Stocking Density Effects on Male Broilers Grown to 1.8 Kilograms of Body Weight[1]

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ABSTRACT This study examined the effects of stocking density on live performance, physiological stress level indicators, and processing yields of male broilers grown to 1.8 kg. A total of 3,120 Ross × Ross 708 male chicks was placed into 32 floor pens (5.57 m^2/pen). Stocking density treatments were 25, (75 birds/pen), 30 (90 birds/pen), 35 (105 birds/pen), and 40 (120 birds/pen) kg of BW/m^2. The BW gain, feed consumption, and feed conversion were adversely affected with increasing stocking densities by 35 d. Physiological stress indicators (plasma corticosterone, glucose, cholesterol, total nitrites, and heterophil:lymphocyte) were not affected. Litter moisture was higher as stocking density increased, which led to higher footpad lesion scores. In parallel to growth responses, carcass weight was depressed by increasing stocking density, but carcass yield, absolute and relative amounts of abdominal fat, and carcass skin defects were not affected. Increasing stocking density decreased breast fillet weight and its relative yield and breast tender weight, but not breast tender yield. As calculated stocking density increased 5 kg of BW/m^2 beyond 25 kg of BW/m^2, final BW and breast fillet weight decreased by 41 and 12 g, respectively. We conclude that increasing stocking density beyond 30 kg of BW/m^2 adversely affects growth responses and meat yield of broilers grown to 1.8 kg but does not alter physiological stress indicators.

Key words: breast muscle weight, feed conversion, footpad lesion, litter moisture, stocking density

2006 Poultry Science 85:344–351

INTRODUCTION

Welfare concerns are influencing sales of poultry products, and stocking density is a major welfare concern (Food Marketing Institute and National Council of Chain Restaurants, 2003). This concern has prompted the National Chicken Council to establish a tiered system for stocking density recommendations based on weight of birds produced in a given floor space area (National Chicken Council, 2005). In the past, the number of birds in a given area was recognized as the sole method of expressing stocking density. Body weight appears to be a better indicator of bird performance and well-being/welfare than number of birds in a given space (Shanawany, 1988; Bilgili and Hess, 1995; Puron et al., 1995; Feddes et al., 2002).

At present, moderate size and large birds (i.e., those in excess of 2.0 kg of final BW) represent the majority of the US broiler production. However, small broilers (i.e., birds marketed at BW from 1.5 to 1.8 kg) account for approximately 30% of the US broiler market. The majority of the small bird market is in the fast food service sector. The question of whether productivity and welfare of both large and small broilers requires different stocking density based on body mass has not been answered.

Research has shown that high stocking densities exert adverse effects on growth, external carcass quality, and processing yields of broilers grown to 2.4 to 2.7 kg (Deaton et al., 1968; Stanley et al., 1989; Bilgili and Hess, 1995; Puron et al., 1995; Feddes et al., 2002). Shanawany (1988) reported that cumulative feed consumption and BW gain were adversely affected as stocking density increased from 20 to 50 birds/m^2 with broilers grown to 1.8 kg. Dozier et al. (2005) recently evaluated performance and well-being of broilers grown to a final BW of 3.1 kg. As stocking density increased from 30 to 45 kg/m^2, cumulative growth rate decreased by approximately 6%. However, physiological indicators of stress were not affected (Thaxton et al., 2005).

The specific objective of this work was to evaluate growth, yield, and physiological indicators of stress of broilers grown to a target weight of 1.8 kg at similar stocking densities as the large birds in our previous study.

MATERIALS AND METHODS

Bird Husbandry

Three thousand one hundred and twenty d-old Ross × Ross 708 (Aviagen, Inc., Huntsville, AL) male chicks were

