR) and 34.0 (SC)		28.0	+		−
	Prevalence of displaced abomasum (P_{DA}, in %)	13.0	13.0 (SR) and 12.0 (SC)		15.0	=		=
	Productive lifespan (PL, in months)	65.2	63.5 (SR) and 56.8 (SC)		57.1	+		+

Table 3. *Cont.*

Reference	Indicator	Result Achieved [1]				Effect [2]		
		CBP	FS	LH	TS	CBP × FS	CBP × LH	CBP × TS
Emanuelson et al. [44]	Prevalence of mastitis infection (P_{MI}, in %) [30]	18.9	12.9			–		
	Prevalence of new high SCC ($P_{NH\text{-}SCC}$, in %) [31]	12.2	8.2			–		
	Prevalence of ketosis risk (P_{KR}, in %)	9.8	10.3			=		
	Prevalence of prolonged calving intervals (P_{PCI}, in %)	34.7	39.8			+		
	Prevalence of dystocia ($P_{Dys.}$, in %)	2.7	3.3			=		
	Prevalence of stillbirth ($P_{Still.}$, in %)	3.9	2.5			–		
	Prevalence of first calving risk (P_{FCR}, in %)	26.9	29.8			+		
	Prevalence of calf mortality (P_{CM}, in %)	0.1	0.1			=		
	Length of life (LL, in months)	68.4	67.8			=		
	Productive lifespan (PL, in months)	33.7	33.7			=		
Emanuelson et al. [44]	Parity at exit from the herd (PEFH, in parity number)	3.5	3.6			=		
	Somatic cell count (SCC, in ×1000 cells mL^{-1})	86.9	67.7			–		

[1] The mean value was only indicated, without standard deviation; [2] Effect of housing in CBP systems, where +, −, or = indicate a statistically significant positive, negative, or no effect on animal health or thermal comfort, as depicted in the selected studies; [3] Evaluated in association with the THI; [4] Assessment performed using the locomotion score (LS), with a score from 1 (normal locomotion) to 5 (severely lame), as described by Sprecher et al. [50] and Flower and Weary [51]; [5] Animals were considered to have clinical lameness when LS ≥ 3; [6] Animals were considered to have severe lameness when LS ≥ 4; [7] Evaluations of hock lesions (HL) were made with a score of 1 (no lesion) to 3 (swollen hock); [8] Animals were considered to have hock lesions when HL ≥ 2; [9] Animals were considered to have severe hock lesions when HL = 3; [10] Animals with CCS > 200.000 cells mL^{-1} were considered to have mastitis infection; [11] Hygiene score (HS) assessment made using a score from 1 (clean) to 5 (dirty), according to the methodology described by Reneau et al. [52]; [12] Body condition score (BCS) evaluation was performed with a score from 1 (thin) to 5 (obese), according to the methodology described by Ferguson et al. [53]; [13] THI was calculated and evaluated using the equation of West et al. [54]—analysis was performed only for the summer period; [14] Results regarding the first cases of clinical mastitis; [15] Animals were considered to have mild lameness when EL = 2; [16] They only portray cases reported by producers; [17] In this systematic review, only data on hoof lesion types where a significant difference was observed between the two systems were included; [18] Knee lesion assessments were performed with a score from 1 (no lesion) to 3 (swollen knee)—prevalence was calculated in relation to the total number of animals; [19] Exact numeric value not specified; [20] Hygiene score (HS) assessment was performed with a score from 1 (clean) to 3 (dirty), according to the methodology described by Lombard et al. [55]; [21] HS score evaluated by body region (udder, leg, and flank)—for this reason, it was not included in this table; [22] BCS score evaluated using body condition type (thin, obese, and ideal)—therefore, it was not included in this table; [23] Other parameters related to the productive performance of the herd were assessed but were not included in this study due to the specific aim of the study; [24] Other parameters related to the health of the herd were evaluated but were not included in this study due to the lack of clarity of the data in the study; [25] Faecal score (FaS) evaluation was performed with a score from 1 (firm, but not hard) to 4 (without solid matter), according to the methodology described by Larson et al. [56]; [26] Other parameters related to the health and cleanliness of the herd were evaluated but were not included in this study because they were evaluated according to body region; [27] Assessment was performed based on a score from 0 (normal gait) to 2 (severely lame); [28] Animals were considered to have clinical lameness when the score was equal to 1; [29] Animals were considered to have severe lameness when the score was equal to 2; [30] Animals with SCC > 150 and >200 × 1000 cells mL^{-1} for first and last calving, respectively, were considered to have mastitis infection; [31] Animals with a new high SCC, compared to the previous day; FS-S—Free Stall systems used straw bedding; FS-CV—Free Stall systems with negative pressure mechanical ventilation; FS-M—Free Stall systems that used rubber mattresses; FS-NV—Free Stall systems with natural and/or positive pressure mechanical ventilation; FS-SC—Free Stall systems with a self-cleaning floor; FS-SR—Free Stall systems barn with a slatted floor scraped by robots; NS—not specified.

