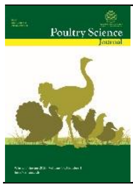

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How Stocking Density Affects Broiler Chicken Production Performance: A Comprehensive Review

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Abstract

To fulfill the substantial demand for broiler chickens from both local consumers and importers, it is imperative to determine the optimal stocking density to maximize production efficiency. A common concern among broiler farmers is the lack of studies evaluating the most suitable stocking densities for commercial practice to enhance broiler production performance. This review examines the impacts of different stocking densities on the production performance, carcass characteristics, and meat quality of broiler chickens. The review followed the PRISMA Statement to ensure a comprehensive approach. Scopus, Science Direct, and Google Scholar electronic databases were searched for literature published between 2012 and 2021 to capture a comprehensive and up-to-date decade of research, ensuring a robust dataset that reflects recent advancements, methodologies, and findings in the field. Generally, broilers raised in a closed-house system at a high stocking density (15 birds/m²) exhibited a better feed conversion ratio compared to those at a lower stocking density (10 birds/m²). However, broilers raised at lower stocking densities generally yielded heavier carcasses (including carcass weight, hot carcass weight, wing, thigh, ribcage, breast muscle, liver, and small intestine) compared to those at higher stocking densities. Nevertheless, stocking density did not have a significant impact on meat quality. In conclusion, this review suggests that a stocking density of 15 birds/m² is optimal for broilers in a closed-house system, considering both production efficiency and carcass yield.

Introduction

Poultry producers worldwide strive to optimize economic returns by maximizing the total weight of chickens produced per square meter of space while mitigating production losses due to overcrowding (Abudabos *et al.*, 2013). The exponential growth in the production and supply of broiler meat to consumers over the past decade can be attributed to advancements in genetic selection, dietary improvements, and strategic innovations (Chung *et al.*, 2020; 2021). Environmental stressors such as stocking density, temperature, and humidity significantly impact production efficiency for broilers (Gholami *et al.*, 2020a). Different countries adhere to government regulations regarding stocking density based on their production systems, such as closed-house and open-house systems. For example, in compliance with EU regulation 43/2077, common

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stocking densities range from 33–42 kg live weight/m² (typically in Europe) to 30 kg live weight/m² in warmer climates (Qaid *et al.,* 2016). However, many developing countries have yet to establish or officially certify specific stocking densities.

Due to its significant impact on broiler chicken growth rates, stocking density ranks among the most crucial environmental factors. According to Abudabos *et al.* (2013), broilers kept at low density (28 kg/m²) and medium density (37 kg/m²) exhibited higher body weight gain and feed intake compared to those at high density (40 kg/m²). Similarly, research by Kryeziu *et al.* (2018) showed that as stocking density per square meter increased, the final live weight decreased. The study concluded that high stocking density (44 kg/m²) might restrict mobility, leading to reduced feed intake and, ultimately, lower body weight at the end of the growth phase (42 days). In comparison, broilers raised at low (28 kg/m²) and medium (36 kg/m²) stocking densities had greater final live weights. Conversely, broilers raised at a high density of 40 kg/m² consumed feed more efficiently than those at a low density of 30 kg/m² (Madilindi *et al.*, 2018). However, research by Weimer e*t al.* (2020) reported that two stocking densities, 29 kg/m² and 27 kg/m², resulted in similar final body weights (2.68 kg) after 42 days. Discrepancies in results could largely be attributed to environmental factors and genotype variations.

On the other hand, Madilindi *et al.* (2018) found that dressing percentages and carcass part proportions, including breast, thigh, drumstick, neck, shank, liver, and gizzard, were significantly impacted by stocking density. Their research indicated that broilers raised at a medium stocking density of 35 kg/m² exhibited the highest dressing and breast percentages, whereas those raised at a high stocking density of 40 kg/m² showed the lowest. However, Tong *et al.* (2012) reported different findings, suggesting that various stocking densities (14.46 kg/m², 19.46 kg/m², and 24.23 kg/m² for low, medium, and high stocking density, respectively) had no discernible effect on carcass yield, eviscerated carcass weight, breast yield, or abdominal fat yield at 42 days. According to Tong *et al*. (2012), stocking density also did not influence water loss rate, shear force, or breast muscle color significantly, although pH values showed a slight increase with higher density.

Therefore, conducting a thorough review regarding different stocking densities can potentially benefit the production performance of broilers. Improving growth performance, carcass characteristics and meat quality, plays a significant role in the broiler market that will eventually lead to profit maximization of producers.

Materials and Methods

PRISMA statement

The study approach was guided by the PRISMA Statement (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). The literature search utilized electronic databases, including Scopus, Science Direct, and Google Scholar.