Received June 6, 2005.
Accepted October 4, 2005.
[1]Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.
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purchased from a commercial hatchery and randomly distributed into 32 floor pens. Experimental facility was solid-sided and light and temperature controlled. Ventilation consisted of a single fan producing positive pressure in the house with still air at brooding and approximately 3.4 m^3/h of airflow per bird approaching market weight. Heating was provided by a heat exchanger fed with hot water from a boiler system. This study was conducted in the fall of 2004. Chicks received vaccinations for Marek's disease, Newcastle disease, and infectious bronchitis at the hatchery. Each pen (5.57 m^2) was equipped with fresh pine shavings, a nipple water-line with 15 nipples, and 2 tube feeders. The capacity of the tube feeders was 17 kg. Feeders were filled once daily from 1 to 28 d of age and twice daily from 29 to 35 d of age. Birds were provided a 3-phase feeding program (starter: 1 to 15 d; grower: 16 to 28 d; finisher: 29 to 35 d). Starter feed was provided as crumbles, and subsequent feeds were pellets. All birds had free access to feed and water. Feeder space/bird consisted of 3.1, 2.6, 2.2, and 1.9 cm/bird, respectively, for the calculated stocking density treatments of 25, 30, 35, and 40 kg of BW/m^2. Nipple waterer densities were 5, 6, 7, and 8 birds/nipple, respectively, with the treatments of 25, 30, 35, and 40 kg of BW/m^2. Feeder and waterer space met or exceeded recommendations in commercial practice (Lacy, 2002). Ambient temperature was maintained at 33°C at the start of experimentation and reduced as the birds progressed in age to ensure comfort with a final temperature set point of 24°C at 32 d and thereafter. The lighting schedule consisted of continuous lighting with an intensity of 20 lx from placement to 7 d, 19L:5D and an intensity of 20 lx from 8 to 14 d, 20L:4D with intensity of 5 lx from 15 to 22 d, and continuous lighting with an intensity of 3 lx from 23 to 35 d. This lighting program is currently used by a major commercial broiler company in the state of Mississippi.

Treatments

Experimental treatments consisted of 4 calculated stocking densities of 25, 30, 35, and 40 kg of BW/m^2. Each treatment was represented by 8 replicate pens. The treatments consisted of 75, 90, 105, and 120 chicks per pen at placement for a calculated stocking density of 25, 30, 35, and 40 kg of BW/m^2, respectively. The equation used to calculate the number of birds per pen to achieve the estimated treatments was: body mass (kg of BW/m^2) × pen area (m^2) ÷ estimated final BW (kg). The estimated final BW and pen area used were 1.8 kg and 5.57 m^2, respectively.

Measurements

Birds on a pen basis and feed were weighed at 15, 28, and 35 d. The incidence of mortality was recorded daily. At 32 d of age, litter samples were collected from each pen for the determination of moisture (AOAC, 1996), and 10 birds from each pen were subjectively scored for footpad scores based on the procedure reported by Hess et al. (1999). Gait scoring was assessed on 10 birds from each pen based on a modification of the method of Garner et al. (2002). Birds were subjectively assigned 0 = for normal gait, 1 = impaired movement, and 2 = reluctant. Normal was defined as no impairment of walking ability. Birds could walk at least 1.5 m with a balanced gait. Impaired was defined as an obvious impairment of walking. Birds could walk at least 1.5 m but showed an unbalanced gait. Reluctant was defined as having severe impairment of walking ability causing unwillingness to stand and walk.

Four birds from each pen were bled by venipuncture at 31 d. Blood samples were collected into heparinized syringes within 45 s after each bird was caught. Blood samples were placed in an ice bath immediately after collection, then transported to the laboratory. One drop of whole blood from each syringe was used to make a thin smear on a clean microscope slide. Slides were then air-dried. Syringes were centrifuged (5000 × g for 10 min at 4°C), and then packed cells in each syringe were expelled. Remaining plasma samples in the syringes were never exposed to ambient air. These samples were stored at −20°C until later analyses. Plasma corticosterone was determined using an enzyme immunoassay (Correlate-EIA for CS, Assay Designs, Inc., Ann Arbor, MI) procedure described previously by Thaxton et al. (2005). Plasma glucose and cholesterol were determined by colorimetric detection using an Autoanalyzer (Ektackem DT-60, Eastman Kodak Co., Rochester, NY; Elliot, 1984). Cholesterol is the major precursor of all steroids produced by the adrenal glands and the gonads. Additionally, a large body of literature shows that cholesterol concentration in the adrenal glands of chickens decreases (Siegel and Beane, 1961; Siegel, 1962; Wolford and Ringer, 1962; Freeman and Manning, 1975) and elevates plasma cholesterol concentrations (Freeman, 1985; Siegel, 1995) following exposure to stressors. Total plasma nitrate concentration, an accepted indicator of nitric oxide, was determined spectrophotometrically (μQuant, Microplate Spectrophotometer, Bio-Tek Instruments, Inc., Winooski, VT) using Griess reagent (Green et al., 1982). The dried blood smears were stained (Cook, 1959), and 100 leukocytes from each smear were identified for cell type and counted. The heterolphil:lymphocyte was calculated by dividing percentage of heterophils by percentage of lymphocytes.

