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Effect of Stocking Density on Health of Broiler Chickens: A Comprehensive Review

Review Article

E.L.T. Chung[1,2*], N.A.A. Fauzi[2], N.A.A. Bakar[2], M.F.H. Reduan[3], F.F.A. Jesse[4] and T.C. Loh[1]

[1] Department of Animal Science, Faculty of Agriculture, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[2] Laboratory of Sustainable Animal Production and Biodiversity, Institute of Tropical Agriculture and Food Security, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[3] Department of Paraclinical Studies, Faculty of Veterinary Medicine, University Malaysia Kelantan, Pengkalan Chepa 16100, Kota Bharu, Kelantan, Malaysia
[4] Department of Veterinary Clinical Studies, Faculty of Veterinary Medicine, University Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

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*Correspondence E-mail: ericlim@upm.edu.my

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ABSTRACT

The health performance of broiler chickens is influenced by various factors, including farm management practices and environmental conditions. However, limited information exists on the relationship between stocking density and broiler health outcomes under commercial conditions. This systematic review aimed to evaluate the impact of different stocking densities on broiler health indicators. Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, a comprehensive search was conducted using databases such as Scopus, Science Direct, and Google Scholar, covering studies published from 2000 to 2021. This review addresses a critical gap by systematically evaluating how stocking density affects broiler health through clinical, hematological, and stress-related indicators across different housing systems. The results indicated that the average low and high stocking densities were 11 birds/m² and 17 birds/m², respectively. Broilers reared at lower stocking densities consistently exhibited better health outcomes, including lower scores for gait abnormalities, footpad dermatitis, hock lesions, and breast blisters. Furthermore, reduced stocking densities were associated with lower heterophil-to-lymphocyte ratios, corticosterone concentrations, and mortality rates. In conclusion, the evidence consistently demonstrates that lower stocking densities improve broiler health and welfare across diverse management systems.

KEY WORDS blood indices, broiler chickens, clinical conditions, stocking density, stress biomarker.

INTRODUCTION

Poultry producers worldwide seek to maximize economic returns by increasing the total live weight of chickens per square meter while minimizing losses associated with overcrowding (Abudabos et al. 2013; Goo et al. 2019). The substantial growth in broiler meat production over the past decade is largely attributed to advancements in genetic selection, nutritional strategies, and farm management innovations (Chung et al. 2020; Chung et al. 2021). Among environmental factors, stocking density, temperature, and humidity are critical determinants of production efficiency (Bouyeh et al. 2017; Gholami et al. 2020). Regulatory guidelines for stocking density vary by country and are typically based on housing system types, such as closed or open housing. For example, European Union Regulation 43/2007 permits stocking densities ranging from 33 to 42 kg of live weight per square meter, while warmer regions generally apply a lower threshold of approximately 30 kg/m² (Qaid et al. 2016). In contrast, many developing countries have yet to establish or enforce standardized regulations for stocking density.

Numerous studies have identified optimal stocking densities under various conditions and environments. Lallo *et al.* (2012) reported that the ideal stocking density for broilers is 25 kg/m², noting that higher densities can lead to heat stress due to reduced airflow in open-sided farms. Increased heat stress can negatively impact overall animal performance (Wasti *et al.* 2020). Additionally, research by Ghosh *et al.* (2012) highlighted that stocking density should align with the farmer's goals whether prioritizing body weight and size or focusing on the number of animals within a fixed area.

Ghosh *et al.* (2012) suggested higher stocking densities for farmers who prioritize quantity overweight in open-sided, naturally ventilated housing. Similarly, Henrique *et al.* (2017) found no significant differences in broiler performance across stocking densities of 25, 30, and 35 kg/m², although productivity increased. Further findings by Madilindi *et al.* (2018) indicated that the highest stocking density of 40 kg/m² may be the most optimal for broiler performance in open-sided housing, compared to densities of 30 and 35 kg/m².

From a production standpoint, many studies suggest that higher stocking densities have minimal effects on growth performance or farm profitability (Seng *et al.* 2025). However, an increasing number of studies have documented the adverse health implications associated with high stocking densities in broiler chickens. For example, McLean *et al.* (2002) observed that broilers reared at lower densities exhibited less severe panting compared to those raised under more crowded conditions. Sekeroglu *et al.* (2011) also reported elevated heterophil-to-lymphocyte (H/L) ratios in broilers kept at stocking densities of 12.5 and 10 birds/m² compared to those housed at 7.5 birds/m². Likewise, Kridtayopas *et al.* (2019) found significantly higher corticosterone levels and H/L ratios in broilers reared at high stocking densities relative to those maintained at standard densities.