Inclusion criteria

One of the primary inclusion criteria involves that the broilers studied must undergo complete production, commencing from the starter phase and continuing through the finisher phase, wherein day-old chicks are obtained and reared until they are harvested. Additionally, selected articles must describe both varying stocking densities and production performances throughout the conducted study. Failure to include either stocking density or production performances in a journal will result in exclusion. Moreover, broilers must be raised in a deep litter system, with those reared in battery cages or free-range systems being excluded, as these practices are not commonly employed in commercial setups. Table 1 illustrates the search terms employed in the journal selection process for the review.

Table 1: The search terms used in the review of stocking densities and the production performances of broiler chickens

Stocking density terms	Production terms
Flock density	Growth performance
Floor space	Carcass characteristics
Rearing density	Carcass yield
Stocking density	Carcass characteristic
	Meat quality
	Production performance

Literature search and extracted information

The literature searches conducted in Scopus, Science Direct, and Google Scholar for research published over the past decade revealed a total of 236 articles spanning from 2012 to 2021. From these, 115 articles were selected based on their titles and abstracts. Subsequently, the remaining 115 publications that met all the inclusion criteria underwent full-text assessment. For each publication, the following details were documented: (1) the country or region of the study; (2) the management system employed (e.g., open-sided, closed-house); (3) the type of bedding material utilized; (4) the stocking density; (5) the types of growth performance parameters measured, such as feed intake, total feed intake, feed conversion ratio, and total weight gain; (6) the carcass characteristics assessed; and (7) the determination of meat quality (Figure 1).

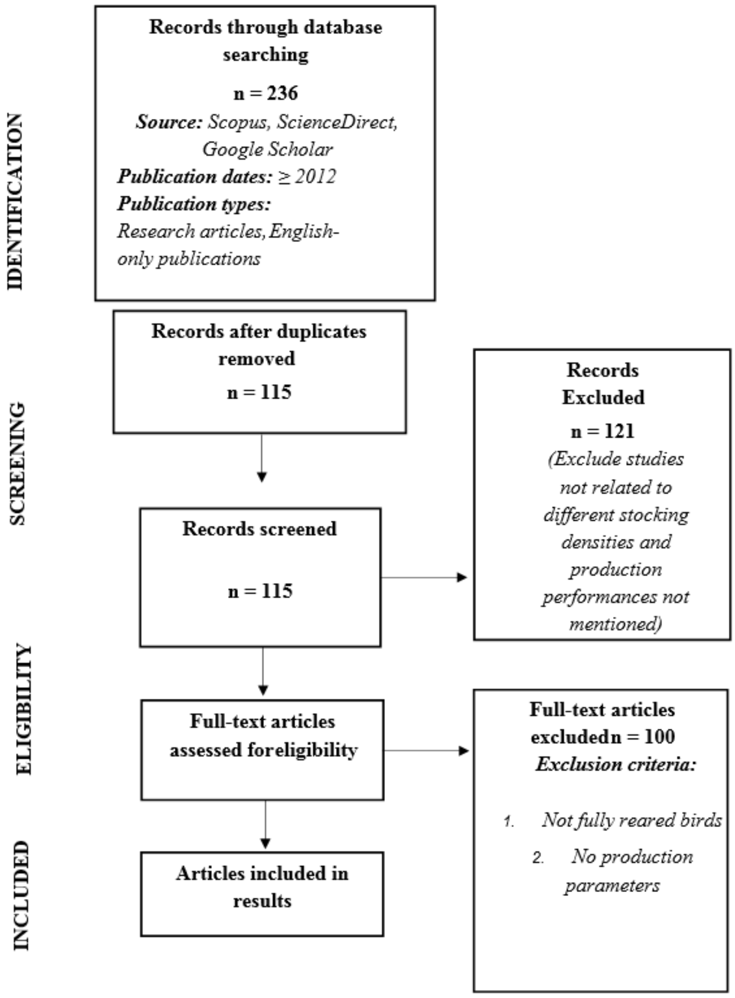

Figure 1. Steps of record inclusion and exclusion of journals based on the PRISMA statement.

Results and Discussion

Region of study

In general, the majority of research investigating the effects of stocking density was conducted in the United States of America (6 out of 15 studies), followed by the Middle East (4), Europe (2), and Africa (2), with the least number originating from an Asian country (1) (Figure 2).

