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Impact of Stocking Density on Welfare and Performance of Ross 708 and Cobb 700 Broilers

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Abstract: Stocking density (SD) may affect broiler productivity and welfare. This study investigated the performance and welfare of Ross 708 and Cobb 700 broilers as affected by four SDs (27, 29, 32, and 44 kg/m^2) until day 56. A total of 432 birds per strain were used, with 10, 12, 14, and 18 birds per pen (1.1 m × 1.5 m), corresponding to the respective SDs. Each SD treatment comprised eight replicates. The target SD was determined based on the projected market weight of 4 kg at 56 days of age. The average body weight (BW), feed intake, and feed conversion ratio (FCR) were measured biweekly. Welfare indicators (four broilers per pen), including gait score, feather cleanliness, feather coverage, body temperature, and footpad condition, were evaluated on days 28 and 56. Tibia strength (two broilers per pen) was measured on day 56. The results show that the BW and FCR of both broiler strains were not affected by SD. For both strains, the male broilers exhibited greater bone strength compared to that of the female broilers (129.06 lbf M vs. 91.70 lbf F for Ross, and 130.86 lbf M vs. 117.40 lbf F for Cobb), but the influence of SD on bone strength was found to be significant only for the Ross male broilers. Most welfare indicators were not affected by the SD on days 28 and 56 for either broiler strain, except for feather cleanliness in Ross broilers and footpad in Cobb broilers on day 56, which improved at lower SDs. Strong age and sex effects on the welfare indicators were also identified for both broiler strains. It was concluded that the SD is not a significant factor for broiler productivity, and it has a minor influence on broiler welfare compared to those of age and sex.

Keywords: broiler; stocking density; production performance; welfare

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1. Introduction

The broiler industry is crucial in meeting the protein needs of the U.S. In 2022, per capita consumption of broiler products in the United States reached 44.1 kg, nearly double the consumption of beef or pork [1]. To meet this high demand, 20.6 billion kg of live broilers were produced in 2022, with a total market value exceeding USD 66 billion [1]. Additionally, the broiler industry significantly contributed to the U.S. economy, generating over 1.5 million jobs and adding USD 417 billion in economic impact [2].

The broiler industry has made significant reductions in the environmental footprint [3] through improvements in productivity and efficiency over the years [4], providing a vital source of affordable yet high-quality animal protein. Modern commercial broiler strains achieve nearly four times the body weight (BW) at day 56 compared to strains from six decades ago, along with a significant 40% improvement in feed conversion ratio (FCR) [5]. However, rapid growth rates and intensive commercial production systems have raised growing public concerns regarding animal welfare [6,7].

Animal welfare is guided by the "five freedoms" [8], which Mellor [9] later refined to include good nutrition, a healthy environment, good health, appropriate behavior, and a positive mental experience. Fast growth and efficiency-oriented feeding and management procedures have led to welfare issues in modern broilers [10]. Welfare issues in broilers are multifaceted, including lameness, footpad dermatitis, metabolic disorders [10], poor environmental conditions [11], etc. Some major welfare concerns are related to stocking density (SD). The SD may affect the litter and air quality, which are major welfare, environmental, and management concerns at commercial broiler farms. High SD can restrict normal behavior in birds and lead to increased moisture in litter due to higher manure production per unit area. High moisture in the litter may foster microbial growth and increase ammonia levels in broiler houses [12], consequently posing the risk of contact footpad dermatitis. Furthermore, high SD restricts heat transfer from the litter to the surrounding space, reducing the effectiveness of ventilation systems in managing heat stress [10].

The current recommended SD in the U.S. varies. The National Chicken Council (NCC) Broiler Welfare Guidelines, widely recognized as the standard for broiler welfare in the U.S. [13], suggest a range of 32 to 44 kg/m^2. This range is based on the birds' final market weight and takes into account the space needed for broilers to express normal behaviors [14]. In comparison, animal welfare programs like the Global Animal Partnership (GAP) recommended lower SDs, from 27 to 29 kg/m^2, to accommodate natural bird behaviors. According to Mckenna [15], only 600 farms (2.4%) out of 25,000 in the U.S. [16] have adopted the GAP SDs for broiler production. The low adoption rate is possibly a result of high production costs. In addition, a lower SD may also be associated with an increase in land use and a larger environmental footprint [17]. Although a lower SD has the potential to enhance welfare, it is essential to balance sustainable production, land use, environmental impact, and animal welfare.