Although several studies have examined the effects of stocking density on broiler performance or welfare outcomes individually, few have offered a systematic synthesis that integrates clinical indicators, hematological parameters, and stress biomarkers across different management systems. Moreover, existing reviews often focus narrowly on performance metrics or do not distinguish between housing types, environmental stressors, and physiological responses. These limitations hinder the development of comprehensive, evidence-based recommendations for stocking density practices. To address this gap, the present review systematically evaluates the effects of varying stocking densities on broiler health indicators including external lesions, mortality, blood indices, and stress biomarkers across both closed and open housing systems. By highlighting patterns and inconsistencies in current findings, this study aims to inform optimal management strategies that support broiler health and welfare under commercial conditions.

MATERIALS AND METHODS

PRISMA guideline

A systematic literature search was conducted using the Scopus database, adhering to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The selection process is illustrated in Figure 1.

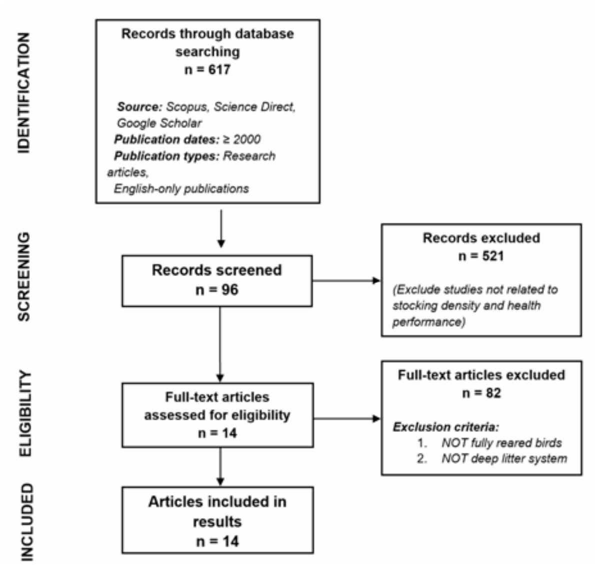

Figure 1 Steps of record inclusion and exclusion journals based on the PRISMA guidelines

Inclusion and exclusion criteria

Table 1 lists the search terms used to identify relevant publications for this review. A primary inclusion criterion was that broilers must be studied across the entire production cycle, from the starter phase to the finisher phase, meaning from day-old chicks to harvest age. Additionally, eligible studies were required to report data on both stocking density and health performance. Articles lacking information on either parameter were excluded. Furthermore, only studies involving broilers raised in deep litter systems were included. Studies conducted on broilers reared in battery cages or free-range systems were excluded, as these methods are less representative of commercial production practices.

Extraction of information

A comprehensive literature search was conducted using Scopus, Science Direct, and Google Scholar to identify studies published between 2012 and 2021. This search initially yielded 617 articles. Following title and abstract screening, 96 articles were selected for detailed evaluation. Among these, 14 publications met all the inclusion criteria and were subjected to full-text analysis. The following information was extracted from each eligible study: (1) study region, (2) management system, (3) bedding type, (4) stocking density, (5) feather scoring, (6) breast blister scoring, (7) footpad dermatitis scoring, (8) mortality rate, (9) hock lesion scoring, (10) gait score, (11) heterophil-to-lymphocyte (H/L) ratio, and (12) corticosterone levels.

Table 1 The search terms used in the review of stocking densities and the health performances of broiler chicken

Stocking density terms	Health terms
Flock density	Health performance
Floor space	Clinical sign
Rearing density	Blood parameters
Stocking density	Blood indices
	Blood biomarkers

RESULTS AND DISCUSSION

Region of study

The majority of the reviewed studies (57%) were conducted in the Middle East, followed by South America, which accounted for 21%. In contrast, only one study each originated from North America, Europe, and Asia (7% each), specifically from the United States, Greece, and China, respectively (Figure 2).

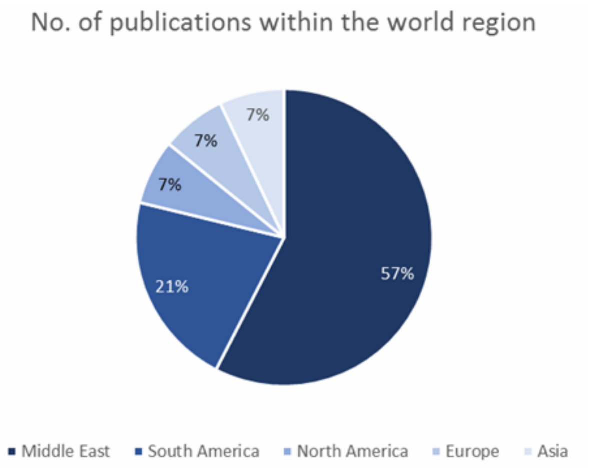

Figure 2 Number of included publications based on the world region

Heat stress has emerged as a significant challenge in tropical and subtropical regions due to hot and humid climates. In the present review, a larger proportion of studies on broiler health performance originated from countries in the Middle East compared to other regions. This trend aligns with previous findings that heat stress negatively affects poultry by reducing egg production, growth rates, and the quality of meat and eggs (Alghirani *et al.* 2022; Alghirani *et al.* 2023).