According to the Food and Agriculture Organization (FAO, 2020), the United States is the world's leading producer of poultry meat, contributing to 17% of global production, followed closely by China and Brazil. This upward trajectory in poultry production is anticipated to continue in the future, elucidating the prevalence of research on stocking densities and production performances primarily conducted in the US compared to other nations. The lack of research conducted in Asia may be attributed to the limited availability of studies within the Scopus search engine, particularly concerning stocking density and production efficiency. Nonetheless, it is noteworthy that China commands a significant presence in the Asian market and remains among the top five broiler meat producers globally.

Management system

Two types of management systems were employed in the studies: closed-house system and open-house system. Out of the 15 selected studies, 11 were conducted in a closed-house system where the microclimate was controlled. On the other hand, the open-house system, which relies on natural ventilation, was represented in 4 out of the 15 studies. In the United States, both open and closed-house systems were practiced, with a majority opting for the closed-house system compared to other regions. Similarly, in Europe, both management systems were utilized, with an equal number of studies conducted in each. Among the selected journals, studies from the Middle East and Asia were exclusively conducted in a closed-house system, while those from Africa solely utilized an open-house system (Figure 3).

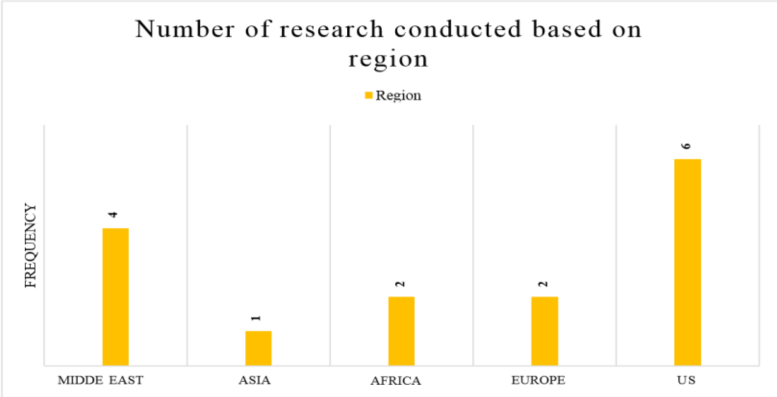

Figure 2. The number of studies conducted investigating the effect of stocking density and production performances of broiler chicken based on region.

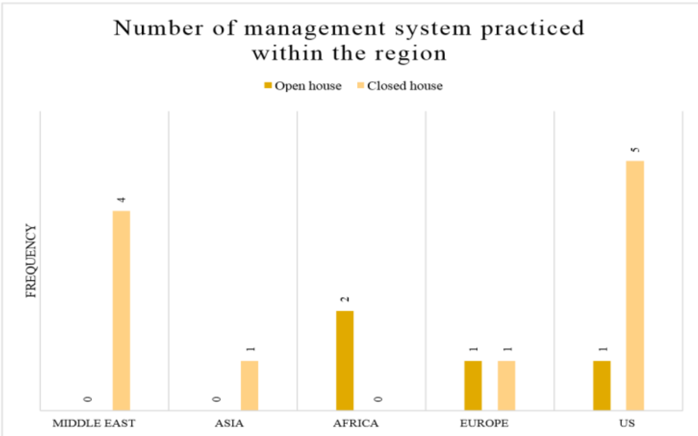

Figure 3. The number of management systems practiced in different regions.

The widespread adoption of closed-house systems in modern poultry farming is primarily attributed to the utilization of tunnel ventilation mechanisms. This technology enables precise control over the microclimate within the house, regulating factors such as air velocity, temperature, lighting, relative humidity, and chemical levels such as ammonia and carbon dioxide (Jaradat *et al.*, 2022). Consequently, more broilers can be housed per square meter without compromising production efficiency. For instance, research conducted by Gillespie *et al.* (2017) demonstrated that evaporative cooling provides a significant cooling effect for broilers, reducing their energy expenditure to maintain comfortable temperatures, particularly during hot summer days, thus leading to a notable decrease in mortality rates. Therefore, the integration of tunnel ventilation with evaporative cooling facilitates efficient cooling of the house, creating a conducive environment for broilers. Several studies have shown that tunnel-ventilated houses with evaporative cooling cells maintain lower average temperatures during hot weather compared to conventional houses (Wheeler *et al.*, 2006; Xin *et al.*, 2009). On the contrary, in Africa, characterized by tropical climates, open-sided housing systems with natural ventilation were the predominant practice observed in this review. Lima *et al.* (2011) highlighted the absence of a universally accepted housing system for broiler farmers in developing and tropical regions as farmers strive to balance financial considerations, animal welfare, and long-term productivity. In line with Gillespie *et al.* (2017), the majority of newly constructed broiler houses feature advanced technology, incorporating tunnel ventilation and evaporative cooling. In many cases, such housing systems are stipulated as the standard in contracts, while older facilities are sometimes converted into closed-house systems to enhance production efficiency.

