



Impact of Stocking Density on Carcass Composition and Quality in Various Broiler Chicken Strains Fed Commercial Diets

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Abstract: The significance of stocking density emerged with the development of industrial animal agriculture, where economical use of floor space became a common strategy to increase meat production per unit area. Skillful adjustment of stocking density is crucial, as excessively high density can reduce carcass quality, while too low density can result in economic losses. This study aimed to evaluate the carcass traits of three strains of broiler chickens reared at two stocking densities and fed commercial diets. A total of 432 one-day unsexed chicks were distributed in a completely randomized design in a 3×2 factorial arrangement, with three strains (Arbor Acre, Cobb-500, and Marshall) and two densities (16 and 18 birds/m²), each with three replicates. The experimental period lasted 56 days, during which carcass traits, proximate analysis of major muscle parts, and the correlation of live weight to carcass traits were evaluated. The results indicated a significant main effect ($p < 0.05$) of strain on live weight (LW), with Marshall weighing more than Arbor Acre, and Arbor Acre weighing more than Cobb-500. Live body weight decreased with increasing density. Furthermore, there was an interaction between strain and density, with a higher weight associated with Arbor Acre x 16 birds per m², Cobb-500 x 18 birds per m², and Marshall x 16 birds per m² compared to the other densities. In terms of bled, plucked, and eviscerated weights, as well as carcass cut parts and giblets as percentages of LW, no significant effects ($p > 0.05$) of strain, density, or strain * density interaction were observed in any of the traits. The results showed strain-dependent differences in live weight (LW), with Marshall being the heaviest, followed by Arbor Acre and Cobb-500. Stocking density affected LW, favoring 16 birds per m². The interaction between strain and density further influenced LW, showing varied effects across strains and densities. Carcass cut parts and non-carcass parts as percentages of LW were not significantly affected by strain, density, or their interaction. However, proximate composition parameters such as moisture content (MC), crude protein (CP), crude fiber (CF), and ash were significantly influenced by strain, density, and their interaction. Arbor Acre exhibited the highest MC and carbohydrate (CHO) contents, while Cobb-500 had superior CP and ash levels. Marshall generally showed intermediate values across parameters. Correlation analyses revealed complex relationships between live weight, carcass traits, and offal components, varying with strain and stocking density. Notably, certain correlations were consistent across strains and densities, suggesting underlying physiological associations. In conclusion, this study underscores the nuanced effects of strain and stocking density on carcass traits and nutritional composition in broiler chickens. Understanding these dynamics is crucial for optimizing production practices and ensuring desirable meat quality in commercial broiler operation.

Keywords: Arbor Acre, Carcass traits, Cobb-500, Commercial diet, Marshall, Stocking density.

INTRODUCTION

Poultry production has experienced exponential growth, particularly in Nigeria, where new commercial lines of broiler chickens with distinct traits have emerged (Arruda *et al.*, 2016). These lines require regional evaluation to determine their suitability for optimizing profitability while maintaining bird welfare standards (Kosarachukwu *et al.*, 2010; Dozier and Gehring, 2014). One crucial aspect of management conditions is stocking density, which refers to the number of animals per unit area. The significance of stocking density arises from its role in maximizing meat production per unit area, a common strategy in

industrial animal agriculture (Mehmood *et al.*, 2014). Additionally, stocking density is a critical welfare issue (Alltane *et al.*, 2018), and adjusting it skillfully is essential to avoid reductions in carcass quality (Sekeroglu *et al.*, 2011; Hassanein, 2011).

However, there is a lack of comprehensive information regarding the interaction effects of strains and stocking density on broiler carcass characteristics in many developing nations, including Nigeria (Rudzani *et al.*, 2017). This gap is particularly concerning as new, more productive genotypes require specific rearing conditions, including stocking density adjustments. The effects of stocking density on carcass weight and percentage vary across

studies and broiler strains. Some studies suggest that high stocking density reduces carcass weight and percentage (Alltane *et al.*, 2018; Simitzis *et al.*, 2012; Hassanein, 2011), while others report no significant effects (Lima *et al.*, 2018; Das and Lacin, 2014; Uzum and Toplu, 2013; Sekeroglu *et al.*, 2011; Moreira *et al.*, 2004). Alltane *et al.* (2018) observed a carcass percentage ranging from 76.79% to 77.49% in Ross 308 at different stocking densities. Similarly, Thomas *et al.* (2004) reported dressing percentages ranging from 70.2% to 71.1% in male broiler chicks at varying densities. Despite these variations, scientific consensus on the optimal stocking density for commercial broiler production remains elusive. This study aims to address this gap by evaluating the effects of stocking density on carcass traits, cut parts, non-carcass components, sensory quality, and proximate composition in Arbor Acre, Cobb-500, and Marshall Broiler strains. Such research is crucial for establishing evidence-based recommendations for stocking densities in commercial broiler production, especially in the Nigerian context.

Materials and Methods

Study Site and Setup

The study was conducted from February to April 2019 at the Poultry Unit, Teaching and Research Farm, Faculty of Agricultural Sciences, Ekiti State University, Ado-Ekiti, Nigeria. Prior to the study, the site underwent thorough cleaning, washing with detergent, fumigation, and a one-week resting period. The concrete floor was lined with wood shavings, equipped with drinkers and charcoal-heating brooders, and covered with polythene curtains to maintain optimal house temperature for broilers.