On d 35, 12 birds per pen were selected for processing. Feed was removed from each pen 12 h prior to placing birds in transportation coops. The birds selected for processing were weighed on d 36, and this weight was used to calculate carcass and breast meat yield. Birds were electrically stunned, bled, scalded, mechanically picked, and manually eviscerated. Carcasses and abdominal fat pad were weighed. Carcass weight was without neck, giblets, and abdominal fat. The incidence of scratches and tears on the back and thighs of the carcass was recorded. Carcasses were placed on ice for 24 h and then deboned to obtain skinless, boneless, breast fillet (pectoralis major muscle) and breast tender (pectoralis minor muscle) weights.

Table 1. Live performance responses of male broilers from placement to 15 d of age subjected to various calculated stocking densities[1]

Treatment[2]	BW (g)	BW gain (g)	FC[3] (g)	FG[4]	Mortality (%)
25 (kg of BW/m^2)	453	412	557	1.351	0.6
30 (kg of BW/m^2)	448	407	552	1.356	0.7
35 (kg of BW/m^2)	460	419	552	1.321	0.7
40 (kg of BW/m^2)	462	421	554	1.319	0.5
	Probability				
Trend analysis					
Linear	0.025	0.029	0.687	0.009	0.883
	Estimate				
Slope	4.00	3.89	–0.86	–0.013	–0.022
SE of slope	1.66	1.66	2.11	0.005	0.144
	Least significant difference (critical value)				
	11	11	15	0.031	1.00

[1]Values represent least-squares means of 8 replicate pens. Average chick BW was 41 g at placement.

[2]Stocking densities of 25, 30, 35, and 40 kg of BW/m^2 were estimated by placing 75, 90, 105, and 120 birds, respectively, in floor pens of 5.57 m^2 at 1 d of age. The following equation was used in the calculation: birds per pen = (final treatment density (kg/m^2) × pen area (m^2)/projected final BW (kg), in which the final BW was considered to be 1.81 kg.

[3]FC = feed consumption per bird.

[4]FG = feed conversion was corrected for mortality.

Statistics

This study was conducted as a randomized complete block design with 8 replicate blocks and 4 stocking density treatments. Four analyses were conducted: 1) ANOVA followed by LSD test (Fisher, 1939) comparing stocking density means; 2) ANOVA using a linear trend to explain potential stocking density effects; 3) addition of feed consumption to the model in the second trend analysis as a covariant with BW gain as the dependent variable; and 4) a correlation between BW gain and physiological stress indicators. In general, a quadratic trend was not significant ($P > 0.05$) for the variables measured in this study. Analyses were performed by PROC MIXED and PROC CORR (SAS, 2004). All mortality data were subjected to arc sine √% transformation. Statistical significance was established at $P \leq 0.05$.

RESULTS AND DISCUSSION

The actual stocking densities were 25, 30, 33, and 38 kg of BW/m^2 at 35 d of age. Average temperatures from 18 to 28 and 29 to 35 d of age were 27 and 26°C, respectively. Increasing the stocking density improved growth rate and feed conversion from 1 to 15 d of age, but feed consumption and the incidence of mortality were not affected (Table 1). Dozier et al. (2005) observed a similar response with increasing stocking density during the early period (1 to 17 d of age) of growth. The improvement in growth responses due to increasing stocking density is not clearly understood. We hypothesized that this difference in growth might be related to metabolic heat production (Kuenzel and Kuenzel, 1977).

Therefore, with additional chicks at the higher densities, there is an increased nonevaporative heat production, which may result in the higher growth rates for these younger birds.

Increasing stocking density above 30 kg of BW/m^2 adversely affected growth rate, feed consumption, and feed conversion calculated at 28 d of age (Table 2). Final BW gain, feed consumption, and nutrient use also were negatively impacted by high stocking densities calculated at 35 d of age (Table 3). The incidence of total mortality was not affected by stocking density treatments. Cumulative BW gain and feed consumption were suppressed by 41 and 39 g, respectively, as stocking density increased 5 kg of BW/m^2 as evidenced by the slope estimates of the trend analysis. As calculated stocking density increased from 35 to 40 kg of BW/m^2, growth performance was not altered based on the LSD comparison.