Bedding material

From the 15 journals selected, there were 7 types of bedding materials used throughout the rearing period of broiler production (Figure 4). Most of the studies used wood shavings as the bedding materials (52.9% of total type of bedding) followed by rice hull and sawdust, which each of them represented 11.8% (equal). In contrast, other bedding materials such as coconut husk, fresh straw, rice straw, and volcanic rock (Tezontle) were mentioned once in those selected studies. Moreover, Figure 5 illustrates the thickness of litter used in the study according to bedding type. Wood shavings were used by the majority of the studies, with an average thickness of 9 cm, followed by rice hull with an average thickness of 6 cm. The sawdust bedding thickness was not stated in the two studies selected. As for coconut hull, only one study used the bedding material with 10 cm of thickness. In addition, fresh straw, rice straw and volcanic rock were applied with the thickness of 5 cm, 5 cm, and 3 cm, respectively.

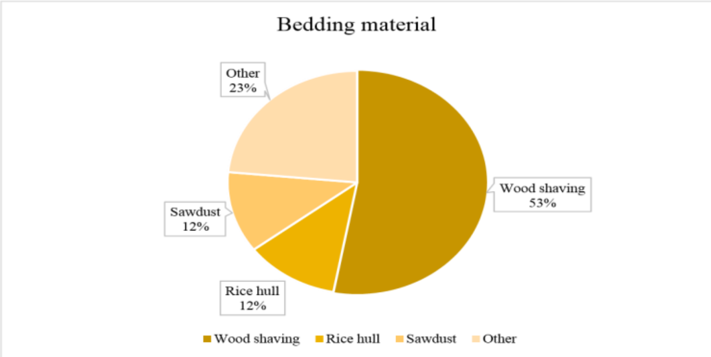

Figure 4. Different types of bedding materials in different studies. Note: Other categories mentioned in the pie chart above represent coconut husk, fresh straw, rice straw and volcanic rock, which were mentioned once in the study.

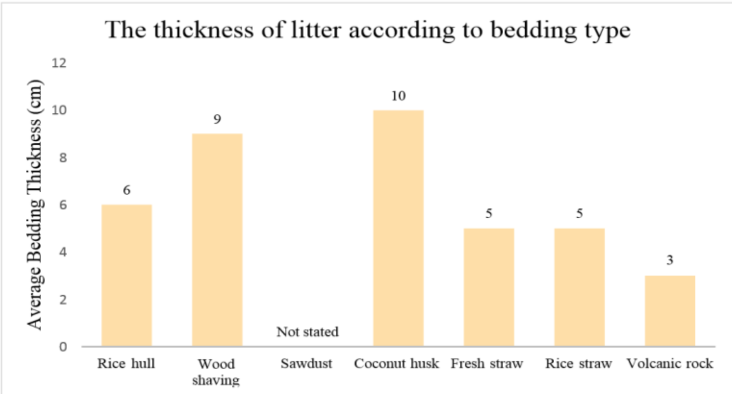

Figure 5. The thickness of litter used in the study according to bedding type.

The choice of bedding material varies among countries, influenced by factors such as price and availability. Wood shavings have emerged as the preferred bedding option for poultry, owing to their widespread use and desirable properties. These include their capacity to absorb moisture and provide thermal comfort to birds (Garcia *et al.*, 2012; Lima *et al.*, 2018; Costa *et al.*, 2021), making them a popular choice globally. This observation is consistent with the current findings, where wood shavings were the predominant bedding material in broiler production. In France, approximately 80% of poultry production utilizes wood shavings, while in Brazil, wood shavings and sawdust are commonly used, alongside regional alternatives like rice husks (Purswell *et al.*, 2020). However, the search for alternative materials has intensified due to challenges such as insufficient supply, high costs, and competing demands for wood shavings in value-added products. Consequently, recent studies have explored alternative sources for broiler litter, including coconut hulls, palm residues, sepiolite-added paper waste sludge, switchgrass hay, maize cobs, chopped palm leaves, cellulose-based industrial wastewater, and Tezontle volcanic rock (Huang *et al.,* 2009; Ritz *et al.,* 2016; Vargas-Galicia *et al.*, 2017; Oke*et al.*, 2019; Purswell *et al.*, 2020). Conversely, the role of litter depth in broiler production is often overlooked, as few studies have focused primarily on this parameter (Shepherd *et al.*, 2017). This limited attention may stem from the prevailing perception that bedding thickness has minimal impact on broiler production performance (Monira *et al.*, 2003; Hossain *et al.*, 2018). Typically, the average litter depth for wood shavings, rice hulls, and straw in various experiments ranges from 5 cm to 10 cm (Lima *et al.*, 2018; Pekel *et al.*, 2020). However, Shao *et al.* (2015) demonstrated that increasing the thickness of sawdust-based bedding from 4 to 16 cm enhanced broiler welfare and production. This finding aligns with Shepherd *et al.* (2017) results, indicating that broilers raised on thicker bedding outperformed those on thinner bedding (2.5, 7.6, and 12.7 cm). Some studies have also suggested that increasing stocking density necessitates proportional increases in litter depth, which can impact bird performance, welfare, and litter quality (Petek *et al.,* 2010; Shao *et al.,* 2015; Diarra *et al.,* 2021).

