Effects of stocking density on growth performance, carcass yield, and immune status of a local chicken breed[1]

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ABSTRACT An experiment was conducted to evaluate the effect of stocking density on growth performance, carcass yield, and immune status of a local chicken breed. In total, 840 one-day-old male Suqin yellow chickens were placed into 4-m^2 cages in groups of 50 (low), 70 (medium), or 90 (high) birds. Each treatment was represented by 4 replicates (cages). The cages measured 2.84 × 1.42 m; half of the area of the cage (2 m^2) was used from 1 to 28 d and the whole cage was used from 29 to 42 d. Stocking densities were 25, 35, and 45 birds/m^2 from 1 to 28 d and 12.5, 17.5, and 22.5 birds/m^2 from 29 to 42 d (low, medium, and high, respectively). Final production (live bird mass after fasting) per unit area was 14.46, 19.46, and 24.23 kg/m^2, respectively, at 42 d of age. Several immune parameters were evaluated, and the growth performance, carcass yield, and meat quality were determined. Body weight at 28 and 42 d of age was significantly reduced as the stocking density increased ($P < 0.05$). A depression in daily weight gain was noticed from 1 to 28 d and 1 to 42 d of age, and daily feed intake decreased significantly in each period as density increased ($P < 0.05$). The feed/gain from 29 to 42 d and from 1 to 42 d of age decreased as density increased ($P < 0.05$). At 42 d, there was no effect of the stocking density on carcass, eviscerated carcass, breast, and abdominal fat yields ($P > 0.05$). The thigh yield of chickens in the medium-density group improved significantly ($P < 0.05$) compared with those of the other 2 groups. The water-loss rate, shear force, and meat color of the muscle were unaffected ($P > 0.05$) by the stocking density, but pH values increased slightly as density increased. No significant difference was noted in the immunological parameters, but the blood total protein and potassium were significantly affected by stocking density ($P < 0.05$). The findings of this study suggest that increasing the stocking density advantageously affected feed/gain and decreased the final BW, whereas no evidence was found that stocking density caused changes in any of the measured immune parameters.

Key words: stocking density, immune status, performance, carcass yield, meat quality

2012 Poultry Science 91:667–673
http://dx.doi.org/10.3382/ps.2011-01597

INTRODUCTION

The Suqin yellow chicken is a major local chicken breed in China. They are medium in body size and have a dual purpose for meat and egg production. Approximately 35 birds/m^2 from 1 to 28 d of age and 17.5 birds/m^2 from 29 to 42 d of age for Suqin yellow chickens in cage housing are typically used in the Chinese broiler industry. With the development of animal husbandry in China, local chicken breed production is becoming specialized and more widespread. However, due to the absence of stocking density standards for local chicken breeds, farmers have to rely on personal experience in determining the space allowances. Therefore, it is necessary to study the effect of stocking density and establish more precise stocking density standards for this local chicken breed to ensure its effective production. In addition, welfare concerns are influencing sales of poultry products, and stocking density is perceived as a top priority for animal welfare (Food Marketing Institute and National Council of Chain Restaurants, 2003; Vanhonacker et al., 2008). Citizens are also concerned with the stocking densities used in commercial livestock production (Vanhonacker et al., 2008).

The stocking densities under which chickens are usually kept vary greatly between breed, countries, and husbandry systems (SCAHAW, 2000). Ravindran et al. (2006) found that relative weights of lymphoid organs (spleen and bursa) decreased as density increased (16, 20, and 24 birds/m^2). Thaxton et al. (2006) found that stocking density did not result in a recognizable trend in corticosterone, glucose, cholesterol, and total nitrite concentrations (29, 36, 44, 51, 58, 65, 73, and 80 birds per 4.18 m^2). Buijs et al. (2009) reported that density

©2012 Poultry Science Association Inc.
Received May 10, 2011.
Accepted October 4, 2011.
[1]This work was supported by a special fund for Agro-scientific Research in the public interest of the Ministry of Agriculture (201003011), National Spark Program Project (S2011C100476), and Agro-three Project of Jiangsu Province [SX(2010)138, SX(2010)019], P. R. China.
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did not affect bursa weight, mortality, or concentrations of corticosterone metabolites in droppings but did influence leg health and footpad and hock dermatitis and tended to influence fearfulness (8, 19, 29, 40, 45, 51, 61, and 72 birds per 3.3 m^2). However, most of the reports focused on heavy birds, and relatively little information is available on lightweight ones (Ravindran et al., 2006; Thaxton et al., 2006; Vanhonacker et al., 2008; Buijs et al., 2009).