Feddes et al. (2002) reported that as stocking density increased from 14 to 18 birds/m^2 cumulative BW and feed consumption were decreased by 3.6 and 3.2%, respectively, with broilers approximating 1.9 kg. Lower BW values occurred with decreasing stocking density from 14 to 11 birds/m^2. Other research found no differences in final BW (1.9 kg) and cumulative feed conversion as stocking density from 11 to 15 birds/m^2 (Puron et al., 1995). Shanawany (1988) reported that when using 1.8-kg broilers with a stocking density at or exceeding 30 birds/m^2, there was a greater decrease in final BW compared with stocking densities of 10 and 20 birds/m^2. In the present study, increasing calculated stocking density from 25 (13 birds/m^2) to 35 (19 birds/m^2) kg of BW/m^2 decreased cumulative BW gain and feed consumption by 6.0 and 3.9%, respectively. As calculated stocking density increased from 30 (16 birds/m^2) to 35 (19 birds/m^2) kg of BW/m^2, cumulative BW gain and feed consumption were suppressed 4.3 and 3.5%, respectively.

Dozier et al. (2005) reported a 6% lower in cumulative BW gain as stocking density increased from 30 to 45 kg

Table 2. Live performance responses of male broilers from placement to 28 d of age subjected to various calculated stocking densities[1]

Treatment[2]	BW (g)	BW gain (g)	FC[3] (g)	FG[4]	Mortality (%)
25 (kg of BW/m^2)	1,430	1,390	1,977	1.421	1.7
30 (kg of BW/m^2)	1,416	1,375	1,974	1.435	1.4
35 (kg of BW/m^2)	1,385	1,345	1,935	1.439	1.2
40 (kg of BW/m^2)	1,394	1,353	1,954	1.444	1.5
	Probability				
Trend analysis					
Linear	0.002	0.002	0.027	0.002	0.705
	Estimate				
Slope	–13.88	–13.94	–10.94	0.007	–0.0081
SE of slope	3.87	3.87	4.63	0.002	0.212
	Least significant difference (critical value)				
	24	24	28	0.014	1.00

[1]Values represent least-squares means of 8 replicate pens.

[2]Stocking densities of 25, 30, 35, and 40 kg of BW/m^2 were estimated by placing 75, 90, 105, and 120 birds, respectively, in floor pens of 5.57 m^2 at 1 d of age. The following equation was used in the calculation: birds per pen = (final treatment density (kg/m^2) × pen area (m^2)/projected final BW (kg), in which the final BW was considered to be 1.81 kg.

[3]FC = feed consumption per bird.

[4]FG = feed conversion was corrected for mortality.

of BW/m^2 with broilers having a final BW of 3.0 kg. In the present study, 6% lower final BW gain occurred as stocking density increased from 25 to 35 kg/m^2 with 1.8-kg broilers. Final BW gain was depressed at similar magnitudes as stocking density was increased to 45 and 35 kg of BW/m^2 with heavy and small broilers, respectively. This provides evidence that a universal stocking density is not appropriate for broilers of various BW.

The reduction in growth rate due to stocking density is highly related to a decrease in feed consumption (Shanawany, 1988). Dozier et al. (2005) used cumulative feed consumption as a covariant and BW gain as the dependent variable and determined that feed consumption represented 95.4% of the sum of squares due to stocking density with 3.1-kg broilers. In the present study, cumulative feed consumption represented 87.2% of the sum of squares attributable to stocking density for final BW gain. Malone et al. (1980) determined that feed conversion was improved as feeder space was increased from 1.8 to 2.3 cm/bird at 27 d for 0.75 kg birds, but at 54 d of age the 2.1-kg birds did not differ in feed conversion by feeder space allocation. Feddes et al. (2002) reported that increasing nipple density from 5 to 20 birds/nipple did not affect growth performance or carcass traits with 2.0-kg broilers. The amount of birds per nipple in the present study should not have affected growth because

Table 3. Live performance responses of male broilers from placement to 35 d of age subjected to various calculated stocking densities[1]

Treatment[2]	BW (g)	BW gain (g)	FC[3] (g)	FG[4]	Mortality (%)
25 (kg of BW/m^2)	1,902	1,861	2,859	1.535	2.2
30 (kg of BW/m^2)	1,869	1,828	2,847	1.558	1.9
35 (kg of BW/m^2)	1,790	1,749	2,747	1.571	1.5
40 (kg of BW/m^2)	1,792	1,750	2,764	1.580	1.9
	Probability				
Trend analysis					
Linear	0.0001	0.0001	0.0001	0.0001	0.545
	Estimate				
Slope	–41.05	–41.06	–38.65	0.015	–0.143
SE of slope	5.82	5.80	7.52	0.002	0.232
	Least significant difference (critical value)				
	34	34	41	0.015	1.6

[1]Values represent least-squares means of 8 replicate pens.