Stocking Density

Table 2 presents the numbers and percentages of studies that used different stocking densities, ranging from 6 bird/m² to 20 birds/m². Among the 13 levels of stocking densities observed in previous studies, 10 birds/m² emerged as the most common stocking density, with 7 studies adopting this level. Following this, stocking densities of 12, 13, 14, 18, and 16 birds/m² were implemented in 6, 5, 5, 4, and 3 studies, respectively. Additionally, only 2 studies each practiced stocking densities of 15 and 20 birds/m². Stocking densities of 6, 7, 8, 9, and 11 birds/m² were each mentioned once. Transitioning to Table 3, displays the stocking densities employed in both open-house and closed-house systems. The mean for low stocking density (LSD) and high stocking density (HSD) is calculated by choosing the lowest and highest stocking density practiced in each of the 15 selected articles. Overall, the mean stocking densities for LSD and HSD across various studies were 10 birds/m² and 16 birds/m², respectively. Specifically, for closed-house systems, the mean stocking densities were 10 birds/m² for LSD and 15 birds/m² for HSD. In contrast, for open-house systems, the mean stocking densities were 11 birds/m² for LSD and 18 birds/m² for HSD.

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

Stocking Density (bird/m²)	Number of studies (n)	Percentage (%)
6	1	2.56
7	1	2.56
8	1	2.56
9	1	2.56
10	7	17.95
11	1	2.56
12	6	15.39
13	5	12.82
14	5	12.82
15	2	5.13
16	3	7.70
18	4	10.26
20	2	5.13

Table 3: Mean stocking density practiced in both open and closed-house systems

Management system	LSD (bird/m²)	HSD (bird/m²)
Overall	10 ± 2.06	16 ± 2.64
Closed-house	10 ± 1.73	15 ± 2.56
Open-house	11 ± 2.80	18 ± 2.40

All values are expressed as mean ± SD. LSD: low stocking density; HSD: high stocking density.

A recent study by Gholami *et al.* (2020a) concluded that there is a significant association between climate (environment) and stocking density. According to the findings of this systematic review, the stocking density of broilers in both closed-house and open-house systems range from 6 birds/m² to 20 birds/m², with an average of 10 birds/m² for LSD and 16 birds/m² for HSD. Interestingly, the mean stocking densities for LSD and HSD in open-house systems are slightly higher than those in closed-house systems. Estevez (2007) concurs with this observation, highlighting that establishing stocking density limits based on scientific evidence is not as straightforward as it may seem, owing to various factors such as differing criteria used to assess health and well-being. Furthermore, the determination of appropriate stocking density limits is complicated by the scarcity of scientific research or significant disparities between experimental findings and real-world commercial conditions (Estevez, 2007). For example, various regulations and industry standards have been established, each with its own set of stocking density guidelines.

The Welfare of Farmed Animals (England) (Amended) Regulations 2010, which Wales and Scotland have adopted, specify a maximum stocking density of 39 kg/m², equivalent to 20 birds/m². In contrast, Red Tractor, the industry standard, recommends a stocking density of 38 kg/m², equivalent to 19 birds/m². Meanwhile, RSPCA Freedom Food advocates for a stocking density of 30 kg/m², equal to 15 birds/m², with an intermediate growth rate for broilers. Additionally, the European Union established acceptable stocking density ranges in 2007 (Council Directive 2007/43/EC), with a standard stocking density of 33 kg/m², equivalent to 17 birds/m², as a baseline. However, under certain conditions, such as maintaining low mortality rates and monitoring production climatic conditions, this limit can be increased to 39 kg/m² (20 birds/m²). Additional stocking density increments, extending to 42 kg/m² (equivalent to 21 birds/m²), may be considered permissible pending verification by monitoring bodies of minimal mortality rates and compliance with effective management protocols. In addition to the collected data, it is noteworthy that the majority of experiments utilized a stocking density of