Three studies also examined the body condition score (BCS), a visual tool used to assess the proportion of body fat in dairy cows [57]. In these studies, average BCS scores of 3.0 were obtained, and they were statistically equal for both systems evaluated (CBP and FS). According to the methodology described by Ferguson et al. [53], these results indicate that the nutritional status of the housed animals could be classified as normal.

Another indicator used to evaluate housing conditions was the hygiene score (HS), which evaluates the cleanliness of the animals and has a direct relationship with somatic cell count (SCC) [20,52]. The results obtained in the four studies that used this indicator to compare body cleanliness conditions between CBP and FS systems were divergent: one study showed higher average HS in CBP systems [20]; two studies indicated that there was no statistical difference between HS values between systems [36,38]; and one study showed lower average HS values in CBP systems [41] (Table 3). Generally, better cleanliness conditions are achieved when a larger area of bedding per animal is provided, as shown in the study conducted by Biasato et al. [41], where the area of bedding per animal was 25.0 m^2.

As mentioned earlier, HS is directly associated with somatic cell count (SCC), an indicator of the number of leukocytes present in milk that can be used as an index of mammary health, as it reflects an immune response and, therefore, the presence of infection [58]. In a study evaluating CBP and LH systems, Astiz et al. [35] reported lower SCC values in CBP [$(96 \pm 135) \times 1000$ cells mL^{-1}, compared to $(139 \pm 242) \times 1000$ cells mL^{-1} in an LH system; Table 3]. The authors indicated that the reduction in SCC can be interpreted as an advantage of housing cows in CBPs during the dry period. Eckelkamp et al. [36] reported numerically higher SCC values in CBP systems [$(242 \pm 21) \times 1000$ cells mL^{-1}, compared to $(229 \pm 23) \times 1000$ cells mL^{-1} in FS systems; Table 3]. However, when evaluating the prevalence of high SCC (P_{MI}), they found no evidence of differences between systems, indicating that, on average, 20% of each herd had subclinical mastitis throughout the year. The results reported by Eckelkamp et al. [36] diverge from those obtained by Emanuelson et al. [44], who reported statistically higher occurrences of SCC, P_{MI}, and the prevalence of new, high SCC ($P_{NH\text{-}SCC}$, which compares SCC with the value obtained in the previous test) for milk samples obtained from confined cattle in CBP systems (Table 3). These results also diverge from those reported by Leso et al. [39], who observed higher SCC values and higher P_{MI} in CBPs (compared to rubber-bedded FS systems; Table 3). Comparing studies is challenging due to variations between housing types, but also in terms of bedding management and climate in the locations where the studies were conducted. However, the results reported are indications that udder health in CBP systems is negatively affected by the increased dirtiness normally observed in cattle housed in this type of system [42,44,59].

The discrepancies between the results obtained in some studies for HS, SCC, and P_{MI} may be attributed not only to differences between housing systems but also to bedding management practices adopted in each case [40]. If bedding management is not effective in keeping the surface dry, as shown in the study conducted by Lobeck et al. [20], the lack of manure incorporation and excess moisture cause HS scores to be higher, indicating that the animals are dirtier [36]. Consequently, animal health may have been affected, as evidenced by the values of SCC, P_{MI}, and $P_{NH\text{-}SCC}$ [15,60]. These findings underscore the fundamental importance of proper bedding management in CBP systems to provide dry, comfortable, and healthy surfaces for housed animals [44], ensuring optimal animal health.