In addition, most of the studies designed the same stocking density in both starter and finisher periods, which was not in accordance with the practice typically used in the Chinese broiler industry. In practice, the stocking density in the finisher period is equal to half that in the starter period. Therefore, 3 stocking density treatments were used in this experiment to evaluate the effect on growth performance, carcass yield, and immune status of a local chicken breed.

MATERIALS AND METHODS

Birds and Housing

This trial was carried out at the Poultry Institute, Chinese Academy of Agricultural Sciences (Yangzhou) from August to September 2010. Birds were vaccinated for Marek's disease, Newcastle disease, and infectious bronchitis at the hatchery. To exclude effects of sex, only male birds were used in this experiment.

In total, 840 one-day-old Suqin yellow chickens were obtained from a commercial hatchery, individually weighed, and placed into 4-m^2 cages in groups of 50 (low), 70 (medium), or 90 (high) birds. The cages measured 2.84 × 1.42 m. Half of the area of the cage (2 m^2) was used from 1 to 28 d of age and the whole cage was used from 29 to 42 d of age. Stocking densities were 25, 35, and 45 birds/m^2 from 1 to 28 d, and 12.5, 17.5, and 22.5 birds/m^2 from 29 to 42 d (low, medium, and high, respectively). Each treatment was represented by 4 replicates (cages).

All birds were reared in an environmentally controlled (cool cells) house. The cool-cell ventilation system works by allowing air to enter the house through 2 humid walls located on both sides of the end of the house. Outside air passes through the humid walls to cool the house, and 4 fans produce a vacuum, allowing entrance of new air and forcing the previously cooled air to exit. With the cool-cell system, an 8°C maximum decrease in temperature compared with outside ambient temperature has been obtained inside the house.

The cages were 80 cm above the ground (2.84 m length × 1.42 m width × 0.6 m height) and can be divided into several parts using wire net. The mesh of the floor was 1.5 × 1.0 cm (inside diameter), which was used commercially in China. The amount of feeding and drinking space available per bird was kept constant across density treatments by blocking a proportion of the feeding area and drinking nipples within the cage. Each cage contained 2 feeding bins (284-cm length each) and 18 drinker nipples, of which all 18 were available in the high density cages, 14 were available in the medium density cages, and 10 were available in the low density cages. Feeder and waterer space met or exceeded recommendations for commercial practice (Lacy, 2002). The room temperature was maintained at 32°C for the first 2 wk of the experiment and was gradually reduced to 24°C by 21 d of age, after which no heat was provided. The ambient temperature in the experimental house was measured. Light was provided continuously throughout the study.

All birds were provided with the same starter and finisher diets (Table 1). The feed changes used were selected at convenient times to approximate industry practice. Access to feed and water was freely available, and all diets were formulated to contain adequate nutrient levels as defined by the NRC (1994). Mortality was recorded when it occurred, and a cubical space was isolated by wire net to make sure the density treatment was not affected.

Sample Collection and Analytical Determination

Individual BW was recorded at 1, 28, and 42 d of age, and feed intakes by cages were measured on a weekly basis. The feed/gain (**F/G**) values were corrected for the BW of any birds that died during the course of the experiment.

At 42 d, 6 birds from each cage were randomly selected and bled to evaluate immune parameters. Plasma adrenocorticotropic hormone, triiodothyronine, thyroxine, as well as serum cholesterol, triglyceride, glucose, blood urea nitrogen, total protein, albumin, K, Na, Cl, Ca, P, lactate dehydrogenase, and creatine kinase were determined on all randomly selected birds (Özbey and Esen, 2007; and as advised by the Center for Disease Prevention and Control, Yangzhou, China). Blood samples used for plasma determination were collected in heparinized syringes, and those used for serum determination were collected in unheparinized syringes. Care was taken to ensure that the elapsed time between catching a bird and collecting the blood sample did not exceed 60 s. After collection, samples were transported to the laboratory. The syringes were centrifuged at 4,000 × *g* for 10 min (4°C). Levels of adrenocorticotropic hormone, triiodothyronine, and thyroxine were measured in the plasma by radioimmunoassay, as described by Darras et al. (1992). The other blood parameters were measured in serum using a Beckman Coulter Unicel DXC 800 Synchron Clinical System autoanalyzer (Beckman Coulter Inc., Fullerton, CA) in the Center for Disease Prevention and Control, Yangzhou, China.