10 birds/m². This finding may suggest that this density represents a minimum standard required to achieve satisfactory economic returns. This assertion is supported by the research of Lallo *et al.* (2012), who investigated bird performance based on parameters such as Minimum Viable Product (MVP) and Minimum Marketable Product (MPP) in Trinidad. Their findings indicated that broiler production at a stocking density of 10 birds/m² in conventional open-sided, naturally ventilated housing can be successfully achieved when birds are harvested at 42 days. Deviating from this stocking density may result in insufficient production efficiency and profitability. Poultry farmers worldwide endeavor to maximize the kilograms of chicken produced per square meter of the area while mitigating production losses associated with overcrowding (Abudabos *et al.,* 2013).

Production performance – Growth performance

Table 4 shows the average growth performance parameters for different management systems practicing both low and high stocking densities. The performance indicators include total feed intake (TFI), total body weight gain (TBWG), and feed conversion ratio (FCR), which were extracted from all 15 selected journals. In the closed-house system, the mean TFI and TBWG for LSD were higher than those for HSD. However, the FCR for HSD was better than that for LSD, with values of 1.91 and 1.93, respectively. A similar trend was observed in the open- house system, where the TFI and TBWG for LSD were higher than for HSD, but the FCR for HSD was better than for LSD, with values of 1.94 and 2.03, respectively. Comparatively, broilers reared at HSD in closed-house systems exhibited a better FCR than those in open-house systems.

Table 4: Average growth performance variables in different management systems practicing both low and high stocking densities

Management system	LSD (10 bird/m²)			HSD (16 bird/m²)		
	TFI (kg/bird)	TBWG (kg/bird)	FCR	TFI (kg/bird)	TBWG (kg/bird)	FCR
Closed- house	4.71 ± 0.59	2.49 ± 0.39	1.93 ± 0.40	4.44 ± 0.52	2.37 ± 0.39	1.91 ± 0.40
Open-house	5.44 ± 0.98	2.66 ± 0.27	2.03 ± 0.20	4.92 ± 0.99	2.51 ± 0.21	1.94 ± 0.20

All values are expressed as mean ± SD. LSD: low stocking density ;HSD: high stocking density; TFI: total feed intake; TBWG: total weight gain; FCR: feed conversion rate.

To lower metabolic heat production and maintain homoeothermic, broiler birds react to excessive heat by limiting their dietary intake, which leads to poor final body weight and feed efficiency (Gholami *et al.*, 2020a; Alghirani *et al.*, 2023). Research by Sevim *et al.* (2021) found that HSD reduced TBWG and FI in broiler chickens throughout the feeding trial, although FCR remained unaffected. This finding aligns with an earlier study by Simitzis *et al.* (2012), which observed that broilers reared at a density of 13 birds/m² had lower TBWG and daily FI compared to those reared at a density of 6 birds/m². However, the cumulative FCR did not show significant variations between the two densities.

It was concluded that HSD impacts broiler chicken health, performance, and product quality due to various factors, including restricted availability of water and feed due to competition, as well as poor air and litter quality (Cengiz *et al.*, 2015). Moreover, energy derived from food digestion within LSD environments is channeled more efficiently into meat yield, resulting in enhanced body mass enhancement. This relationship is directly linked to nutrient accessibility, as highlighted by Estevez (2007) and Lima *et al.* (2018). However, the current review revealed a contrary result where broilers reared at HSD demonstrated a better FCR than those at LSD, with values of 1.91 and 1.93, respectively. This finding aligns with Lima *et al.* (2018), who reported that broilers grown at a density of 13 birds/m² had a better FCR than those raised at a density of 10 birds/m². The improved FCR in HSD conditions can be attributed to reduced mobility due to increased density, causing the energy that would have been expended on locomotion to be diverted towards weight gain, thereby not adversely affecting FCR (Costa *et al.,* 2021). Although the lower FCR for chickens raised in HSD could be attributed to reduced FI, the increased stocking density may also create an unfavorable microenvironment due to decreased airflow and heightened heat production by the birds themselves (Costa *et al.*, 2021). To lower metabolic heat production and maintain homoeothermic, broilers react to excessive heat by reducing their dietary intake, which leads to poorer final body weight, FCR, and breast meat yield (Gholami *et al.*, 2020b). Benyi *et al.* (2015) suggested that efficient cooling systems in broiler houses could mitigate this problem. However, such facilities are often financially out of reach for many farmers in developing countries. Additionally, the presence of efficient cooling systems in broiler houses can effectively prevent or reduce heat stress (Beg *et al.,* 2011). These findings align with the current review, which illustrated that broilers in closed-house systems had better FCR compared to those in open-houses due to the superior efficiency of closed systems in controlling microclimate conditions.