The market share of commercial broilers is mainly dominated by the Ross and Cobb strains in the United States [18]. The production responses of these two strains to SD are different. For Ross broilers raised to approximately 42 days of age, an SD of 13–15 birds/m^2 (equivalent to 32.5–37.5 kg/m^2, based on an average weight of 2.5 kg at 42 days) was recommended for achieving higher BWs [19–21] and a lower FCR [22–24]. In comparison, a density of 10 birds/m^2 (28.5 kg/m^2, calculated based on an average weight of 2.85 kg at 42 days) for raising Cobb broilers is suggested for maximizing BW [25–27]. However, an SD of 17 birds/m^2 for Cobb broilers provided the best economic return of USD 3.98/m^2, despite a slightly lower BW and FCR [27]. Currently, there is a lack of research comparing the NCC- and GAP-recommended SDs under similar production conditions. As such, investigating the impacts of NCC- and GAP-recommended SDs on major broiler strains under similar production conditions is warranted.

The objective of this study was to evaluate the performance and welfare of Ross 708 and Cobb 700 broilers under different SDs. Precision livestock farming (PLF) technologies were utilized for an objective assessment of feather coverage through temperature analysis.

2. Materials and Methods

2.1. Birds, Diets, and Management

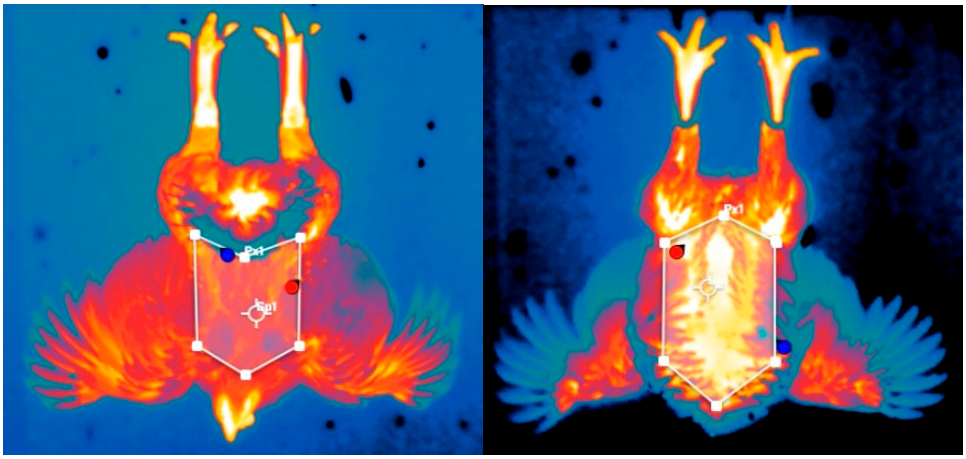
A total of 432 one-day-old broilers from each strain (obtained from a local commercial hatchery) were raised under four SDs. The initial weight of the Ross 708 birds was about 38 g, and that of the Cobb 700 birds was about 36 g. Identical pens (1.1 m × 1.5 m) were stocked with 10, 12, 14, or 18 birds, and each SD treatment had eight replicate pens. The target SD was determined based on the projected market weight of 4 kg at 56 days of age. Due to the limited size of the experimental room, we conducted the trial with Ross 708 broilers in September-October 2022 and the trial with Cobb 700 broilers in January-February 2023. Each pen was equipped with one 36 cm diameter tube feeder and three nipple drinkers. The feeder space and the number of drinkers were sufficient for all treatments, based on the NCC recommendation [14]. The broilers were feather-sexed (for Ross birds) or vent-sexed (for Cobb birds) and distributed evenly in experimental pens

at a 1:1 male-to-female ratio. Environment management, including light intensity and temperature, in the experimental room was adjusted according to the Ross 708 [28] and the Cobb 700 [29] broiler management guidelines by bird age. At the study's commencement, each pen was bedded with topsoil (Farmer Green topsoil, 0.14 cubic feet per pen) and covered with black mulch (Earthgro black wood shredded mulch, 0.04 cubic feet per pen), which remained unchanged throughout the study period. Every two weeks, the total weight of all birds in each experimental pen was determined. Feed intake was also measured biweekly to calculate the FCR (feed intake/body weight gain). The empty feed bucket was weighed initially. Feed was added daily, and the amount provided was recorded. Every two weeks, the bucket, with any remaining feed, was weighed, and the total feed intake for the pen over that period was calculated by subtracting the final feed weight from the total weight of the feed added during the two weeks. The broilers were raised over a 56-day production cycle.

2.2. Welfare and Behavior Measurement

Broiler welfare was assessed manually based on feather cleanliness, footpad dermatitis, gait score, and bone strength according to the methods of Zhou et al. [30], and the Welfare Quality® assessment protocol [31]. Scores for each indicator reflected varying degrees of welfare, with lower scores representing better conditions. For feather cleanliness, the scores ranged from 0 (clean) to 3 (severely soiled), and for footpad dermatitis, the scale extended from 0 (no lesions) to 4 (severe lesions). Gait scores ranged from 0 (normal mobility) to 5 (unable to walk), with gait scores of 3 and above signaling a welfare concern [32].