South America contributed the second-highest number of studies. According to Arana (2021), Brazil ranks as the world's second-largest poultry producer, accounting for 12.5% of global output. In 2019, Brazil processed approximately 6.47 billion chickens, underscoring its prominence in South American poultry production. Only one study from Asia, conducted in China, was included, indicating a notable gap in regional representation and a need for more research from Asian and other underrepresented regions.

Management system

The selected studies reported two types of broiler management systems: closed house and open house systems (Figure 3). Closed house systems were the predominant type, appearing in 92.9% of the reviewed publications. Among the 14 included articles, only one study (7.1%) employed an open house system, which was conducted in South America.

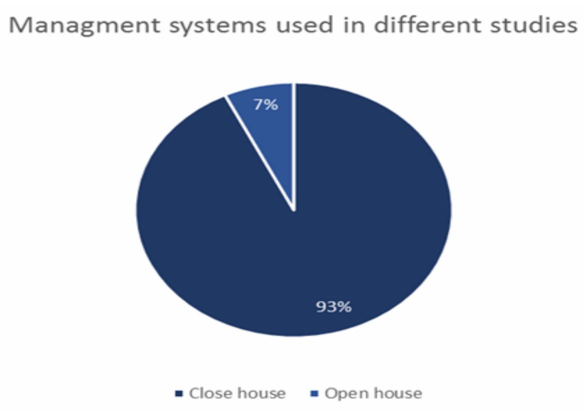

Figure 3 Number of included publications based on management system

The choice of broiler management system plays a vital role in achieving optimal animal performance. Multiple studies have demonstrated that housing type significantly influences broiler welfare, health status, and growth outcomes (Fortomaris *et al.* 2007; Santos *et al.* 2012). Closed house systems are generally preferred due to their ability to offer greater environmental control. In the present review, 92.9% of the included studies employed closed house systems. These systems help mitigate environmental stressors, enhance productivity, and improve labor efficiency by maintaining a stable internal climate (Pakage *et al.* 2015; Perera and Dematawewa, 2016). In contrast, open house systems are more susceptible to adverse environmental fluctuations, which can compromise broiler performance if not properly managed. Only one study included in this review used an open house system (Vargas-Galicia *et al.* 2017), and such systems have been associated with decreased productivity, poorer environmental conditions, and adverse health outcomes (Xin *et al.* 2009; Gillespie *et al.*

2017). Accordingly, the predominance of closed house systems in the reviewed literature reflects their effectiveness in supporting broiler health and performance.

Bedding type

Among the reviewed studies, wood shavings were the most commonly used bedding material, reported in 40% of the publications. Other bedding types included rice hulls (20%), coir litter (6%), volcanic rock (6%), fresh straw (6%), and fresh pine shavings (6%). Additionally, two studies did not specify the type of bedding used (Figure 4).