Production performance – Carcass characteristics

From the 15 journals selected, there were 16 different measurements taken to assess carcass characteristics, specifically according to weight. Table 5 depicts the carcass characteristics classified by two stocking density categories. Overall, all carcass characteristics parameters for LSD were heavier compared to HSD. However, the leg quarter, abdominal fat, heart, and gizzard weights were lower in LSD broilers than in HSD broilers. Meanwhile, there was no difference in spleen weight between the two stocking densities.

Table 5: Carcass characteristics in both low and high stocking densities

Carcass characteristics	LSD (10 bird/m²)	HSD (16 bird/m²)
Carcass weight(kg)	2.21 ± 0.38	2.09 ± 0.34
Hot carcass(kg)	2.00 ± 0.16	1.51 ± 0.35
Leg quarter(g)	27.82 ± 4.56	27.98 ± 3.58
Wing(g)	7.52 ± 1.05	6.87 ± 2.04
Thigh (g)	12.68 ± 5.48	10.61 ± 5.46
Drumstick(g)	10.48 ± 4.77	11.25 ± 5.37
Ribcage(g)	432 ± 0.00	421 ± 0.00
Neck(g)	4.70 ± 0.00	5.40 ± 0.00
Abdominal fat(g)	1.87 ± 6.53	1.97 ± 5.67
Breast muscle(g)	29.00 ± 5.00	27.72 ± 5.86
Heart(g)	0.44 ± 0.07	0.50 ± 0.12
Liver(g)	1.92 ± 0.28	1.91 ± 0.24
Crop(g)	0.36 ± 0.00	0.36 ± 0.00
Gizzard(g)	1.21 ± 0.84	1.39 ± 0.18
Spleen(g)	0.12 ± 0.02	0.12 ± 0.02
Small intestine (g)	1.81 ± 0.34	1.80 ± 0.30

All values are expressed as mean ± SD. LSD: low stocking density; HSD: high stocking density.

Consumer demand for healthy meat products that require less cooking time is increasing. As a result, boneless-skinless chicken breast meat is becoming increasingly popular (Napolitano *et al.,* 2013). Škrbić *et al.* (2011) showed that chickens raised at a lower stocking density exhibited greater breast production. They highlighted that maintaining a lower density could lead to improved body growth, carcass yield, and breast muscle development. Madilindi *et al*. (2018) similarly discovered that lower to intermediate stocking densities (30 and 35 kg BW/m², corresponding to 15 and 18 birds/m², respectively) led to notable increased percentages of carcass. In contrast, a higher stocking density (40 kg BW/m², or 20 birds/m²) was associated with a notable decrease of carcass characteristics, breast, thigh, drumstick, and shank. These findings concur with the data in the current review, which showed that the majority of carcass characteristics measured were better in LSD conditions compared to HSD. On the other hand, some carcass parts such as the leg quarter, abdominal fat, heart, and gizzard were found to be heavier in broilers raised at HSD compared to LSD, probably due to faster feed intake. (Madilindi *et al.*, 2018). Consequently, the gizzard becomes larger or develops faster to grind larger amounts of grain in a shorter period. Avcılar *et al.* (2019) found that high stocking densities lead to a larger percentage of broiler hearts due to increased respiration rates caused by excessive litter. Additionally, the decreased mobility of broilers at high stocking densities contributes to increased abdominal fat (Beg *et al.*, 2011). Nevertheless, Sevim *et al.* (2021) stated that broiler chicken carcass, breast, and thigh yields were unaffected by HSD. Similarly, other studies have found that HSD did not affect broiler chicken carcass, breast, or thigh yields (Vargas-Rodriguez *et al.*, 2013; Adeyemo *et al.*, 2016). Supporting this, Simitzis *et al.* (2012) used stocking densities of 12.6 and 27.2 kg/m² (6 birds/m² and 14 birds/m² respectively), while Tong *et al.* (2012) used stocking densities of 14 and 24 kg/m² (7 birds/m² and 12 birds/m² respectively), and observed no difference in carcass yield, although there was a decrease in BWG and FI with higher stocking density levels. The differences in outcomes between trials could be attributed to variations in genotypes, sex, housing conditions, management practices, diet nutrient composition, and stocking density levels.