SCC values > 200×1000 cells mL^{-1} are typically used to calculate the prevalence of mastitis infection (P_{MI}), which is used as an indirect measure of animal welfare [20]. Mastitis is a disease caused by bacteria and is considered endemic in the dairy industry, as it is responsible for high economic costs (prevention and treatment) and an increase in animal morbidity and culling rates [9,61]. In most studies that evaluated P_{MI}, no significant difference was found between animals housed in CBP and FS systems [9,20,36,39] (Table 3). However, CBPs presented statistically lower P_{MI} values when compared to LH [35] and higher values when compared to TS [9]. Regarding the prevalence of clinical mastitis ($P_{M\text{-}Clin.}$), statistically equal results were also obtained for CBP and FS systems. These outcomes suggest that, if well managed, CBP systems can provide environments as adequate as those obtained in FS, which are considered to have a lower risk for mastitis [9,48].

In the study conducted by Biasato et al. [41] fecal score (FaS) was also evaluated. FaS is scored on a scale from 1 (firm, but not hard) to 4 (devoid of solid matter), and is used to analyze diet digestion and the gastrointestinal health of animals [56,62]. The results indicated no significant difference between CBP and FS systems, and, therefore, gastrointestinal health was adequate in both systems. For the prevalence of ketosis risk (P_{KR}), a metabolic disease associated with fat, the study conducted by Emanuelson et al. [44] also showed equal values between these systems.

In addition to the aforementioned indicators, it is also important to evaluate reproductive disorders, which, along with lameness, mastitis, and metabolic diseases, are a major concern for the dairy cattle production sector [44]. The results of some studies have indicated lower prevalences of cytological endometritis (P_{CE}), purulent vaginal discharge (P_{PVD}), prolonged calving intervals (P_{PCI}), first calving risk (P_{FCR}), retained placenta (P_{RP}), and parturient paresis (P_{PP}) for cattle housed in CBP systems (Table 3). The lower rates observed for reproductive disorders may be associated with the reduction in the prevalence of diseases and/or lesions of hooves and limbs in CBP systems, as these problems could also compromise the reproductive performance of the housed animals [49].

No evidence of improvements in the indicators as prevalences of dystocia ($P_{Dys.}$) and of calf mortality (P_{CM}), and higher prevalences of stillbirth ($P_{Still.}$) and miscarriage ($P_{Misc.}$), were observed in CBP systems compared to FS and TS systems, respectively. This could be attributed to the greater freedom of interaction between cows in CBP systems, which, due to dominance order conflicts, can increase $P_{Still.}$. However, it is extremely difficult to provide a specific explanation, as this result may be associated with other factors not evaluated [44]. Therefore, it is important that new studies on the topic be conducted. Regarding $P_{Misc.}$, the better results achieved in TS can be justified by the lower probability of slipping, tripping, and/or pushing in this type of system, as animals do not need to compete for space in the feeding aisle, as can occur in CBP systems [9].

The prevalences of respiratory disorders such as pneumonia ($P_{Pneu.}$), coughing (P_C), and nasal discharge (P_{ND}) were not significantly different between CBP and FS systems. These respiratory disorders are caused by infectious agents (bacteria, fungi, parasites, or viruses), and their occurrence can also be related to environmental, hygiene, and ventilation conditions [9,63]. Despite the low occurrence of P_C (<1.0%), relatively high $P_{Pneu.}$ and P_{SN} (>25.0%) were observed for all confinement systems evaluated (CBP, FS, and TS). It is estimated that these results are associated with the higher housing density used in confinement systems, which can facilitate the rapid spread of diseases when animals with respiratory problems are not isolated, compared to pasture production [64]. Some studies conducted in CBP systems have associated the occurrence of respiratory disorders with excessive levels of humidity and dust, which can be observed in some situations in this system [59,65]. However, more studies are still needed on the topic to obtain more conclusive results.

The evaluation of indicators related to eye health is also important, as the presence of certain concentrations of gases and dust in the facilities can cause eye irritation in animals [66]. The frequency of occurrence of conjunctivitis ($P_{Conj.}$) was higher in CBP and FS-SC systems compared to FS-SC and TS systems [9] (Table 3). According to the study authors, these results were associated with the accumulation of manure in the bedding and under the slatted floor in these two systems, respectively, which caused higher emissions of ammonia (NH_3) and, consequently, higher P_{Conj}. However, another study found no statistical difference between CBP and FS systems in terms of the prevalence of ocular discharge (P_{OD}) [43] (Table 3).