Precision agriculture technologies, including thermography and image processing [33], were utilized to measure the bare-skin ratio and surface body temperature (Figure 1. For Ross and Cobb broilers at 28 days of age, a threshold of 33.5 °C was used to calculate the bare-skin ratio. At 56 days of age, the threshold was set at 35 °C for the calculation. The back and belly parts correspond to the back and breast regions illustrated by Zhao et al. [33].



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

Figure 1. These thermal images depict a Cobb broiler (SD-44 treatment, Pen 31, Bird #5) on day 56. (**a**) A thermal image of the broiler's back, with the white polygon outlining the back area. Using a 35 °C threshold, the average temperature of the area was calculated to be 25.4 °C, and no bare skin was detected (0% bare-skin ratio). (**b**) A thermal image of the broiler's belly, with the white polygon outlining the belly area. With the same 35 °C threshold, the average temperature was measured at 34.2 °C, and the bare-skin ratio was 55.5%. The red dots in the figure indicate the highest temperature points within the selected range, while the blue dots represent the lowest temperature points. These measurements were automatically determined using the "FLIR Thermal Studio Pro" software. Any overlapping content in the figure was generated automatically by the software's measurement tools and can be disregarded.

At 28 days of age, four birds (two males and two females) per pen were randomly selected for assessments of feather cleanliness, footpad dermatitis, and gait score. At 56 days of age, four birds (two males and two females) were randomly selected for the same assessments. During measurements, the selected birds were temporarily removed from their pens. A thermal camera (T865, Teledyne FLIR, Wilsonville, OR) was used to measure the back and belly surface temperatures, allowing for the calculation of the ratio of bare skin to feather coverage. Additionally, two broilers (one male and one female) per pen were euthanized using the carbon dioxide method for tibia-breaking strength assessment at the trial's conclusion. The left tibia-breaking strength was measured using a three-point bending method with an MTS Alliance RT/30 apparatus (MTS Systems Corporation, Eden Prairie, MN), maintaining a 4 cm distance between the two supporting points [30]. All procedures followed the guidelines in the Guide for the Care and Use of Agricultural Animals in Research and Teaching [34] and were approved by the University of Tennessee's Institutional Animal Care and Use Committee (IACUC Protocol #2876-1221).

2.3. Statistical Analysis

All statistical analyses were performed using JMP, version 16.0.0 (SAS Institute, Cary, NC, USA). A randomized complete block design was employed with SDs of 27, 29, 32, and 44 kg/m^2, each having eight replications. Broilers were randomly selected at different ages, meaning that the individuals selected at days 28 and 56 were not necessarily the same. A mixed analysis of variance (ANOVA) was used to assess the impact of SD on continuous variables (bone-breaking strength, average temperature, and bare-skin ratio), with pens as the random block effect. All scored variables, including gait score, footpad dermatitis, feather coverage, and feather cleanliness, were analyzed using a mixed ANOVA on ranks with pens as the random block effect to assess the effect of SD. Tukey's HSD test was used for post hoc pairwise comparisons with significance set at the 0.05 level, following the calculation of least squares means. The normality of residuals was assessed using the Shapiro–Wilk normality test. Additionally, the Kruskal–Wallis test was utilized to evaluate differences between ages (days 28 and 56) for scoring and continuous variables, with significance set at $p < 0.05$.

3. Results

The intention of this study was not to compare the Ross 708 and Cobb 700 strains but rather to evaluate the responses of each strain independently. Despite our efforts to maintain similar personnel, management, and environmental conditions for both strains, some variation in management was inevitable. Furthermore, the breeder hen age plays a crucial role in the performance of their offspring. Since we only employed one batch of chicks from each strain, without considering their parent age, it would neither be feasible nor appropriate to compare them due to the lack of replication.

3.1. Effects of SD on BW and FCR

Table 1 shows the effects of SD on BW and FCR for Ross and Cobb broilers. Stocking density did not significantly affect the BW and FCR of Ross 708 and Cobb 700 broilers. At 28 days, the Ross 708 broilers had an average weight of 1.01 kg ($p = 0.57$) and an FCR of 1.81 ($p = 0.57$). At 56 days, the Ross birds reached an average weight of 3.59 kg ($p = 0.57$), with an FCR of 1.90 ($p = 0.57$). The Cobb broilers weighed 1.42 kg at day 28 ($p = 0.69$), with an FCR of 1.62 ($p = 0.15$). By day 56, their average BW had increased to 4.31 kg ($p = 0.15$). Due to accidentally missing data, it was not possible to calculate FCR on day 56.