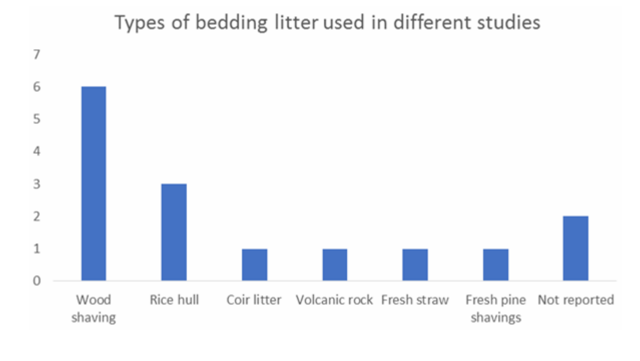

Figure 4 Types of bedding litter used in different studies

Bedding materials play an important role in influencing broiler health and management efficiency (Costa *et al.* 2021). In the present review, wood shavings were the most frequently used bedding material, followed by rice hulls. This preference may be attributed to the favorable characteristics of wood shavings, including low moisture content, minimal dust, and high absorbency. Broilers reared on wood shavings have also demonstrated improved carcass quality and body weight (Sarica and Cam, 2000; Garcia *et al.* 2012). However, the increasing cost and limited availability of wood shavings have led to the exploration of alternative bedding materials (Lima *et al.* 2018). Alternatives such as rice hulls (Petek *et al.* 2010; Purswell *et al.* 2020; Chegini *et al.* 2019), coir litter (Lima *et al.* 2018), volcanic rock (Vargas-Galicia *et al.* 2017), and fresh straw (Simitzis *et al.* 2012) have produced mixed results. Some studies suggest that these substitutes may be less effective or even detrimental when compared to wood shavings. For instance, Lima *et al.* (2018) reported a higher incidence of hock and footpad lesions associated with lower-quality alternative bedding. In contrast, other research found no significant differences in growth or health performance and recommended mixing bedding materials to enhance overall quality (Petek *et al.* 2010).

Stocking density

Table 2 presents the frequency and distribution of stocking densities reported across the reviewed studies, which ranged from 6 to 23 birds/m². Among the 16 different stocking densities identified, 18 birds/m² was the most commonly applied, appearing in eight studies. This was followed by densities of 12 birds/m² in seven studies, 13 birds/m² in six studies, and 10 birds/m² in three studies. Additionally, two studies each reported using 14, 15, 16, and 20 birds/m². The remaining stocking densities 6, 8, 9, 11, 17, 19, 22, and 23 birds/m² were each reported in only one study.

Table 3 summarizes the stocking densities reported for both open and closed house systems. The mean values for low and high stocking densities were determined by identifying the lowest and highest values reported in each of the 14 selected studies. Across all studies, the average low stocking density was 11 birds/m², while the average high stocking density was 17 birds/m². These averages were consistent within closed house systems, where the mean low and high stocking densities were also 11 and 17 birds/m², respectively. In contrast, open house systems reported slightly higher averages, with 13 birds/m² for low stocking density and 18 birds/m² for high stocking density.

Commercial broiler stocking density is primarily influenced by considerations of productivity and animal welfare (Tong *et al.* 2012; Weimer *et al.* 2020). In the present review, stocking densities were generally higher in open house systems compared to closed house systems. This difference may be attributed to the larger body size typically achieved by broilers raised in closed house systems, which are known to support better feed efficiency and growth performance (Bogosavljević-Bošković *et al.* 2012; Muharlien *et al.* 2020). Consequently, broilers in closed environments may require more space per bird, resulting in lower stocking densities. In contrast, open house systems are more vulnerable to external stressors such as disease exposure and climate fluctuations, which can negatively affect broiler health and welfare.

Zhao *et al.* (2014) further reported that housing systems with outdoor access may lead to reduced performance and higher mortality. These findings suggest that elevated stocking densities in open house systems could compromise broiler health and productivity.

Health performance–feather scoring

Three studies reported feather scoring outcomes in relation to stocking density. The average stocking densities were 12 birds/m² for the low-density group and 18 birds/m² for the high-density group. These studies used a 4-point feather scoring system, where 1 indicated severe feather loss, 2 moderate feather loss, 3 mild feather loss, and 4 intact plumage.

Table 2 The number and percentage of different stocking densities used in different studies

Stocking density	Number of study (n)	Percentage (%)
6 birds/m^2	1	2.50
8 birds/m^2	1	2.50
9 birds/m^2	1	2.50
10 birds/m^2	3	7.50
11 birds/m^2	1	2.50
12 birds/m^2	7	17.5
13 birds/m^2	6	15.0
14 birds/m^2	2	5.00
15 birds/m^2	2	5.00
16 birds/m^2	2	5.00
17 birds/m^2	1	2.50
18 birds/m^2	8	20.0
19 birds/m^2	1	2.50
20 birds/m^2	2	5.00
22 birds/m^2	1	2.50
23 birds/m^2	1	2.50

Table 3 Mean stocking density practiced in both open house and closed house system

Management system	LSD (bird/m²)	HSD (bird/m²)
Overall	11.0±2.65	17.0±3.19
Close house	11.0±2.71	17.0±3.31
Open house	13.0±0.00	18.0±0.00

LSD: low stocking density and HSD: high stocking density.

As shown in Table 4, broilers reared at lower stocking densities recorded slightly higher average feather scores. However, the scores for both low and high stocking density groups were generally comparable, falling within the range of mild feather loss to intact plumage.