[2]Stocking densities of 25, 30, 35, and 40 kg of BW/m^2 were estimated by placing 75, 90, 105, and 120 birds, respectively, in floor pens of 5.57 m^2 at 1 d of age. The following equation was used in the calculation: birds per pen = (final treatment density (kg/m^2) × pen area (m^2)/projected final BW (kg), where the final BW was considered to be 1.81 kg.

[3]FC = feed consumption per bird.

[4]FG = feed conversion was corrected for mortality.

Table 4. Physiological stress indicators of male broilers at 31 d of age subjected to various calculated stocking densities[1]

Treatment[2]	H:L[3]	CS[4] (pg/mL)	GL[5] (mg/dL)	CH[6] (mg/dL)	Total nitrites (μ)
25 (kg of BW/m^2)	0.92	912	242	131	82
30 (kg of BW/m^2)	0.94	911	248	135	83
35 (kg of BW/m^2)	1.03	963	250	136	81
40 (kg of BW/m^2)	0.90	897	264	132	80
	Probability				
Trend analysis					
Linear	0.95	0.96	0.11	0.77	0.59
	Estimate				
Slope	0.002	0.54	6.84	0.59	–0.93
SE of slope	0.039	9.96	4.15	2.03	1.70
	Least significant difference (critical value)				
	0.25	60	28	13	12

[1]Values represent least-squares means of 8 replicate pens with 4 birds from each pen.

[2]Stocking densities of 25, 30, 35, and 40 kg of BW/m^2 were estimated by placing 75, 90, 105, and 120 birds, respectively, in floor pens of 5.57 m^2 at 1 d of age. The following equation was used in the calculation: birds per pen = (final treatment density (kg/m^2) × pen area (m^2)/projected final BW (kg), in which the final BW was considered to be 1.81 kg.

[3]H:L = heterophil:lymphocyte.

[4]CS = corticosterone concentration.

[5]GL = glucose concentration.

[6]CH = cholesterol concentration.

the number of birds per nipple was in the range of the nipple waterer density reported by Feddes et al. (2002).

Stocking density did not influence physiological indicators of stress (Table 4). The overall mean of corticosterone was 921 pg/mL. Puvadolpirod and Thaxton (2000a,b,c,d) and Thaxton and Puvadolpirod (2000) published a stress model by placing osmotic pumps containing ACTH under the skin of broilers. At the onset of stress, corticosterone increased to 1,500 to 3,000 pg/mL (2.5- to 4.5-fold increase over the controls), whereas the control birds had an average plasma corticosterone concentration of 624 pg/mL. In the present study, plasma corticosterone concentration of broilers subjected to various stocking densities was not indicative of stress based on the data reported by Puvadolpirod and Thaxton (2000c). Thaxton et al. (2005) reported that stocking density (30 to 45 kg of BW/m^2) did not influence plasma corticosterone, glucose, cholesterol, and total nitrites of broilers grown to 3.1 kg. However, the heterophil:lymphocyte increased as stocking increased. These values were not considered stressful based on previous research (Puvadolpirod and Thaxton, 2000c).

Table 5. Litter moisture and foot pad scores of male broilers at 32 d subjected to various calculated stocking densities[1]

Treatment[2]	Litter moisture (%)	Pad lesion score[3]
25 (kg of BW/m^2)	29.6	0.375
30 (kg of BW/m^2)	36.0	0.750
35 (kg of BW/m^2)	36.4	0.963
40 (kg of BW/m^2)	43.3	1.238
	Probability	
Trend analysis		
Linear	0.0001	0.0001
	Estimate	
Slope	4.14	0.28
SE of slope	0.73	0.04
Least significant difference (critical value)	4.7	0.263

[1]Values represent least-squares means of 8 replicate pens.