Table 1. Effect of stocking density (SD, kg/m^2) on the body weight (BW, kg) and feed conversion ratio (FCR) of Ross 708 and Cobb 700 broilers.

Effect of SD on the BW and FCR of Ross 708							
BW (kg) or FCR	SD 27	SD 29	SD 32	SD 44	Average	Std Error	*p*-value
BW (Day 14)	0.33	0.34	0.33	0.33	0.33	<0.01	0.35
BW (Day 28)	1.00	1.10	0.97	0.97	1.01	0.02	0.48
BW (Day 42)	2.10	2.06	2.02	2.06	2.06	0.04	0.61
BW (Day 56)	3.66	3.56	3.54	3.60	3.59	0.07	0.57
FCR (Day 0–28)	1.83	1.77	1.75	1.88	1.81	0.03	0.06
FCR (Day 0–56)	1.92	1.93	1.89	1.87	1.90	0.03	0.57
Effect of SD on the BW and FCR of Cobb 700							
BW (kg) or FCR	SD 27	SD 29	SD 32	SD 44	Average	Std Error	*p*-value
BW (Day 14)	0.39	0.40	0.40	0.39	0.40	0.01	0.40
BW (Day 28)	1.44	1.40	1.42	1.41	1.42	0.02	0.69
BW (Day 42)	2.80	2.80	2.77	2.67	2.76	0.05	0.20
BW (Day 56)	4.38	4.35	4.35	4.15	4.31	0.08	0.15
FCR (Day 0–28)	1.64	1.66	1.56	1.63	1.62	0.03	0.15

3.2. Effects of SD, Sex, and SD by Sex Interactions on Bone-Breaking Strength

Tables 2 and 3 show the effects of SD, sex, and the SD by sex interactions on bone-breaking strength for Ross and Cobb broilers. Reducing the SD from 32 to 27 reduced the bone-breaking strength of male Ross broilers from 142.95 to 101.82 lbf ($p = 0.01$), while the bone strength of female Ross birds was not affected by SD, with an average bone-breaking strength of 91.70 lbf. There was no interaction effect of SD and sex on Cobb broilers ($p = 0.79$). The bone strength of Ross (average 110.38 lbf, $p = 0.14$) and Cobb (average 124.12 lbf, $p = 0.11$) broilers was not affected by SD. The bone strength of male broilers was higher than that of females for both the Ross (37.36 lbf higher, $p < 0.01$) and Cobb (13.46 lbf higher, $p < 0.01$) birds.

Table 2. Effects of stocking density (SD, kg/m^2), sex, and SD by sex interaction on Ross 708 broiler's bone-breaking strength (lbf).

Effect of SD on bone strength of Ross						
SD 27	SD 29	SD 32	SD 44	Average	Std Error	*p*-value
99.19	114.63	116.33	111.36	110.38	5.65	0.14
Effect of sex on bone strength of Ross						
Male		Female		Std Error	*p*-value	
129.06 ^{a}		91.70 ^{b}		3.89	<0.01	
SD by sex interaction effects of Ross						
	SD 27	SD 29	SD 32	SD 44	Std Error	*p*-value
Male	101.82 ^{bc}	135.49 ^{ab}	142.95 ^{a}	135.99 ^{ab}	7.72	0.01
Female	96.56 ^{c}	93.78 ^{c}	89.72 ^{c}	86.73 ^{c}		

$^{a, b, c}$ means in the same row with no common superscripts differ ($p < 0.05$).

Table 3. Effects of stocking density (SD, kg/m^2), sex, and SD by sex interaction on Cobb 700 broiler's bone-breaking strength (lbf).

Effect of SD on bone strength of Cobb						
SD 27	SD 29	SD 32	SD 44	Average	Std Error	*p*-value
120.27	131.98	116.07	128.16	124.12	5.02	0.11
Effect of sex on bone strength of Cobb						
Male		Female		Std Error	*p*-value	
130.86 ^{a}		117.40 ^{b}		3.55	<0.01	

Table 3. *Cont.*

	SD by sex interaction effects of Cobb					
	SD 27	SD 29	SD 32	SD 44	Std Error	*p*-value
Male	125.64	138.58	120.13	139.11	7.09	0.79
Female	114.89	125.40	112.02	117.21		

[a, b] means in the same row with no common superscripts differ ($p < 0.05$).

3.3. Effects of SD on Gait Score, Footpad Dermatitis, Feather Cleanliness, Back and Belly Temperature, and Bare-Skin Ratio

Tables 4 and 5 show the effects of SD on gait score, footpad dermatitis, feather cleanliness, back and belly temperature, and bare-skin ratio for Ross and Cobb broilers. The welfare values in these tables represent the average welfare scores for birds under each treatment.