Sevim *et al.* (2021) observed that variations in feather condition can be influenced by differences in management practices, stocking densities, and broiler breeds. In the present review, broilers raised at lower stocking densities exhibited better feathering compared to those at higher densities. Poorer feather condition, such as mild feather loss, has been associated with increased moisture levels that often accompany higher stocking densities. Several studies have reported a higher incidence of lesions in broilers raised under crowded conditions (Dozier *et al.* 2006; Petek *et al.* 2010; Karaarslan and Nazlıgül, 2018). Greater bird density leads to increased excreta production, which elevates litter moisture and contributes to skin lesions. Moreover, broilers exposed to wet litter are more susceptible to inflammation and dermal damage (Dawkins *et al.* 2004; Petek *et al.* 2010). From a physiological standpoint, chronic exposure to high moisture environments may disrupt the skin barrier function and increase transdermal absorption of irritants such as ammonia, triggering oxidative stress and inflammatory cascades. These responses can damage feather follicles and impair feather regeneration. Stress-related endocrine responses may further aggravate feather quality. Elevated corticosterone levels, common in high-density conditions, are known to interfere with protein synthesis and keratinocyte proliferation, both essential for feather development. These observations are consistent with previous findings linking stocking density to changes in neuroendocrine and integumentary function (McLean *et al.* 2002; Najafi *et al.* 2015). These findings support the recommendation of maintaining lower stocking densities to improve broiler health and feather condition. Future research should investigate the molecular pathways associated with feather follicle response to chronic stress, as well as explore potential interventions, such as dietary supplementation with antioxidants or anti-inflammatory compounds, to mitigate the adverse effects of high stocking densities.

Health performance–breast blister scoring

Of the 14 articles included in this review, only one study reported data on breast blister scoring. The reported stocking densities were 10 birds/m² for the low-density group and 13 birds/m² for the high-density group. A 3-point scoring system was used, where 0 indicated no lesion, 1 represented a lesion without inflammation, and 2 indicated a lesion with inflammation. Although broilers raised at lower stocking densities had lower average scores, both groups exhibited signs of breast blisters and inflammation (Table 5).

In this review, the findings showed little difference between low and high stocking density groups in terms of breast blister occurrence. Similar results were reported by Lima *et al.* (2018), who found no significant impact of stocking density on breast blister development. This lack of variation may be attributed to the relatively small differences in stocking densities and the similarity of litter types used across studies. It is also possible that adherence to national animal welfare guidelines contributed to a lower incidence of breast lesions overall. Moreover, increased litter moisture from excreta accumulation remains a known factor associated with a higher occurrence of lesions (Dozier *et al.* 2006; Petek *et al.* 2010; Karaarslan and Nazlıgül, 2018). Biochemically, prolonged exposure of the sternal region to damp bedding may compromise dermal tissue integrity by promoting maceration, localized inflammation, and microbial infiltration, which in turn lead to subcutaneous blistering. The pressure exerted on the keel bone during prolonged recumbency, particularly in heavy broilers, may exacerbate vascular compression and tissue necrosis, further contributing to blister formation (Kaukonen *et al.* 2016). Although these mechanisms are well-documented in studies involving contact dermatitis, there is a paucity of focused investigations on the pathophysiology of breast blisters under variable stocking densities. Future research should examine tissue-level changes in the pectoral region under high moisture and pressure conditions, and assess the role of genetic predisposition and body conformation in susceptibility to breast blistering.

Table 4 Average feather scoring and stocking densities for each article included in study

	Stocking density (birds/m^2)	Score (1-4)
LSD	12.0±0.00	3.50±0.33
HSD	18.0±0.00	3.20±0.55

LSD: low stocking density and HSD: high stocking density.

Table 5 Breast blister of broilers at different stocking densities

	Stocking density (birds/m^2)	Score (0-2)
LSD	10.0±0.00	1.60±0.00
HSD	13.0±0.00	1.70±0.00

LSD: low stocking density and HSD: high stocking density.

Health performance–footpad dermatitis scoring

Of the 14 studies reviewed, 9 (64%) reported data on footpad dermatitis. The average stocking densities were 13 birds/m² for the low-density group and 18 birds/m² for the high-density group. A 4-point scoring system was used to assess footpad condition: 0 indicated normal footpads, 1 indicated burnt footpads, 2 represented footpads with crust, and 3 indicated lesions on one or both feet. As shown in Table 6, broilers reared at lower stocking densities had lower average footpad dermatitis scores compared to those at higher densities. Birds in the low-density group predominantly exhibited burnt footpads, whereas those in the high-density group showed a combination of burnt footpads and footpads with crust.