Production performance – Meat quality

From the 15 journals selected, only four papers reported on meat quality parameters. In these studies, the most commonly measured parameters were pH, color, water-holding capacity, cooking loss, and shear force. Table 6 represents meat quality based on two classes of stocking densities. Generally, the pH, color lightness, color redness, color yellowness, water-holding capacity, and shear force of meat from LSD were slightly greater than those from HSD. However, there was no difference in cooking loss between LSD and HSD broilers.

Meat quality is significantly impacted by stress experienced during the pre-slaughter and slaughter phases, leading to lactic acid build-up in the muscles and a consequent decrease in meat pH. Mir *et al*. (2017) indicated that broiler breast meat with a higher pH possesses greater water-binding capacity compared to meat with a lower pH. Pre-slaughter stress might reduce muscle pH, thereby influencing the meat's water-holding capacity and overall quality. This review found that broilers raised at LSD exhibited slightly better pH, color, water-holding capacity, and shear force of meat compared to those raised at HSD. This difference could be attributed to lower stress levels in LSD conditions, leading to a higher ultimate pH and thus, superior water-holding capacity (WHC) (Berri *et al.*, 2007; Schmidt *et al.*, 2009).

Table 6: Meat quality in both low and high stocking densities

Carcass characteristics	LSD (10 bird/m²)	HSD (16 bird/m²)
pH	5.95 ± 0.16	5.94 ± 0.21
Color		
L*(lightness)	58.41 ± 2.81	58.08 ± 3.70
a*(redness)	5.73 ± 4.00	5.53 ± 4.00
b*(yellowness)	11.83 ± 4.01	11.44 ± 3.78
Water holding capacity (%)	9.91 ± 4.57	9.59 ± 5.03
Cooking loss(%)	24.76 ± 5.55	24.76 ± 6.39
Shear force (kilograms-force)	1.09 ± 0.42	1.11 ± 0.32

All values are expressed as mean ± SD. LSD: low stocking density; HSD: high stocking density.

A low pH in the muscle induces more protein denaturation, causing greater damage to the muscle fibers and impairing their ability to retain water and preserve texture, which was observed in HSD conditions (Mir *et al.*, 2017). Additionally, meat with a higher level of protein denaturation transmits less light through the muscle surface, resulting in a pale appearance that may reduce consumer preference and acceptability (Fletcher *et al.*, 1999; Chung *et al.*, 2021). Contrary to the findings of the current review, Simitzis *et al.* (2012) reported that two levels of stocking density (6 birds/m² and 13 birds/m²) showed no significant differences in breast pH, breast and thigh color characteristics, cooking loss, and shear values. This observation was consistent with other studies where no significant influences were found between stocking density and cooking loss or water-holding capacity, except for an interaction between amino acid density and stocking density on cooking loss at 48 hours post-mortem (Pekel *et al.*, 2020). Additionally, stocking density did not affect the color of breast meat (L*=lightness, a*=red, b*=yellow), pH, meat temperature, weight loss during thawing or cooking, or shear force of meat from 42-day-old broilers (Costa *et al.*, 2021). Furthermore, Nasr *et al.* (2021) reported that the results of cooking loss and drip loss percentage were consistent with those of Moreira *et al.* (2004), who found that broilers maintained at densities of 10 to 16 birds/m² had no effect on the meat quality of Ross 308, Cobb 500, and Hybro PG commercial strains. Generally, various factors such as nutrition (including dietary energy, protein levels, and fatty acid profile), management systems, slaughter age, health status, environment, vaccination, carcass temperature, genetic diversity, and pre-slaughter practices are known to influence meat quality (Mir *et al.*, 2017; Alghirani *et al.*, 2022). Therefore, the variations in these factors could explain why different research studies yield different outcomes.

Conclusion

The present systematic review assessed data from broiler chickens raised at different stocking densities to analyze the effects on production performance. The findings indicate that broilers raised in a closed-house system at HSD had better FCR compared to those at LSD. However, there was a positive relationship between LSD and both carcass characteristics and meat quality. Specifically, broilers grown at LSD exhibited heavier carcass characteristics due to their greater final body weight. Additionally, the meat quality of broilers at LSD was slightly superior. Therefore, the review concludes that while an HSD of 15 birds/m² is optimal for FCR in a closed-house system, an LSD of 10 birds/m² may be preferable from the perspective of carcass characteristics and meat quality. Given that the analyzed studies were conducted under experimental conditions, the recommended stocking density may differ when applied to current industry conditions due to various variables, including nutrition, management, veterinary practices, and microclimate. Thus, further studies are needed to determine the efficiency and sustainability of these practices for local farmers and producers, particularly in hot and humid conditions.

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Declaration of competing interests

The authors declare no conflict of interest.

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