Table 4. Effects of stocking density (SD, kg/m^2) on the gait score, footpad dermatitis, feather cleanliness, back and belly body temperature (°C), and bare-skin ratio (%) of Ross 708 broilers. Scores for feather cleanliness, gait score, and footpad dermatitis were determined following the Welfare Quality® (2009) assessment protocol.

Measurement Items	**Ross 708**						
On day 28	SD 27	SD 29	SD 32	SD 44	Average	Std Error	*p*-value
Gait score	0.31	0.34	0.32	0.25	0.31	0.09	0.93
Footpad	1.84	2.16	1.91	2.16	1.84	0.25	0.77
Feather cleanliness	0.06	0.00	0.00	0.03	0.06	0.03	0.35
Back temperature	31.96	31.88	32.68	32.46	32.25	0.37	0.36
Belly temperature	36.62	36.99	37.21	36.91	36.93	0.18	0.17
Back-skin ratio	19.73	19.27	27.25	22.50	22.19	3.15	0.28
Belly-skin ratio	64.61	65.77	69.08	64.69	66.04	1.89	0.32
On day 56	SD 27	SD 29	SD 32	SD 44	Average	Std Error	*p*-value
Gait score	1.56	1.16	1.50	1.22	1.36	0.16	0.38
Footpad	0.94	1.09	1.22	1.50	1.19	0.15	0.08
Feather cleanliness	1.34 [b]	1.41 [b]	1.59 [b]	2.19 [a]	1.63	0.15	<0.01
Back temperature	25.03	24.80	25.15	24.89	24.97	0.28	0.82
Belly temperature	31.75	31.82	32.23	31.82	31.91	0.24	0.46
Back-skin ratio	2.35	3.29	3.49	3.30	3.11	0.84	0.77
Belly-skin ratio	54.49	55.66	59.43	56.99	56.64	1.98	0.35

[a, b] means in the same row with no common superscripts differ ($p < 0.05$).

For Ross 708 broilers, the gait score (0.31, $p = 0.93$) and footpad dermatitis (1.84, $p = 0.77$) on day 28 and the gait score (1.36, $p = 0.38$) and footpad dermatitis (1.19, $p = 0.08$) on day 56 were not affected by SD. Lowering the SD improved feather cleanliness for the SD-27 (1.34), SD-29 (1.41), and SD-32 (1.59) groups compared with those of the SD-44 (2.19) birds on day 56 ($p < 0.01$). On day 28, SD did not affect back or belly temperature or bare-skin ratio. The belly temperature was 4.68 °C higher and the bare-skin ratio was 43.85% higher the scores for the back. Similarly, on day 56, SD had no significant effect on these parameters, with the belly temperature 6.94 °C higher and the bare-skin ratio 53.53% higher than the scores for the back.

For Cobb 700 broilers, SD affected the footpad on day 56 ($p = 0.04$), with birds at 27 kg/m^2 (1.22) displaying healthier footpads than those at 44 kg/m^2 (2.27). The gait scores, feather cleanliness, back and belly temperature, and bare-skin ratio of the Cobb birds were unaffected by SD on either day 28 or day 56. On day 28, the belly temperature was 3.88 °C higher, and the belly bare-skin ratio was 40.3% greater than that for the back. Similarly,

on day 56, the belly temperature exceeded the back temperature by 7.17 °C, and the belly bare-skin ratio was 56.43% higher than that for the back.

Table 5. Effects of stocking density (SD, kg/m^2) on the gait score, footpad dermatitis, feather cleanliness, back and belly body temperature (°C), and bare-skin ratio (%) of Cobb 700 broilers.

Measurement Items	**Cobb 700**						
On day 28	SD 27	SD 29	SD 32	SD 44	Average	Std Error	*p*-value
Gait score	0.41	0.19	0.56	0.47	0.41	0.12	0.18
Footpad	1.16	1.47	1.53	1.56	1.43	0.26	0.62
Feather cleanliness	0.72	0.44	0.47	0.63	0.56	0.13	0.47
Back temperature	31.29	30.28	31.23	30.63	30.86	0.38	0.20
Belly temperature	35.12	34.52	34.66	34.67	34.74	0.28	0.45
Back-skin ratio	28.91	22.93	30.64	26.80	27.32	3.35	0.41
Belly-skin ratio	71.61	66.85	65.93	66.10	67.62	2.37	0.30
On day 56	SD 27	SD 29	SD 32	SD 44	Average	Std Error	*p*-value
Gait score	1.97	2.00	2.00	1.87	1.96	0.13	0.89
Footpad	1.22 ^{b}	1.81 ^{ab}	1.86 ^{ab}	2.27 ^{a}	1.79	0.24	0.04
Feather cleanliness	2.09	2.44	2.22	2.45	2.30	0.18	0.57
Back temperature	24.55	24.48	24.62	24.33	24.50	0.24	0.84
Belly temperature	32.00	31.48	31.62	31.58	31.67	0.28	0.57
Back-skin ratio	0.80	0.93	0.96	0.48	0.80	0.25	0.55
Belly-skin ratio	59.03	55.69	56.97	57.21	57.23	2.82	0.87

$^{a, b}$ means in the same row with no common superscripts differ ($p < 0.05$).