The findings of this review indicate that footpad lesion scores tend to increase with higher stocking densities. This trend is consistent with the results observed for feather condition and is likely associated with increased litter moisture resulting from greater bird density. In addition to stocking density, the quality, quantity, and type of bedding play a critical role in the development of footpad lesions, as broilers spend the majority of their time in direct contact with the litter. Inappropriate bedding materials can therefore negatively affect broiler health and performance. Previous research has reported no significant differences in growth or health outcomes across various alternative bedding types, but has recommended mixing different materials to enhance bedding quality (Benabdeljelil and Ayachi, 1996). This recommendation aligns with the present findings, where broilers at lower stocking densities mostly exhibited mild symptoms, such as burnt footpads, while those at higher densities displayed more severe conditions, including footpads with crust. From a physiological perspective, footpad dermatitis arises when prolonged exposure to wet litter disrupts the stratum corneum, the outermost layer of the skin, compromising its barrier function and facilitating the penetration of irritants such as ammonia and pathogens. This leads to inflammatory responses, epithelial erosion, and in advanced cases, ulceration. Oxidative stress and immune dysregulation under chronic exposure may further exacerbate lesion severity, particularly in broilers genetically predisposed to rapid weight gain and reduced mobility (Shepherd and Fairchild, 2010). These observations reinforce the conclusion that both stocking density and bedding characteristics are key factors influencing the incidence of footpad dermatitis. Future studies should evaluate the interaction between bedding material properties such as absorbency, pH buffering capacity, and microbial load and skin histopathology in broilers under varying density conditions. Such research would support the development of targeted strategies for lesion prevention and welfare optimization.

Health performance–Mortality

Six of the reviewed studies reported data on broiler mortality rates. The average stocking densities were 12 birds/m² for the low-density group and 19 birds/m² for the high-density group. Reported mortality rates ranged from approximately 2% to as high as 15%, depending on study conditions. Overall, broilers reared at higher stocking densities exhibited greater mortality rates compared to those raised at lower densities (Table 7).

The findings of this review indicate that mortality rates were consistently higher in broilers reared at elevated stocking densities compared to those at lower densities. Gabanakgosi *et al.* (2014) reported that overcrowding can significantly contribute to increased mortality. Additionally, environmental stressors, even under moderate climatic conditions, may exacerbate mortality risks (Lolli *et al.* 2010; Beg *et al.* 2011). Factors such as poor air and litter quality, suppressed immune function, and reduced feed intake often associated with overcrowded environments have also been linked to higher mortality rates (Türkyilmaz, 2008). Based on the reviewed evidence, stocking densities above 19 birds/m² appear to pose a substantial risk to broiler survival. Dozier *et al.* (2006) further emphasized that as broilers grow, metabolic heat production increases, which may outpace their ability to dissipate heat under crowded conditions. This heat retention can result in hyperthermia, compromising cellular respiration and enzyme function, thereby triggering multi-organ dysfunction and death. Overcrowding also heightens psychological stress and aggressive behavior, which may lead to competition for feed and water, further reducing resilience to environmental challenges (Najafi *et al.* 2015). Future studies should examine the threshold at which thermoregulatory failure occurs in relation to body mass, ventilation efficiency, and housing type. Integrating physiological monitoring (e.g., core body temperature, blood gas profiles, and stress biomarkers) could enhance early detection of mortality risk under commercial conditions.

Table 6 Footpad dermatitis of broilers at different stocking densities

	Stocking density (birds/m^2)	Score (0-3)
LSD	13.0±1.87	1.00±1.22
HSD	18.0±3.44	1.50±1.19

LSD: low stocking density and HSD: high stocking density.

Table 7 Mortality rate of broilers at different stocking densities

	Stocking density (birds/m^2)	Mortality (%)
LSD	12.0±3.76	5.00±3.59
HSD	19.0±3.66	5.80±5.30

LSD: low stocking density and HSD: high stocking density.

Health performance–Hock lesion

Two studies included hock lesion assessment as part of their evaluations. The average stocking densities in these studies were 13 birds/m² for the low-density group and 18 birds/m² for the high-density group. A 4-point scoring system was employed, where 0 indicated normal hocks, 1 indicated burnt hocks, 2 represented hocks with crust, and 3 signified lesions on one or both feet. Of the two studies, only one reported a significant effect of stocking density on hock lesion severity. As shown in Table 8, broilers raised at lower stocking densities exhibited mostly normal to mildly burnt hocks, whereas those reared at higher densities more commonly showed signs of burnt hocks.