[2]Stocking densities of 25, 30, 35, and 40 kg of BW/m^2 were estimated by placing 75, 90, 105, and 120 birds, respectively, in floor pens of 5.57 m^2 at 1 d of age. The following equation was used in the calculation: birds per pen = (final treatment density (kg/m^2) × pen area (m^2)/projected final BW (kg), in which the final BW was considered to be 1.81 kg.

[3]Values represent scoring the pads as 0 = no lesions; 1 = lesion < 1.5 cm; and 2 = lesion > 1.5 cm.

Table 6. Carcass yield, skin scratches, and tears of male broilers at 36 d subjected to various calculated stocking densities[1]

Treatment[2]	Carcass wt[3] (g)	Carcass yield[4] (%)	Fat wt[5] (g)	Fat yield[4] (%)	Scratches[6] (%)	Tears[6] (%)
25 (kg of BW/m^2)	1,414	71.6	17	0.87	50.0	8.3
30 (kg of BW/m^2)	1,370	71.5	18	0.95	58.3	11.5
35 (kg of BW/m^2)	1,316	71.9	16	0.87	57.9	12.9
40 (kg of BW/m^2)	1,311	71.9	17	0.94	45.8	15.6
	Probability					
Trend Analysis						
Linear	0.0001	0.211	0.512	0.416	0.594	0.146
	Estimate					
Slope	–36.2	0.09	–0.20	0.01	–1.29	2.33
SE of slope	5.2	0.08	0.30	0.02	2.40	1.55
	Least significant difference (critical value)					
	32	0.5	2	0.10	15.1	10.7

[1]Values represent least-squares means of 8 replicate pens with each providing 12 carcasses.

[2]Stocking densities of 25, 30, 35, and 40 kg of BW/m^2 were estimated by placing 75, 90, 105, and 120 birds, respectively, in floor pens of 5.57 m^2 at 1 d of age. The following equation was used in the calculation: birds per pen = (final treatment density (kg/m^2) × pen area (m^2)/projected final BW (kg), in which the final BW was considered to be 1.81 kg.

[3]Carcasses without necks and giblets and removal of abdominal fat.

[4]Relative to BW.

[5]Amount of abdominal fat.

[6]Defects on the back and thigh correspond to scratched skin and torn skin.

In the present study, plasma corticosterone, glucose, cholesterol, and heterophil:lymphocyte were not correlated ($P \geq 0.11$) to final BW gain, but total nitrites were positively correlated ($P = 0.004$) to 35-d BW gain. This infers that as stocking density increased, both BW gain and total nitrites decreased. The interpretation of decreased nitrites associated with reduced growth is not understood. Reduction in growth as influenced by stocking density seems to be due to limited feeder space. Research is warranted to evaluate increased feeder space with broilers reared under current commercial stocking densities.

Litter moisture content increased with progressive additions of stocking density (Table 5). The slope was estimated as 4.1, indicating that as calculated stocking density increased by 5 kg of BW/m^2, litter moisture should increase by 4 percentage points. Litter moisture was not different for calculated stocking densities of 30 vs. 35

Table 7. Breast meat yield of male broilers at 36 d of age subjected to various calculated stocking densities[1]

Treatment[4]	Fillet[2] Wt (g)	Fillet[2] Yield[5] (%)	Tender[3] Wt (g)	Tender[3] Yield[5] (%)
25 (kg of BW/m^2)	319	16.1	70	3.56
30 (kg of BW/m^2)	305	15.9	68	3.52
35 (kg of BW/m^2)	289	15.8	67	3.64
40 (kg of BW/m^2)	286	15.6	66	3.60
	Probability			
Trend analysis				
Linear	0.0001	0.006	0.004	0.196
	Estimate			
Slope	–11.6	–0.16	–1.36	0.025
SE of slope	1.8	0.05	0.42	0.019
	Least significant difference (critical value)			
	12	0.4	3	0.12

[1]Values represent least-squares means of 8 replicate pens.

[2]Pectoralis major breast muscles.

[3]Pectoralis minor breast muscles.

[4]Stocking densities of 25, 30, 35, and 40 kg of BW/m^2 were estimated by placing 75, 90, 105, and 120 birds, respectively, in floor pens of 5.57 m^2 at 1 d of age. The following equation was used in the calculation: birds per pen = (final treatment density (kg/m^2) × pen area (m^2)/projected final BW (kg), in which the final BW was considered to be 1.81 kg.