3.4. Effect of Age on Gait Score, Footpad Dermatitis, Feather Cleanliness, Back and Belly Temperature, and Bare-Skin Ratio

Table 6 highlights the significant effects of age on broiler welfare indicators. From day 28 to day 56, the footpad health in the Ross birds improved by 0.78, while in the Cobb birds, it declined by 0.36 (both $p < 0.01$). The gait scores worsened, and feather cleanliness declined for both the Ross and Cobb broilers over this period. However, the average back and belly temperatures, along with bare-skin ratios, decreased, indicating improved feather coverage with age (all $p < 0.01$).

Table 6. Effects of age on the gait score, footpad dermatitis, feather cleanliness, back and belly body temperature (°C), and bare-skin ratio (%) of Ross 708 and Cobb 700 broilers.

Measurement Items	Ross 708			
	Day 28	Day 56	Std Error	*p*-value
Gait score	0.30 ^{b}	1.36 ^{a}	0.16	<0.01
Footpad	1.97 ^{a}	1.19 ^{b}	0.10	<0.01
Feather cleanliness	0.02 ^{b}	1.63 ^{a}	1.27	<0.01
Back temperature	32.24 ^{a}	24.97 ^{b}	0.95	<0.01
Belly temperature	36.93 ^{a}	31.90 ^{b}	0.07	<0.01
Back-skin ratio	22.19 ^{a}	3.11 ^{b}	0.11	<0.01
Belly-skin ratio	66.04 ^{a}	56.64 ^{b}	0.05	<0.01
	Day 28	Day 56	Std Error	*p*-value
Gait score	0.41 ^{b}	1.95 ^{a}	0.06	<0.01
Footpad	1.43 ^{b}	1.79 ^{a}	0.12	<0.01
Feather cleanliness	0.56 ^{b}	2.30 ^{a}	0.08	<0.01
Back temperature	30.86 ^{a}	24.49 ^{b}	0.15	<0.01
Belly temperature	27.32 ^{a}	0.81 ^{b}	1.20	<0.01

Table 6. *Cont.*

Measurement Items	Ross 708		Std Error	*p*-value
	Day 28	Day 56		
Back-skin ratio	34.74 [a]	31.67 [b]	0.13	<0.01
Belly-skin ratio	67.62 [a]	57.24 [b]	1.13	<0.01

[a, b] means in the same row with no common superscripts differ ($p < 0.05$).

3.5. Effect of Sex on Gait Score, Footpad Dermatitis, Feather Cleanliness, Back and Belly Temperature, and Bare-Skin Ratio

Table 7 illustrates the effects of sex on welfare indicators in Ross 708 and Cobb 700 broilers. At 28 days of age, no significant differences were observed between males and females for any welfare parameters in either strain. By 56 days of age, however, several significant differences emerged. In the Ross 708 broilers, females exhibited lower back temperatures (24.58 °C vs. 25.35 °C; $p < 0.01$) and a reduced back-skin ratio (1.70% vs. 4.52%; $p < 0.01$) compared to those of males. No significant differences were found in regards to gait score, footpad condition, feather cleanliness, belly temperature, or belly-skin ratio for the Ross 708 broilers. In the Cobb 700 broilers at 56 days of age, females showed improved gait scores (1.78 vs. 2.14; $p = 0.01$), healthier footpad scores (1.63 vs. 1.95; $p = 0.04$), and cleaner feathers (2.21 vs. 2.39; $p = 0.04$) compared to those of males. However, no significant differences were observed between males and females for back temperature, belly temperature, back-skin ratio, or belly-skin ratio in Cobb 700 broilers.

Table 7. Effects of sex on the gait score, footpad dermatitis, feather cleanliness, back and belly body temperature (°C), and bare-skin ratio (%) of Ross 708 and Cobb 700 broilers.