The findings on hock lesion scoring in this review are consistent with trends observed for footpad lesions and feather scores, suggesting that increased stocking density contributes to more severe integumentary conditions. Although one study reported no statistically significant effects of stocking density or bedding type on hock lesion scores, an overall increase in severity was still noted (Lima *et al.* 2011). The authors proposed that bedding material characteristics, particularly particle size and length, may influence lesion development. Longer bedding materials are more prone to compaction, which can limit proper mixing of excreta and increase direct contact between the birds' limbs and soiled litter. Similar findings were reported by Farhadi *et al.* (2016), who observed no significant differences in lesion incidence based on litter thickness or stocking density. However, their study suggested that prolonged exposure to wet litter remains a likely contributing factor to the development of hock lesions. Physiologically, sustained contact with moisture-rich litter leads to epidermal maceration, compromising skin barrier function and facilitating microbial invasion, inflammation, and localized necrosis of the hock tissue. These integumentary disruptions can impair locomotion and increase susceptibility to systemic infection. Prior research has also associated poor litter conditions with elevated levels of pro-inflammatory cytokines, which may exacerbate dermal inflammation and tissue breakdown (Shepherd and Fairchild, 2010). Further investigation is needed to explore the biochemical pathways underlying these lesions, including histopathological changes, inflammatory mediators, and microbial load within the litter environment. Identifying the threshold at which litter moisture triggers lesion development may offer actionable targets for improving broiler welfare.

Health performance–Gait score

Of the 14 articles reviewed, two studies included gait scoring in their evaluations. However, only one study provided detailed scoring data. In that study, the average stocking densities were 13 birds/m² for the low-density group and 18 birds/m² for the high-density group. Gait was assessed using a 6-point scale, where 0 indicated fluid locomotion, 1 unsteady movement, 2 a visible gait defect within 20 seconds, 3 birds that did not run and squatted within 15 seconds, 4 birds that remained squatting when approached, and 5 complete lameness. The study reported higher average gait scores in broilers raised at higher stocking densities. Nonetheless, the differences between groups were not statistically significant. Broilers in both density groups exhibited signs of unsteady movement and reluctance to walk (Table 9).

The present findings indicate that gait scores were relatively similar across both low and high stocking density groups. Two studies assessed gait performance and reported no statistically significant relationship between stocking density and bedding type (Dozier *et al.* 2006; Vargas-Galicia *et al.* 2017). Although Vargas-Galicia *et al.* (2017) observed improved gait scores at lower stocking densities, the differences were not statistically significant and were attributed to a lower incidence of footpad lesions. In contrast, Dozier *et al.* (2006) found no association between stocking density and gait performance. However, Sanotra *et al.* (2001) suggested that increased stocking density may impair walking ability, likely due to a higher incidence of lesions, limited space for movement, and rapid growth rates. Overcrowding can restrict locomotion and elevate excreta accumulation, thereby increasing litter moisture and the risk of foot and leg problems in broilers. Biomechanically, constrained movement in crowded pens can limit musculoskeletal development, resulting in joint misalignment and muscle imbalance that adversely affect gait. Additionally, prolonged exposure to wet litter can induce dermal inflammation, pain, and joint stiffness, which compromise motor coordination. Previous studies have also reported that heavier birds, especially under high stocking densities, exhibit abnormal walking patterns due to the strain placed on underdeveloped skeletal structures (Kapell *et al.* 2012). Future investigations should include kinematic gait analysis and muscle histopathology to better understand how structural and neuromuscular factors interact with environmental constraints. This would facilitate the identification of early biomarkers for locomotor deficits under commercial conditions.

Table 8 Hock lesion of broilers at different stocking densities

	Stocking density (birds/m^2)	Hock lesion score (0-3)
LSD	13.0±4.24	0.40±0.03
HSD	18.0±6.36	1.00±0.00

LSD: low stocking density and HSD: high stocking density.

Table 9 Gait score of broilers at different stocking densities

	Stocking density (birds/m^2)	Gait score (0-5)
LSD	13.0±0.00	1.00±0.00
HSD	18.0±0.00	1.10±0.00

LSD: low stocking density and HSD: high stocking density.

Health performance–H/L ratio

Eight studies included data on the heterophil-to-lymphocyte (H/L) ratio as a physiological indicator of stress. Among these, two studies reported no significant effect of stocking density on the H/L ratio. The lowest H/L ratio was observed in a study that used rice hulls as bedding material, with stocking densities ranging from 10 to 14 birds/m². On average, the stocking densities were 11 birds/m² for the low-density group and 18 birds/m² for the high-density group. As shown in Table 10, both groups exhibited similar average H/L ratios of approximately 0.9.