[5]Relative to BW.

kg of BW/m^2 as evidenced by the LSD critical value. This indicates that reduced growth performance by increasing calculated stocking density from 30 to 35 kg of BW/m^2 may not be due to litter moisture differences. The increase in litter moisture among the treatments also led to a higher incidence of footpad lesions. Previous research has shown that high stocking density increases litter moisture and footpad burns (Sorensen et al., 2000). In addition to litter quality measurements, stocking density did not alter the proportion of birds with abnormal movement or lameness as assessed by gait scoring.

High stocking density influenced carcass weight but not its relative yield (Table 6). Carcass weight decreased linearly as calculated stocking density increased. With each unit increase of calculated stocking density (5 kg of BW/m^2), carcass weight was estimated to decrease 36 g based on the trend analysis. The amount of abdominal fat and the incidence of skin scratches and tears of the whole carcass were not affected. High stocking density has increased the incidence of scratches (Bilgili and Hess, 1995; Elfadil et al., 1996; Dozier et al., 2005) but not the incidence of carcass tears (Bilgili and Hess, 1995; Dozier et al., 2005).

Breast fillet weight and its associated yield were negatively impacted by high stocking density (Table 7). As calculated stocking density increased, the slope estimate was −11.6, indicating fillet weight decreased by 12 g with each unit increase (5 kg of BW/m^2) in stocking density. Tender weight decreased linearly as calculated stocking density increased, whereas breast tender yield was similar among the treatments. Other research determined that increasing stocking density (from 10 to 13 birds/m^2) decreased breast fillet yield, although breast tender yield was unaffected (Bilgili and Hess, 1995).

In conclusion, increasing calculated stocking density beyond 35 kg of BW/m^2 (7 lb/ft^2) suppressed final BW by 6%. Final BW gain, cumulative feed consumption, and breast fillet weight were decreased 41, 39, and 12 g, respectively, with each 5 kg of BW/m^2 increase of calculated stocking density. Reduction in feed consumption was highly related to the adverse response in final BW gain due to high stocking density rates. Physiological indicators of stress were not affected by the experimental stocking densities.

ACKNOWLEDGMENTS

The authors thank M. Carden, D. Chamblee, and M. Robinson for their contribution to this research.

REFERENCES

AOAC. 1996. Official Methods of Analysis of AOAC International. 16th ed. AOAC Int., Gaithersburg, MD.

Bilgili, S. F., and J. B. Hess. 1995. Placement density influences broiler carcass grade and meat yields. J. Appl. Poult. Res. 4:384–389.

Cook, F. W. 1959. Staining fixed preparations of chicken blood cells with combinations of May-Grünwald-Wright-Phyloxine B stain. Avian Dis. 3:272–290.

Deaton, J. W., F. N. Reece, and T. H. Vardaman. 1968. The effect of temperature and density on broiler performance. Poult. Sci. 47:293–300.

Dozier III, W. A., J. P. Thaxton, S. L. Branton, G. W. Morgan, D. M. Miles, W. B. Roush, B. D. Lott, and Y. Vizzier-Thaxton. 2005. Stocking density effects on growth performance and processing yields of heavy broilers. Poult. Sci. 84:1332–1338.

Elfadil, A. A., J. P. Vaillancourt, and A. H. Meek. 1996. Impact of stocking density, breed, and feathering of the prevalence of abdominal skin scratches in broiler chickens. Avian Dis. 40:546–552.

Elliot, R. J. 1984. Ektachem DT-60 Analyzer. Physican's Leading Computer J. 2:6–13.

Feddes, J. J. R., E. J. Emmanuel, and M. J. Zuidhof. 2002. Broiler performance, body weight variance, feed and water intake, and carcass quality at different stocking densities. Poult. Sci. 81:774–779.

Fisher, R.. 1939. The Design of Experiments. Oliver and Boyd, London, UK.

Food Marketing Institute and National Council of Chain Restaurants. 2003. FMI-NCCR Animal Welfare Program. Food Marketing Inst., Washington, DC.

Freeman, B. M. 1985. Stress and the domestic fowl: Physiological fact or fantasy. Worlds Poult. Sci. J. 41:45–51.

Freeman, B. M., and A. C. C. Manning. 1975. The response of the immature fowl to multiple injections of adrenocorticotrophic hormone. Br. Poult. Sci. 16:121–129.