Indicators related to herd longevity, such as length of life (LL), productive lifespan (PL), parity at exit from the herd (PEFH), and prevalence of mortality (P_{Mo}) were also evaluated in some studies [9,20,35,43,44] (Table 3). When only CBP and FS systems were compared, no significant difference was observed between LL, PL, and PEFH; however, lower P_{Mo} was reported [44] (Table 3), as when compared to LH systems [35] (Table 3). In a study that also evaluated TS systems, a longer PL time was observed for cattle housed in CBP systems [43]—Table 3. These results suggest that, when well-managed, the use of CBP systems can help to reduce the rates of morbidity and culling of cattle, which can lead to significant economic losses for the dairy industry [61].

3.3. Thermal Comfort

For thermal comfort, only experimental studies comparing CBPs with other types of intensive housing systems were also included to ensure equal conditions for obtaining the indicators. Consequently, the thermal-ambient indicators were limited to the following: respiration rate (RR) in association with the Temperature and Humidity Index (THI) [20]; dry-bulb air temperature (t_{db}) and THI [34]; and bedding surface temperature ($t_{B\text{-}Sur.}$) in the resting areas (Bed-Surface Temp.) [36].

Lobeck et al. [20] used RR in conjunction with the THI to assess the thermal comfort of dairy cattle housed in CBP systems with positive-pressure mechanical ventilation, compared to FS systems with positive-pressure mechanical ventilation (FS-NV) and cross-ventilation in association with evaporative cooling (FS-CV). In this study, 75% of the RR measurements were performed under some degree of thermal stress (THI $\geq$ 70, as defined by Cook et al. [67] and Vitali et al. [68]). Based on the results, the authors noted that numerically lower THI values were obtained in FS-CV systems (2.0 and 2.1 units lower than the THI values obtained in CBP and FS-NV, respectively). However, the RR values were statistically equal between systems, suggesting that the environmental conditions in the CBP and FS-NV housing systems did not lead to as significant an increase in this animal physiological response as the FS-CV system (58.4, 59.3, and 57.5 breaths min^{-1} for CBP, FS-NV, and FS-CV, respectively; Table 3).

In another study conducted in the same facilities described previously, Lobeck et al. [34] assessed the thermal comfort conditions of the animals housed based on the t_{db} and the THI (only evaluated in the summer, as it is a metric used to assess heat stress). The study was conducted between January and November 2008, with one collection in each climatic season (winter, spring, summer, and fall). Based on the results obtained, the authors observed that the prevalence of t_{db} values was statistically equal between the CBP, FS-NV, and FS-CV systems in the spring and summer periods, but different in the winter and fall periods, when the FS-CV systems ensured the maintenance of slightly higher tbs values (Table 3). The THI, one of the main indices used to assess heat stress in dairy cattle [29,69,70], was also used to compare the thermal performance of the three housing types. During the summer, it was found that FS-CV systems maintained statistically lower THI values (65.9, compared to 68.0 and 68.4 obtained in CBP and FS-NV systems, respectively; Table 3).

According to Lobeck et al. [34], the best results observed during extreme climatic conditions in FS-CV systems were achieved due to the greater insulation provided by the installation during the winter and the use of evaporative cooling during the summer, respectively. The use of side closures during the winter can help to ensure that heat is retained within the facility, and, consequently, that higher air temperature levels are maintained [18]. In fully enclosed facilities with negative pressure ventilation, exhaust fans suck air out of the facility, causing the internal pressure to be lower. Due to this pressure difference between the exterior and interior of the facility, external air is forced to enter the facility through wet plates [71]. When air passes through wet plates, simultaneous heat and mass exchange occurs: part of the water is converted from liquid to vapor, increasing the relative humidity of the air; the sensible heat present in the air is converted into latent heat and used for the phase change of water, and the result of this conversion is a reduction in the temperature of the air entering the facility [71,72]. Therefore, in closed facilities with the use of evaporative cooling, it is possible to achieve more pleasant thermal conditions during the summer [34,73]. Despite the good results obtained with the use of cross ventilation associated with evaporative cooling in FS systems, the use of this type of thermal conditioning solution should be carefully evaluated before implementation in CBPs. In this type of system, in addition to meeting criteria related to animal comfort, ventilation, and cooling systems must be sized and managed to ensure the physical-chemical quality of the bedding (especially in relation to humidity). Therefore, they must also consider aspects related to the specificities of each facility, as well as the local climatic and geographic conditions.