The H/L ratio is widely used as an indicator of physiological stress and immune status in poultry. Six of the selected studies emphasized the relevance of this parameter in relation to stocking density. In the present review, lower stocking densities were generally associated with reduced H/L ratios, suggesting a lower level of physiological stress. Several studies have reported that increased stocking densities are linked to elevated H/L ratios in broilers (Onbasilar *et al.* 2008; Simitzis *et al.* 2012; Astaneh *et al.* 2018). This trend is often attributed to overcrowding and the accompanying heat stress. For example, Simitzis *et al.* (2012) observed that broilers exposed to heat stress during the final ten days of the production cycle exhibited significantly higher H/L ratios. Increased bird numbers and accelerated weight gain may also contribute to this physiological response. However, some studies have found no significant relationship between stocking density and H/L ratio (Dozier *et al.* 2006; Sekeroglu *et al.* 2011). These inconsistencies may stem from differences in genetic strains, environmental conditions, and management practices across studies (Onbasilar *et al.* 2008). Physiologically, an elevated H/L ratio reflects a corticosterone-mediated shift in leukocyte profiles, with stress inducing lymphopenia and heterophilia through the hypothalamic–pituitary–adrenal (HPA) axis. Prolonged activation of this axis impairs immune function and increases susceptibility to infection. Broilers at high stocking densities may experience chronic stress that suppresses adaptive immunity, thereby compromising disease resistance and performance outcomes (Gholami *et al.* 2020; Kassim *et al.* 2023). Further research should explore the integration of H/L ratio data with plasma cytokine levels and oxidative stress markers to better understand the immunosuppressive effects of stocking-related stressors. Investigating breed-specific thresholds for stress resilience could also inform tailored management practices.

Health performance–Corticosterone levels

Only two studies assessed corticosterone levels as an indicator of physiological stress in broilers. Both studies reported no statistically significant effect of stocking density on corticosterone concentrations. However, broilers raised at an average stocking density of 11 birds/m² exhibited lower corticosterone levels compared to those reared at a higher density of 18 birds/m² (Table 11), suggesting a potential trend toward increased stress under crowded conditions.

Table 10 Gait score of broilers at different stocking densities

	Stocking density (birds/m^2)	H/L ratio
LSD	11.0±2.75	0.89±0.45
HSD	18.0±3.16	0.94±0.33

LSD: low stocking density and HSD: high stocking density.

Table 11 Gait score of broilers at different stocking densities

	Stocking density (birds/m^2)	Corticosterone levels (nmol/mL)
LSD	11.0±3.54	548±514
HSD	18.0±2.83	553±487

LSD: low stocking density and HSD: high stocking density.

The findings of this review suggest that broilers reared at higher stocking densities tend to exhibit increased corticosterone levels compared to those kept at lower densities. Although the two included studies (Dozier *et al.* 2006; Cai *et al.* 2019) did not report statistically significant differences, a trend toward elevated stress under crowded conditions was observed. Other studies have indicated that stocking density can influence corticosterone concentrations, particularly under suboptimal management or environmental conditions. For example, Najafi *et al.* (2015) found that different management systems significantly affected corticosterone levels, with more pronounced effects at higher ambient temperatures. High stocking densities in deep litter systems can limit effective heat dissipation from the litter surface to the ventilated space, increasing internal temperatures. Overcrowding may also intensify microbial activity, raising ammonia levels and contributing to the development of contact dermatitis and leg disorders, which in turn may heighten corticosterone secretion. Corticosterone, the primary glucocorticoid in avian species, plays a central role in the physiological stress response by modulating energy metabolism, suppressing immune function, and altering behavior. Chronic elevation of corticosterone due to sustained stress may impair feed efficiency, reduce disease resistance, and slow growth rates in broilers (Alghirani *et al.* 2023). These physiological disruptions underline the importance of maintaining optimal stocking densities to mitigate endocrine stress responses. Future studies should investigate longitudinal corticosterone fluctuations in relation to both microclimatic parameters and behavioral outcomes, such as aggression or social withdrawal, to better elucidate the mechanistic links between housing density and broiler welfare.

CONCLUSION

This systematic review demonstrates that stocking density plays a critical role in broiler health and welfare outcomes, with lower densities generally associated with reduced physiological stress, fewer lesions, and lower mortality rates. Despite some inconsistencies in specific indicators, such as gait scores or corticosterone levels, the overall evidence supports the implementation of moderate stocking densities to balance productivity and animal welfare. This review highlights the urgent need for context-specific, scientifically informed stocking density guidelines, particularly in regions lacking formal regulation. Future research should prioritize longitudinal, climate-sensitive studies that incorporate physiological and biochemical markers to identify optimal density thresholds for different production systems. Policymakers and producers alike are encouraged to consider stocking density not merely as a production variable, but as a critical determinant of ethical and sustainable poultry management.

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