The experimental procedures were approved by the Yangzhou University Animal Care and Use Committee. At 42 d, after fasting for 12 h before slaughter, all birds were weighed individually and 8 birds of each cage were euthanized and manually exsanguinated. The eviscer-

Table 1. Composition and calculated analysis of the experimental diets[1]

Item	Starter (1–28 d)	Finisher (29–42 d)
Nutrient (%)		
Corn	61.00	64.86
Soybean meal	30.45	25.00
Corn gluten meal	5.00	7.00
Limestone	1.40	1.25
Calcium hydrogen phosphate	1.40	1.25
Methionine	0.16	0.05
Salt	0.30	0.30
Choline chloride	0.12	0.12
Phytase	0.02	0.02
Vitamin and trace mineral premix	0.15	0.15
Composition		
CP (%)	21.50	20.20
ME (MJ/kg)	12.13	12.38
Calcium (%)	1.03	0.92
Available P (%)	0.45	0.42
Lysine (%)	1.00	0.80
Methionine (%)	0.50	0.40

[1]Diet and analyzed nutrient composition were both provided by Yangzhou Hope Feed Co. (Yangzhou, China).

ated carcass, abdominal fat, breast meat (including pectoralis major and pectoralis minor), and leg meat (including thigh and drumstick) were weighed. Eviscerated carcass percentage was calculated as a percentage of live BW. The weight percentages of breast meat, leg meat, and abdominal fat were calculated as a percentage of eviscerated carcass weight. The weights of liver, spleen, bursa, and thymus were determined and liver/body, spleen/body, bursa/body, and thymus/body weight ratios were calculated.

Muscle samples were collected from the left side of the pectoralis major muscle for meat quality analysis. Physicochemical characteristics of breast muscle samples, such as water-loss rate, shear force, meat color, and pH were evaluated.

Water-loss rate was estimated by determining expressible fluid using a modification of the filter paper press method described by Wiebicki and Deatherage (1958), as follows. A raw meat sample weighing 1,000 mg was placed between 18 pieces of 11-cm-diameter filter paper and pressed at 35 kg for 5 min. Expressed fluid was defined as the loss in weight after pressing and presented as a percentage of the initial weight of the original sample (Bouton et al., 1971). The water loss rate was calculated as a ratio of initial weight of the original sample (expressible juice/initial weight).

Shear force was determined using a texture analyzer and a Warner-Bratzler device (C-LM2, Northeast Agricultural University Ltd., Harbin, China). Muscle samples were stored at 4°C for 24 h and were then individually cooked in a water bath at 80°C in plastic bags to an internal temperature of 70°C. The samples then were removed and chilled to room temperature. Strips [1.0 cm (width) × 0.5 cm (thickness) × 2.5 cm (length)] parallel to the muscle fiber were prepared from the medial portion of the meat and sheared vertically (Molette et al., 2003). Shear force was expressed in kilograms.

Meat color was estimated as follows. A raw meat sample weighing 3,000 mg was cut into pieces, homogenized for 10 min using a homogenizer after adding 10 mL of distilled water, centrifuged at 4,000 × g for 10 min, and the supernatant was collected for analysis in a spectrophotometer (722N, Shanghai Precision and Science Instrument Co. Ltd., Shanghai, P. R. China) at 540-nm wavelength.

The ultimate pH values of the pectoralis muscle were measured 45 min postmortem using a portable pH meter (IQ150, IQ Scientific Instruments Inc., Carlsbad, CA) equipped with an insertion glass electrode. The average pH value was calculated from 3 measurements on the same muscle samples. Before measurement, the pH electrode was calibrated using 3 buffers with pH values of 4.01, 7.00, and 9.01. The samples were always measured at the same place (GB/T 9695.5–88).