Measurement Items	**Ross 708**				**Cobb 700**			
On day 28	Male	Female	Std Error	*p*-value	Male	Female	Std Error	*p*-value
Gait score	0.33	0.28	0.06	0.58	0.38	0.44	0.09	0.37
Footpad	2.01	1.92	0.16	0.65	1.27	1.59	0.16	0.07
Feather cleanliness	0.02	0.03	0.02	0.58	0.63	0.50	0.08	0.22
Back temperature	32.04	32.45	0.28	0.34	30.65	31.06	0.08	0.30
Belly temperature	36.96	36.91	0.12	0.74	30.65	31.06	0.27	0.87
Back-skin ratio	20.31	24.07	2.53	0.34	25.26	29.38	0.27	0.23
Belly-skin ratio	67.07	65.00	1.32	0.26	34.76	34.73	0.17	0.72
On day 56	Male	Female	Std Error	*p*-value	Male	Female	Std Error	*p*-value
Gait score	1.45	1.27	0.12	0.38	2.14 [a]	1.78 [b]	0.09	0.01
Footpad	1.17	1.20	0.12	0.78	1.95 [a]	1.63 [b]	0.15	0.04
Feather cleanliness	1.63	1.64	0.09	0.82	2.39 [a]	2.21 [b]	0.10	0.04
Back temperature	25.35 [a]	24.58 [b]	0.18	<0.01	24.56	24.42	0.14	0.43
Belly temperature	31.94	31.87	0.15	0.73	31.50	31.83	0.17	0.13
Back-skin ratio	4.52 [a]	1.70 [b]	0.60	<0.01	0.97	0.62	0.18	0.19
Belly-skin ratio	56.71	56.57	1.30	0.93	55.40	59.05	1.70	0.06

[a, b] means in the same row with no common superscripts differ ($p < 0.05$).

4. Discussion

4.1. Effects of Stocking Density on Body Weight and FCR

The SD had no significant effect on the BW or FCR of the Ross and Cobb broilers, with the final BW averaging 3.59 kg for the Ross and 4.31 kg for the Cobb birds. These results align with the findings by Wang et al. [35], who reported no significant influence of SD on broiler performance. Weimer et al. [36] also found that the broiler's BW (2.714 kg) and FCR (1.55) on day 42 were unaffected by SD, specifically comparing with 29 kg/m^2 and 37 kg/m^2. These findings suggest that precise control of SD can allow poultry producers to optimize space usage without compromising growth performance. However, contrasting studies have reported that higher SDs can negatively impact broiler BW and feed intake

under specific conditions [25,27,37–39]. Son et al. [40] demonstrated that increased densities (23–26 birds/m^2) under heat stress conditions led to reduced BW and increased oxidative stress markers. Consistent with this, Goo et al. [38] found that a high SDs combined with heat stress significantly impaired broiler growth performance. These findings highlight the importance of considering environmental factors, such as temperature and ventilation, alongside SD. Differences in results across studies may stem from variations in feeding strategies, rearing environments, or genetic strains. As noted by Ekstrand and Carpenter [41], the impact of SD on broiler performance is strongly influenced by environmental conditions, such as litter quality and ventilation. Therefore, a holistic management approach addressing both density and environmental variables is essential to mitigate potential adverse effects. Our findings reinforce the efficacy of SD recommendations, such as the NCC's recommended 44 kg/m^2 [14]. Adherence to such guidelines supports consistent production outcomes, while maintaining bird welfare. This approach allows producers to optimize economic returns without negatively affecting animal welfare or growth performance, making it a practical strategy for sustainable poultry production.

4.2. Effects of SD, Sex, and SD by Sex Interactions on Bone-Breaking Strength

Generally speaking, broilers raised at higher densities exhibit lower bone-breaking strength compared to those raised at lower densities [20,42–44]. The limited space affects their movement and bone development, leading to weaker bones and higher susceptibility to leg issues [44,45]. However, lowering the SD was sometimes related to compromised leg health. Tablante et al. [46] reported that reducing the SD from 20 to 10 birds/pen increased the incidence of tibial dyschondroplasia by 10.6%. Buijs et al. [47] found an unexpected latency-to-lie improvement (related to better leg health and walking ability) in birds raised under an SD of 47 kg/m^2 compared to birds raised at an SD ranging from 23 to 41 kg/m^2. The significance reported in this study was for males; reducing the SD from 32 to 27 reduced the bone-breaking strength of male Ross broilers, while the bone strength of female Ross birds was not affected by the reduction of SD. Although broilers raised at a lower SD had more space to move around, the lack of competition for feeding between male broilers due to the decreased SD may be the reason for the reduced bone-breaking strength.

The bone strength of Cobb broilers was not affected by SD. This is inconsistent with the previous report that increasing SD will reduce bone-breaking strength at around 45 days of age [20,30,43]. The fact that broilers were selected at different ages for measuring bone strength may explain this discrepancy. The bone-breaking strength in this experiment was measured at 56 days of age; the additional 11 days may have allowed bones to become stronger, eliminating the potential impact of SD. The bone-breaking strength of the Cobb birds at 56 days of age in this experiment was 124.12 lbf, which was higher than the 91.25 lbf of the Cobb at 45 days reported by Zhou et al. [30]. The bone strength of male broilers was higher than that of females for both the Ross and Cobb birds. This is in line with our expectations and consistent with previously reported results [48–50]. Mönch et al. [51] suggested that hormonal differences, which affect skeletal development, might explain the variance in bone strength between male and female broilers.