Eckelkamp et al. [36] evaluated the bedding surface temperature ($t_{B\text{-}Sur.}$) conditions that dairy cattle had available to lie down in CBP and FS systems. The authors found that there was no difference in $t_{B\text{-}Sur.}$ between these two types of housing, and that the recorded values were close to the air temperature values. In fact, the environmental conditions, the bedding materials used in CBP systems (usually sawdust and wood shavings, which typically have thermal insulation characteristics), and the use of ventilation yield $t_{B\text{-}Sur.}$ similar to air temperature, even when temperature levels are higher throughout the depth of the bedding [18,19,74,75].

When considering thermal comfort, it is also important to describe in detail the climatic conditions and the characteristics of the housings in which the studies were conducted. Detailed characterization is crucial because the local climate, the construction characteristics, and the thermal conditioning solutions used typically have more direct implications for the thermal conditions achieved in the housings [71,72].

Two studies that evaluated thermal comfort indicators [20,34] were conducted in CBP and FS systems located in Minnesota and eastern South Dakota, United States, in a region with high annual thermal amplitude (≈36 °C). In these studies, sampling was conducted at different times of the year: winter (January to February; average external temperature ranging from −14 to −7 °C, according to the Minnesota Department of Natural Resources [76]), spring (April to May; average external temperature ranging from 2 to 8 °C, according to the Minnesota Department of Natural Resources [76]), summer (July to August; average external temperature ranging from 15 to 22 °C, according to the Minnesota Department of Natural Resources [76]), and fall (October to November; average external temperature ranging from 4 to 9 °C, according to the Minnesota Department of Natural Resources [76]). The third study [36] was also conducted in CBP and FS systems located in a region with high annual thermal amplitude (Kentucky, USA, where the temperature variation can be greater than 30 °C, according to the National Weather Service [77]).

As the regions where the studies of Lobeck et al. were conducted [20], the results obtained by Lobeck et al. [34] and Eckelkamp et al. [36] have a high annual thermal amplitude, and the use of closed facilities with negative pressure ventilation associated with evaporative cooling may be a good option for improving housing thermal conditions. This is because it ensures higher internal temperatures during the cold season and more mild temperatures during hot and dry periods (summer), as shown in the study by Lobeck et al. [34]. Notably, significant gains can be achieved during hot and dry periods (low air humidity) when evaporative cooling systems can provide air cooling of up to 11 °C, depending on local environmental conditions [71,78].

Therefore, the use of closed facilities (with mechanical ventilation associated with evaporative cooling) is recommended for areas with high annual thermal amplitude (requiring greater control), as well as for those where temperatures exceed the upper critical limit of thermal comfort for lactating dairy cows (≥24 °C, according to Baêta and Souza [72]) and relative humidity not too high (≤80%, according to Arcidiacono [78]). However, considering that housing and thermal conditioning solutions must align with the reality of each location, it is crucial to conduct more studies evaluating the thermal performance of CBP systems compared with other housing models (FS, LH, and/or TS) in locations with diverse climatic realities not covered in the described studies.

Concerning the architectural and technological characterization of the facilities used in the studies, the work conducted by Lobeck et al. [34] provided detailed and comprehensive information on the housing conditions. This includes various relevant data such as the length and width of the barns, ceiling height, width of aisles, dimensions of the bedding area (when applicable), and types of ventilation and lighting systems, among other details (for a more in-depth exploration, refer to the original study). However, only average values of thermal-environmental characterization were reported for each system type (CBP, FS-NV, and FS-CV). Consequently, establishing correlations between the thermal results achieved and the specific housing conditions in each experimental unit became relatively difficult. In the study conducted by Eckelkamp et al. [36], the architectural and technological characteristics of the facilities were not described, possibly because the main objective was to evaluate indicators related to animal health. Again, it was not possible to establish relationships between the specific housing conditions and the achieved thermal results.