Statistical Analysis

Performance data were subjected to repeated measures analysis, with cage means as the experimental unit (SAS Institute, 1996). The parameters were averaged per cage. Prior to analysis, homogeneity of variance was examined and the normality of the data was verified. The data were analyzed by using categorical model analysis (low, medium, and high). Stocking density was treated as one variable. Data were compared in a completely randomized design by the GLM procedure of SAS software (SAS Institute, 1996). Statements of significance were based on $P < 0.05$, unless otherwise stated.

RESULTS AND DISCUSSION

Stocking Density and Bird Performance

The BW (average cumulative BW), daily weight gain, daily feed intake, F/G (g/g), and mortality (%) are shown in Table 2. At 28 and 42 d of age, BW was reduced by 11.38 and 6.17%, respectively ($P < 0.05$)

as stocking density rose. The results are in contrast to Feddes et al. (2002), who reported similar BW of birds reared at densities of 12, 18, and 24 birds/m^2. Also, Buijs et al. (2009) found no difference in final BW at 39 d of age as stocking density increased. However, our findings are in agreement with some previous evaluations involving stocking density ranges of 10 to 20 birds/m^2 in which the general trend was a linear decrease in individual BW and feed intake with increasing population density (Proudfoot et al., 1979; Shanawany, 1988; Cravener et al., 1992; Dozier et al., 2005). It is likely that difference in husbandry and prevailing disease challenges may have been responsible, at least in part, for the observed discrepancy between the studies. Increasing the stocking density decreased daily weight gain and daily feed intake from 1 to 28 d of age ($P < 0.05$), but the F/G was not affected ($P > 0.05$; Table 2), which was different from the findings of Dozier et al. (2006), who found that growth rate and feed conversion from 1 to 15 d of age were improved as the stocking density increased but feed consumption was not affected.

There was no difference in daily weight gain from 29 to 42 d of age ($P > 0.05$), even though daily feed intake decreased significantly ($P < 0.05$) as stocking density rose. The result was similar to the report in another experiment (Dozier et al., 2005), who found a depression in daily weight gain, and the cumulative feed consumption was reduced as the stocking density increased. Thomas et al. (2004) found there was no difference in weight gain and feed intake of birds reared at densities of 10, 15, and 20 birds/m^2. Similarly, in a recent study, no differences in average weight gain and feed intake were observed between the 3 density treatments (16, 20, and 24 birds/m^2; Ravindran et al., 2006), although F/G decreased as the stocking density rose ($P < 0.05$). However, other reports found that feed conversion ratio was not affected by stocking density (Cravener et al., 1992; Feddes et al., 2002). When some birds may have to travel further to access a feeder, or if feeder space is limited, feed conversion may be negatively affected by increased stocking density (Feddes et al., 2002). However, the amount of feeding and drinking space available per bird was kept constant across density in this study, and the maximum distance from a feeder was less than 0.7 m. Therefore, feeder accessibility cannot explain the changes in F/G.

Upon processing, stocking density did not lead to apparent differences in the incidence of mortality ($P > 0.05$), which was in agreement with Cravener et al. (1992), Feddes et al. (2002), and Buijs et al. (2009). The mortality during the study ranged between 1.33 and 2.34% and was not related to any treatment (Table 2). Published data from studies conducted under research farm conditions indicate that stocking density has no effect on mortality (Shanawany, 1988; Cravener et al., 1992; Feddes et al., 2002; Thomas et al., 2004; Ravindran et al., 2006), and these findings were confirmed in the present study.

Carcass Yield

An increase in stocking density was expected to decrease breast muscle thickness, as the more-crowded birds were not expected to grow to their full potential. However, in the present study, stocking density did not influence carcass and eviscerated carcass yields and abdominal fat yields ($P > 0.05$, Table 3). This result was consistent with the data of Dozier et al. (2005, 2006), who found that stocking density did not influence carcass and abdominal fat yields relative to BW. Breast muscle yield as a percentage of eviscerated carcass weight ranged between 16.27 and 16.60%, which was consistent with Bilgili and Hess (1995), Feddes et al. (2002), and Dozier et al. (2005), who concluded that the stocking density had no effect on breast meat yield. In contrast, other research determined that increasing stocking density decreased breast fillet yield (Ricard, 1977; Castellini et al., 2002; Dozier et al., 2006).