4.3. Effects of SD on Gait Score, Footpad Dermatitis, Feather Cleanliness, Back and Belly Temperature, and Bare-Skin Ratio

Reducing SD improved Ross's feather cleanliness at 56 days. Feathers serve as a protective layer, maintaining body temperature and shielding birds from physical damage [52]. Clean feathers are a critical welfare indicator, and improving feather cleanliness through optimized SD could enhance overall welfare. A higher SD, such as SD-44 in Ross broilers, compromised feather cleanliness at 56 days, likely due to overcrowding. Overcrowding increases feeding, drinking, and excretion activities, leading to elevated moisture and ammonia levels in litter, which are known to negatively affect feather and footpad health [53,54]. Adjusting the SD during specific growth phases may help maintain better feather and litter quality, minimizing welfare issues.

Lowering the SD improved the Cobb's footpad health at 56 days, as a higher SD was associated with wetter litter, compromising footpad conditions [53]. Integrating litter management systems to control moisture and ammonia levels could enhance footpad health outcomes, reducing potential welfare issues. In contrast, the footpad health of Ross broilers was unaffected by SD. Other welfare indicators, including gait score, back and belly temperature, and bare-skin ratio, were not significantly influenced by SD in either strain. These findings suggest that welfare is generally well maintained within the SD-44 kg/m^2 recommended by the NCC [14].

4.4. Effects of Age and Sex on Broiler Welfare

Age significantly impacts all welfare indicators in broilers. As broilers mature, feather coverage increases, but feather cleanliness declines, and gait scores worsen due to increasing BW and pressure on joints. These trends align with typical broiler growth patterns and are consistent with the findings of Taira et al. [55]. The average footpad dermatitis score of Ross broilers was lower at 56 days than at 28 days, likely due to changes in litter conditions. At 28 days, wet litter adhered to the birds' feet, contributing to footpad dermatitis. By 56 days, litter naturally dried and caked litter fell off, allowing for the partial healing of footpad damage without manual intervention. Although litter moisture was not measured in this study, this observation underscores the importance of litter management in controlling footpad dermatitis. Similar findings by Taira et al. [55] suggest that transitioning broilers from wet to dry litter slows the progression of footpad issues. Future studies should include the continuous monitoring of litter moisture to confirm its relationship with footpad health and overall welfare. These findings reinforce the role of litter management in mitigating footpad issues and improving broiler welfare as birds age.

The impact of sex on broiler welfare indicators becomes increasingly significant as birds age, with females consistently showing advantages across multiple welfare parameters by 56 days of age. Females tend to have a lighter BW, which reduces the stress on their legs and likely contributes to improved gait scores and footpad condition. These differences may result from inherent physiological or behavioral variations between sexes, including disparities in BW, activity levels, and metabolism. Given that commercial broilers are typically raised as mixed-sex flocks, managing production separately for males and females may not be practical. However, understanding these sex-based differences can inform strategies to optimize overall flock welfare.

4.5. Limitations and Future Research Directions

The range of SDs tested may not fully capture the variety found in commercial settings, and trials with higher densities could offer additional insights. Further exploring practical applications such as tailored density strategies across different growth stages can provide producers with actionable insights. Developing adaptable management systems that adjust densities dynamically based on age or seasonal conditions could enhance production efficiency. The trials for the Ross 708 and Cobb 700 broilers were conducted months apart, which might have introduced seasonal variability, affecting the results. While some welfare indicators were measured objectively, others, like gait score and feather cleanliness, were manually assessed, introducing subjectivity. Additionally, litter quality, which significantly impacts welfare, was not systematically measured.

Future research should explore a broader range of SDs, both higher and lower, to identify welfare and performance thresholds. More precise measurements of litter conditions, including moisture and ammonia levels, could provide deeper insights. Cross-seasonal studies would help assess the interaction between SD and varying environmental conditions. Incorporating automated technologies such as image analysis for welfare assessment could reduce bias and improve accuracy.

5. Conclusions

This study comparatively investigated the effect of SD on the production performance and welfare of Ross 708 and Cobb 700 broilers. The results indicated that reducing SD improved feather cleanliness in Ross broilers and footpad health in Cobb broilers on day 56, although it led to a decrease in bone-breaking strength in male Ross birds. However, other key production parameters, including BW, FCR, gait score, body temperature, and bare-skin ratio, were unaffected by variations in SD. Overall, the current SD practices commonly used by farmers did not compromise the production performance or overall welfare of the Ross and Cobb broilers, suggesting that existing guidelines remain effective in balancing productivity and animal welfare.

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