Garner, J. P., C. Falcone, P. Wakenell, M. Martin, and J. A. Mench. 2002. Reliability and validity of a modified gait scoring system and its use in assessing tibial dyschondroplasia in broilers. Br. Poult. Sci. 43:355–363.

Green, L. C., D. A. Wagner, J. Glogowski, P. L. Skipper, J. S. Wishnok, and S. R. Tannenbaum. 1982. Analysis of nitrate, nitrite and [^{15}N] nitrate in biological fluids. Anal. Biochem. 126:131–138.

Hess, J. B., M. A. Alley, and S. F. Bilgili. 1999. Influence of diet density and strain cross on broiler live performance and WOG yield at different processing ages. Poult. Sci. 78:125. (Suppl. 1) (Abst.)

Kuenzel, W. J., and N. T. Kuenzel. 1977. Basal metabolic rate of growing chicks *Gallus domesticus*. Poult. Sci. 56:619–627.

Lacy, M. P. 2002. Broiler management. Pages 829–868 in Commercial Chicken Meat and Egg Production. 4th ed., D. Bell and W. D. Bell, ed. Kluwer Acad. Publ., 3300 AH Dordrecht, The Netherlands.

Malone, G. W., G. W. Chaloupka, J. W. Merkley, and L. H. Littlefield. 1980. The effect of feeder space and light treatment on broiler performance. Poult. Sci. 59:2697–2702.

National Chicken Council. 2005. National Chicken Council Animal Welfare Guidelines and Audit Guidelines. Natl. Chicken Council, Washington, DC.

Puron, D., R. Santamaria, J. C. Segura, and J. L. Alamilla. 1995. Broiler performance at different stocking densites. J. Appl. Poult. Res. 4:55–60.

Puvadolpirod, S., and J. P. Thaxton. 2000a. Model of physiological stress in chickens 1. Response parameters. Poult. Sci. 79:363–369.

Puvadolpirod, S., and J. P. Thaxton. 2000b. Model of physiological stress in chickens 2. Dosimetry of adrenocorticotropin. Poult. Sci. 79:370–376.

Puvadolpirod, S., and J. P. Thaxton. 2000c. Model of physiological stress in chickens 3. Temporal patterns of response. Poult. Sci. 79:377–382.

Puvadolpirod, S., and J. P. Thaxton. 2000d. Model of physiological stress in chickens 4. Digestion and metabolism. Poult. Sci. 79:383–390.

SAS. 2004. SAS User's Guide. Statistics. Version 9.1 ed. SAS Inst., Inc., Cary, NC.

Shanawany, M. M. 1988. Broiler performance under high stocking densities. Br. Poult. Sci. 29:43–52.

Siegel, H. S. 1962. Age and sex modification of responses to adrenocorticotropin in young chickens 2. Changes in adrenal cholesterol and blood constituent levels. Poult. Sci. 41:321–334.

Siegel, H. S. 1995. Stress, strains, and resistance. Br. Poult. Sci. 36:3–22.

Siegel, H. S., and W. L. Beane. 1961. Time responses to single intramuscular doses of ACTH in chickens. Poult. Sci. 40:216–219.

Sorensen, P., G. Su, and S. C. Kestin. 2000. Effects of age and stocking density on leg weakness in broiler chickens. Poult. Sci. 79:864–870.

Stanley, V. G., J. E. Bailey, and W. F. Krueger. 1989. Research Note: Effect of iodine-treated water on the performance of broiler chickens reared under various stocking densities. Poult. Sci. 68:435–437.

Thaxton, J. P., W. A. Dozier, III, S. L. Branton, G. W. Morgan, D. M. Miles, W. B. Roush, B. D. Lott, and Y. Vizzier-Thaxton. 2005. Evaluation of stocking density on physiological adaptive responses of broilers. Abstr. 17 in Int. Poult. Sci. Forum. SPSS, Tucker, GA.

Thaxton, J. P., and S. Puvadolpirod. 2000. Model of physiological stress in chickens 5. Quantitative evaluation. Poult. Sci. 79:363–369.

Wolford, J. H., and R. H. Ringer. 1962. Adrenal weight, adrenal ascorbic acid, adrenal cholesterol and differential leucocyte counts as physiological indicators of "stressor" agents in laying hens. Poult. Sci. 41:1521–1529.