However, the thigh yield of chickens in the medium-density group improved significantly ($P < 0.05$), which was different from Ricard (1977) and Castellini et al.

Table 2. Effect of stocking density on BW (g), daily BW gain (g/bird), daily feed intake (g/bird), feed/gain (g/g), and mortality (%)[1]

		Stocking density[2] (bird/m^2)				
Item	Age (d)	Low	Medium	High	SEM	Significance
BW	28	690.17	652.74	611.91	6.298	0.000
	42	1,172.38	1,139.01	1,100.03	14.574	0.005
Daily BW gain	1 to 28	23.33	22.08	20.55	0.221	0.000
	29 to 42	34.45	34.52	34.50	0.848	0.998
	1 to 42	27.03	26.23	25.20	0.357	0.004
Daily feed intake	1 to 28	42.55	39.90	37.47	0.475	0.000
	29 to 42	88.86	81.54	78.65	1.792	0.001
	1 to 42	57.98	53.78	51.20	0.853	0.000
Feed/gain	1 to 28	1.8250	1.8092	1.8258	0.017	0.744
	29 to 42	2.5900	2.3683	2.3008	0.065	0.010
	1 to 42	2.1458	2.0517	2.0367	0.030	0.029
Mortality	1 to 42	1.33	2.34	1.92	1.11	0.815

[1]Each value represents the mean of 4 replicates.

[2]Stocking densities were 25, 35, and 45 birds/m^2 from 1 to 28 d and 12.5, 17.5, and 22.5 birds/m^2 from 29 to 42 d (low, medium, and high, respectively).

Table 3. Effect of stocking density on carcass performance[1]

Item (%)	Stocking density[2] (bird/m^2)			SEM	Significance
	Low	Medium	High		
Slaughter yield[3]	91.27	91.01	91.43	0.572	0.871
Eviscerated carcass yield[3]	67.29	67.24	68.04	0.489	0.437
Breast yield[4]	16.50	16.60	16.27	0.275	0.684
Thigh yield[4]	22.78	24.07	22.68	0.312	0.005
Abdominal fat yield[4]	0.77	0.79	0.73	0.113	0.932

[1]Each value represents the mean of 4 replicates of 8 birds each.

[2]Stocking densities were 25, 35, and 45 birds/m^2 from 1 to 28 d and 12.5, 17.5, and 22.5 birds/m^2 from 29 to 42 d (low, medium, and high, respectively).

[3]Calculated as a percentage of live BW.

[4]Calculated as a percentage of eviscerated carcass weight.

(2002), who found that percentages of thigh meat increased when birds had a lower stocking density and outdoor access in an organic production system because of forced motor activity.

Meat Quality

The effect of stocking density on meat quality is presented in Table 4. Upon processing, no significant difference in water-loss rate was observed among the 3 treatments ($P > 0.05$). Castellini et al. (2002) and Fanatico et al. (2007) found that an outdoor (free-range) production system resulted in a significantly lower water-loss rate when evaluating the effect of the free-range raising system on meat quality. Water-loss rate is important in whole-meat and further-processed meat products that will lack juiciness if the water-loss rate is poor. A lower water-loss rate indicated losses in the nutritional value through exudates that were released, and this resulted in drier and tougher meat (Dabes, 2001). Exercise is an important factor affecting the water-loss rate of tissues. In this experiment, the maximum distance from a feeder was less than 0.7 m, which might not reach the critical value influencing the water-loss rate. Ambient temperature is another factor affecting the water-loss rate of tissues, but there was no difference in temperature in this study.

Among the organoleptic characteristics, tenderness, which can be defined as how easily the meat can be chewed or cut, is considered the most important by consumers. In the present study, stocking density did not influence tenderness ($P > 0.05$). This finding agreed with the work of Dozier et al. (2005) that the breast tenderness was not affected by stocking density. However, Dozier et al. (2006) found a different result, the tender weight decreased linearly as calculated stocking density increased, whereas breast tender yield was similar among the treatments.