Although only three studies have been listed where thermal comfort was evaluated comparatively between CBP and FS systems, the results suggest that thermal conditions are more influenced by the level of thermal conditioning adopted in the facilities than by the presence of composting bedding. In truth, it is recognized that the use of engineering solutions can make it possible to fully control the thermal environment. However, it is essential to evaluate which forms of thermal conditioning best suit the local reality, considering technical, economic, and social factors [71]. Therefore, regardless of the construction type of the facility, the thermal conditioning techniques to be used must ensure optimal conditions for the animals, allowing them to express their maximum productive and reproductive potential [16,64,79,80].

3.4. Limitations and Future Directions

Studies examining the impact of housing systems (CBP, FS, LH, and/or TS) on the health and thermal comfort of confined dairy cattle have been conducted in diverse locations, including Austria, Germany, Brazil, Slovenia, the United States of America, The Netherlands, Italy, Poland, and Sweden. However, the comparison of the results of the studies for different systems was hindered due to the variations in the construction typologies, management practices, and climatic conditions that can affect the production systems studied [44]. In addition, the housing systems included through systematic results in this study were not grouped by farm size. Therefore, some caution is needed regarding the extrapolation of the results.

The studies addressed used various indicators to assess animal health and thermal comfort. For this reason, it was not possible to analyze the quality of the studies through a meta-analysis, which could influence the results obtained. Additionally, studies published as conference proceedings, book chapters, and/or not published in English were excluded. However, it was not possible to determine to what extent the results were affected by such exclusions.

The number of studies on animal health and thermal comfort in CBP systems is still low, and it is even lower when considering only studies that compared CBPs with other housing systems (FS, LH, and/or TS). This is likely because CBP is a relatively new housing model, and more comprehensive studies are needed to expand knowledge in this area.

In terms of animal health, the limited number of studies comparing CBPs with other systems (FS, LH, and/or TS) may have made it difficult to obtain conclusive results for some indicators used, such as for example, respiratory disorders and their interrelationships with environmental and bedding management. As discussed previously, the diseases studied in these systems are caused by multiple factors, and, therefore, in-depth studies on this topic have great potential to generate knowledge about animals in different construction typologies. A similar condition was observed for thermal comfort, where, in addition to the limited number of studies, only results obtained in facilities located in the same climatic region were portrayed, making it impossible to achieve more comprehensive results. Therefore, it is crucial to conduct new experimental studies on animal health and thermal comfort in CBP systems, with comparisons to other housing systems when possible. Preferably, future studies should group the housing technologies employed according to the size of the farm and consider the effects of housing on animal health and welfare in the long term. In all cases, they should comprehensively describe the many variations that can be found in terms of facility typologies, climatic and geographical conditions, ventilation systems, materials, environmental and bedding management practices, size and breed of animals housed, etc.

Finally, regarding the assessment of animal health and thermal comfort in intensive dairy production systems, it is also important to develop and validate new precision livestock farming tools. These tools should be applicable and accessible to a wide range of producers, enabling remote and real-time assessment. This can reduce the need for labor and operational costs, as well as improve the detection of thermally stressful conditions, injuries, and diseases in the early stages, facilitating the implementation of thermal conditioning solutions and early treatment to improve the health and thermal comfort of housed animals [3,61,62,81].

4. Conclusions

In this study, the results available in the literature on the health and thermal comfort of dairy cattle housed in CBP systems, compared to FS, LH, and/or TS systems, were described and discussed. Regarding animal health, it was evidenced that the incidence of problems such as lameness, limb injuries, and reproductive disorders is significantly lower in CBP systems. However, if bedding management is not effective in ensuring the provision of dry, comfortable, and healthy surfaces for housed animals, an increase in somatic cell count (SCC) and prevalence of mastitis incidence (P_{MI}) may occur. For thermal comfort, it was found that the CBP system exhibited higher temperatures during summer and lower temperatures during winter when compared to FS with cross-ventilation in association with evaporative cooling. However, no differences were observed in terms of thermal comfort in spring and autumn. Therefore, thermal comfort indicators are more directly related to the time of year and thermal conditioning solutions than to the type of housing system. Although the results achieved in this systematic review do not fully clarify how animal health and thermal comfort can be affected by housing type, they represent the state of the art in this topic and can provide valuable insights for future research.

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