Meat color is an important quality attribute, both for the consumer's selection of fresh meat at the retail level and for the consumer's final evaluation and acceptance of a meat product at the time of consumption. Many factors affecting the color of poultry products have been investigated but have not yet been fully elucidated (Maga, 1994). The oxidative state of muscle pigments plays an important role in meat color. Redness is related to myoglobin content and its chemical state in meat (Mancini and Hunt, 2005). In this study, there was no significant difference in meat color, although the absorbance values were different ($P > 0.05$). This might be because stocking density did not change protein oxidation to any extent.

Muscle pH is a significant parameter in terms of preservation and stability of meat, and it is known that a high muscle pH results in shorter shelf life stability, especially as it pertains to microbial growth (Aberle et al., 2001). The rate of pH decline is dependent on the activity of glycolytic enzymes just after death, and the ultimate pH is determined by the initial glycogen reserves of the muscle (Bendall, 1973). In the present study, the muscle pH of birds in the low-density group was significantly lower than that of birds in other

Table 4. Effect of stocking density on meat quality[1]

Item	Stocking density[2] (bird/m^2)			SEM	Significance
	Low	Medium	High		
Water loss rate (%)	31.71	31.33	29.29	1.104	0.264
Shear force (kg)	2.03	2.04	2.17	0.084	0.444
Meat color	0.288	0.309	0.295	0.016	0.620
pH	5.78	5.84	5.83	0.012	0.004

[1]Each value represents the mean of 4 replicates of 8 birds each.

[2]Stocking densities were 25, 35, and 45 birds/m^2 from 1 to 28 d and 12.5, 17.5, and 22.5 birds/m^2 from 29 to 42 d (low, medium, and high, respectively).

Table 5. Effect of stocking density on lymphoid organs[1]

Item	Stocking density[2] (bird/m^2)			SEM	Significance
	Low	Medium	High		
Liver weight (g)	21.87	22.26	20.86	0.415	0.062
(Liver weight/BW) × 100	1.99	2.10	2.04	0.034	0.097
Spleen weight (g)	1.36	1.36	1.25	0.087	0.637
(Spleen weight/BW) × 100	0.12	0.13	0.12	0.008	0.607
Bursa weight (g)	1.07	1.19	1.16	0.099	0.693
(Bursa weight/BW) × 100	0.10	0.11	0.11	0.009	0.423
Thymus weight (g)	6.67	6.71	6.12	0.388	0.494
Thymus weight/BW) × 100	0.61	0.62	0.60	0.034	0.838

[1]Each value represents the mean of 4 replicates of 8 birds each.

[2]Stocking densities were 25, 35, and 45 birds/m^2 from 1 to 28 d and 12.5, 17.5, and 22.5 birds/m^2 from 29 to 42 d (low, medium, and high, respectively).

groups ($P < 0.05$). Culioli et al. (1990) and Castellini et al. (2002) also had similar results when studying the effect of the free-range raising system on meat quality.

Immunological Parameters

Lymphoid organ weights and the organ to BW ratios are shown in Table 5. Treatments did not significantly affect weights of the liver, spleen, bursa, and thymus, and there were no significant differences in the organ to BW ratios as density increased ($P > 0.05$). Measures of immunity that have been commonly used and assessed in poultry are lymphoid organ weights and the organ to BW ratios (Pope, 1991). Our findings are in agreement with Heckert et al. (2002), who reported the density treatments did not significantly affect the spleen and bursa weights, but there was a tendency toward smaller weights of birds reared at densities of 10, 15, and 20 birds/m^2. Similarly, in a recent study, no significant density effects were found on either the absolute bursa weight or the bursa:BW ratio of birds reared at densities of 8, 19, 29, 40, 45, 51, 61, and 72 birds per 3.3 m^2 (Buijs et al., 2009).

The effects of stocking density on some blood parameters are shown in Table 6. The stocking density of birds was found to significantly affect the levels of blood total protein and K ($P < 0.05$), but no significant differences were found in other blood parameters ($P > 0.05$). The results were in agreement with Thaxton et al. (2006), who found that stocking density did not result in a recognizable trend in corticosterone, glucose, cholesterol, and total nitrite concentrations. This was primarily due to a great degree of variability seen between birds when applying these immunological measures. Talebi et al. (1995) also found that there was a great deal of individual bird variability in the lymphocyte blastogenesis assay under even more controlled conditions than used in this study. However, stocking density of rock partridges was found to significantly affect the levels of blood total protein, total cholesterol, triglyceride, urea, glucose, calcium, phosphorus, alkaline phosphatase, sodium, chlorine, and potassium (Özbey and Esen, 2007).

Table 6. Effect of stocking density on some blood parameters[1]

Item[2]	Stocking density[3] (bird/m^2)			SEM	Significance
	Low	Medium	High		
CHOL (mmol/L)	2.503	2.647	2.537	0.125	0.711
TRG (mmol/L)	0.233	0.267	0.280	0.022	0.367
GLU (mmol/L)	11.413	10.913	11.127	0.231	0.37
BUN (mmol/L)	1.093	1.09	0.993	0.105	0.757
TP (g/L)	32.293	37.033	33.503	0.994	0.035
ALB (g/L)	16.433	17.61	16.777	0.288	0.066
K (mmol/L)	5.370	5.427	4.827	0.138	0.040
Na (mmol/L)	149.42	149.423	147.343	0.554	0.059
Cl (mmol/L)	119.093	118.38	117.34	0.462	0.092
Ca (mmol/L)	2.517	2.56	2.487	0.019	0.092
P (mmol/L)	2.58	2.53	2.54	0.075	0.886
LDH (U/L)	680.86	619.777	646.083	34.164	0.490
CK (U/L)	7,599.583	5,742.75	5,656.443	897.384	0.297
ACTH (ng/L)	8.593	7.877	8.053	1.089	0.891
T3 (nmol/L)	0.887	0.917	1.007	0.068	0.479
T4 (nmol/L)	20.157	22.937	20.987	1.255	0.341

[1]Each value represents the mean of 4 replicates of 6 birds each.

[2]CHOL = cholesterol; TRG = triglyceride; GLU = glucose; BUN = blood urea nitrogen; TP = total protein; ALB = albumin; LDH = lactate dehydrogenase; CK = creatine kinase; ACTH = adrenocorticotropic hormone; T3 = triiodothyronine; and T4 = thyroxine.

[3]Stocking densities were 25, 35, and 45 birds/m^2 from 1 to 28 d and 12.5, 17.5, and 22.5 birds/m^2 from 29 to 42 d (low, medium, and high, respectively).

This might be because the degree of variability in broilers is greater than that for rock partridges.

The findings of this study suggest that decreasing the stocking density adversely affects F/G and increased the final BW, whereas no evidence was found that stocking density caused changes in any of the measured immune parameters.

ACKNOWLEDGMENTS

This work was financially supported by a special fund for Agro-scientific Research in the public interest of the Ministry of Agriculture (201003011, National Spark Program Project (S2011C100476), and Agro-three Project of Jiangsu Province [SX(2010)138, SX(2010)019], P. R. China.

REFERENCES

Aberle, E. D., J. C. Forrest, D. E. Gerrard, and E. W. Mills. 2001. Principles of Meat Science. 4th ed. Kendall/Hunt Publ. Co., Dubuque, IA.

Bendall, J. R. 1973. Postmortem changes in muscle. Page 243 in Structure and Function of Muscle. G. H. Bourne, ed. Acad. Press, New York, NY.

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

Bouton, P. E., P. V. Harris, and W. R. Shorthose. 1971. Effect of ultimate pH upon the water-holding capacity and tenderness of mutton. J. Food Sci. 36:435–439.

Buijs, S., L. Keeling, S. Rettenbacher, E. Van Poucke, and F. A. M. Tuyttens. 2009. Stocking density effects on broiler welfare: Identifying sensitive ranges for different indicators. Poult. Sci. 88:1536–1543.

Castellini, C., C. Mugnai, and A. Dal Bosco. 2002. Effect of organic production system on broiler carcass and meat quality. Meat Sci. 60:219–225.

Cravener, T. L., W. B. Roush, and M. M. Mashaly. 1992. Broiler production under varying population densities. Poult. Sci. 71:427–433.

Culioli, J., C. Touraille, P. Bordes, and J. P. Giraud. 1990. Carcass and meat quality in fowls given the "farm production label." Arch. Geflugelkd. 53:237–245.

Dabes, A. C. 2001. Propriedades da carne fresca. Rev. Nac. Carne. 25:32–40.

Darras, V. M., S. Van der Geyten, and E. R. Kühn. 1992. Thyroid hormone metabolism in poultry. Biotechnol. Agron. Soc. Environ. 4:13–20.

Dozier, W. A., III, 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.

Dozier, W. A., III, J. P. Thaxton, J. L. Purswell, H. A. Olanrewaju, S. L. Branton, and W. B. Roush. 2006. Stocking density effects on male broilers grown to 1.8 kilograms of body weight. Poult. Sci. 85:344–351.

Fanatico, A. C., P. B. Pillai, J. L. Emmert, and C. M. Owens. 2007. Meat quality of slow-growing chicken genotypes fed low-nutrient or standard diets and raised indoor or with outdoor access. Poult. Sci. 86:2245–2255.

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.

Food Marketing Institute and National Council of Chain Restaurants. 2003. FMI-NCCR animal welfare program. Food Marketing Inst., Washington, DC.

Heckert, R. A., I. Estevez, E. Russek-Cohen, and R. Pettit-Riley. 2002. Effects of density and perch availability on the immune status of broilers. Poult. Sci. 81:451–457.

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., Dordrecht, the Netherlands.

Maga, J. A. 1994. Pink discoloration in cooked white meat. Food Rev. Int. 10:273–286.

Mancini, R. A., and M. C. Hunt. 2005. Current research in meat color. Meat Sci. 71:100–121.

Molette, C., H. Remignon, and R. Babile. 2003. Maintaining muscle at a high postmortem temperature induces PSE-like meat in turkey. Meat Sci. 63:525–532.

NRC. 1994. Nutrient Requirements of Poultry. 9th rev. ed. Natl. Acad. Press, Washington, DC.

Özbey, O., and F. Esen. 2007. The effects of breeding systems and stocking density on some blood parameters of rock partridges (*Alectoris graeca*). Poult. Sci. 86:420–422.

Pope, C. R. 1991. Pathology of lymphoid organs with emphasis on immunosuppression. Vet. Immunol. Immunopathol. 30:31–44.

Proudfoot, F. G., H. W. Hulan, and D. R. Ramey. 1979. The effect of four stocking densities on broiler carcass grade, the incidence of breast blisters, and other performance traits. Poult. Sci. 58:791–793.

Ravindran, V., D. V. Thomas, D. G. Thomas, and P. C. H. Morel. 2006. Performance and welfare of broilers as affected by stocking density and zinc bacitracin supplementation. Anim. Sci. J. 77:110–116.

Ricard, T. 1977. Influence de l'age et du patrimone genetique sur l'etat d'engraissement du poulet. Pages 79–86 in La Composition Corporelle des Volailles. INRA, Paris, France.

SAS Institute. 1996. SAS User's Guide: Statistics. Version 7.0. SAS Inst. Inc., Cary, NC.

SCAHAW. 2000. The welfare of chickens kept for meat production (broilers). Pages 62–66 in European Commission: Health & Consumer Protection Directorate-General. http://ec.europa.eu/food/fs/sc/scah/out39_en.pdf.

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

Talebi, A., P. R. Torgerson, and G. Mulcahy. 1995. Optimal conditions for measurement of blastogenic responses of chickens to concanavalin A in whole blood assays. Vet. Immunol. Immunopathol. 46:293–301.

Thaxton, J. P., W. A. Dozier III, S. L. Branton, G. W. Morgan, D. W. Miles, W. B. Roush, B. D. Lott, and Y. Vizzier-Thaxton. 2006. Stocking density and physiological adaptive responses of broilers. Poult. Sci. 85:819–824.

Thomas, D. G., V. Ravindran, D. V. Thomas, B. J. Camden, Y. H. Cottam, P. C. H. Morel, and C. J. Cook. 2004. Influence of stocking density on the performance, carcass characteristics, and selected welfare indicators of broiler chickens. N. Z. Vet. J. 52:76–81.

Vanhonacker, F., W. Verbeke, E. Van Poucke, S. Buijs, and F. A. M. Tuyttens. 2008. Societal concern related to stocking density, pen size, and group size in farm animal production. Livest. Sci. 123:16–22.

Wiebicki, E., and F. E. Deatherage. 1958. Determination of water-holding capacity of fresh meats. J. Agric. Food Chem. 6:387–392.