Experimental Design and Bird Management

A total of 432 unsexed chicks (144 Arbor acre, 144 Cobb-500, and 144 Marshall), aged 4 weeks were used for the study. The birds were fed *ad libitum* with a commercial broiler finisher diet containing specific nutritional values. The birds had free access to clean water throughout the study period. The experimental design followed a completely randomized 3x2 factorial arrangement, with six treatments replicated thrice, totaling 18 experimental pens with 24 birds per pen. The treatments included different strains reared at two stocking densities: T1 = Arbor Acre at 16 birds per m², T2 = Arbor Acre at 18 birds per m², T3 = Cobb-500 at 16 birds per m², T4 = Cobb-500 at 18 birds per m², T5 = Marshall at 16 birds per m², and T6 = Marshall at 18 birds per m².

Sampling and Slaughter Procedure

At the end of the 56-day experimental period, after an eight-hour feed deprivation, all birds were weighed. Three birds per pen, close to the pen's average weight, were selected for further analysis. These birds were slaughtered using cervical dislocation, followed by bleeding, scalding, plucking, and evisceration. Carcasses without head, neck, feet, and viscera were weighed to determine carcass yield relative to live weight. Various cuts (breast, drumstick, thigh, back, and wing) were removed and weighed to calculate their yield in relation to live weight.

Proximate Analysis

Breast, drumstick, and thigh cuts were de-boned, deskinning, and subjected to proximate analysis. Samples were dried, milled, and stored before determining their moisture, crude protein, crude fat, crude fiber, ash, and carbohydrate contents using AOAC (2000) methods.

Statistical Analysis

Data were analyzed using a 3 × 2 factorial arrangement in a completely randomized design with SPSS version 20. Duncan's Multiple Range Test was used for mean separation at a significance level of 5%. Pearson Bivariate correlation analysis was conducted to assess the relationship between body weight and body traits.

Results

The carcass traits measured at 16 and 18 birds per m² at 8 weeks of age are summarized in Table 1. A main effect (p<0.05) of strain on live weight (LW) was observed, with Marshall having the heaviest weight, followed by Arbor Acre, and Cobb-500 having the least weight. There was also a main effect (p<0.05) of density, indicating higher live weight in the group of 16 birds per m². A strain x density interaction effect (p<0.05) showed a bigger weight associated with 16 birds per m² in Arbor Acre and Marshall, and 18 birds per m² in Cobb-500. However, bled, plucked, and eviscerated weights as percentages of LW showed no effects (p>0.05) of strain, density, or their interaction.

The percentages of carcass cut parts and non-carcass parts as percentages of LW are shown in Tables 2 and 3, respectively. These parameters, including back (BCK), breast (BS), thigh (TH), drumstick (DS), wing (WG), head (HD), neck (NK), shank (SHK), heart (HRT), liver (LIV), lung (LNG), intestine (INT), proventriculus (PRO), and gizzard (GIZ), did not show main effects (p>0.05) of strain, density, or their interaction.

Table 1: Carcass characteristics as percentages of live weight of three broiler strains reared at two stocking densities

Strains	Densities	LW (g)	BLD (%)	PLK (%)	EVI (%)
Arbor Acre		1887.63±42.87 ^b	94.77±1.45	89.46±2.02	78.52±1.4280.
Cobb-500		1796.88±42.87 ^c	97.00±1.45	93.13±2.02	04±1.4277.67±
Marshall		1911.63±42.87 ^a	95.57±1.45	89.27±2.02	1.4277.86±1.1
	16 birds/m ²	1927.08±35.00 ^a	95.01±1.19	89.26±1.65	679.64±1.1677
	18 birds/m ²	1803.67±35.00 ^b	95.56±1.19	91.98±1.65	.16±2.0179.89
Arbor acre x 16 birds/m ²		1969.63±60.23 ^a	92.49±2.06	85.83±2.86	±2.0179.93±2.
Arbor acre x 18 birds/m ²		1805.63±60.23 ^b	97.06±2.06	93.08±2.86	0180.15±2.017
Cobb-500 x 16 birds/m ²		1785.63±60.23 ^b	96.79±2.06	93.24±2.86	6.48±2.0178.8
Cobb-500 x 18 birds/m ²		1808.63±60.23 ^a	97.22±2.06	93.02±2.86	7±2.010.51
Marshall x 16 birds/m ²		2026.63±60.23 ^a	95.75±2.06	88.70±2.86	0.29 0.80
Marshall x 18 birds/m ²		1796.63±60.23 ^b	95.39±2.06 0.56	89.85±2.86 0.34	
p-values (Strain)		0.02	0.34 0.45	0.26 0.40	
p-values (Density)		0.02			
p-values (Density * Strain)		0.03			

a,b,c = Means of the same column with no superscripts are statistically similar ($p>0.05$); ±SEM= Standard Error Mean; LW= Live weight; BLDW= Bled weight; PLK= Plucked weight; EVI= Eviscerated weight

Table 2: Carcass cut parts as percentages of live weight of three broiler strains raised at two stocking densities and their significance

Strains	Density	BCK (%)	BS (%)	TH (%)	DS (%)	WG (%)	HD (%)	NK (%)	SHK (%)
Arbor Acre		13.70±0.31	20.15±0.86	11.47±0.42	11.41±0.81	8.87±0.41	4.66±0.15	2.62±0.11	4.10±0.23
Cobb-500		13.71±0.31	19.13±0.86	11.84±0.42	11.31±0.81	9.29±0.41	4.82±0.15	2.92±0.41	4.51±0.23
Marshall		13.55±0.26	20.56±0.70	11.93±0.34	11.36±0.15	8.98±0.34	4.74±0.12	2.79±0.09	4.15±0.19
16 birds/m ²		13.44±0.26	18.89±0.70	11.04±0.34	11.31±0.15	9.34±0.34	4.94±0.12	2.70±0.09	4.59±0.19
18 birds/m ²		13.06±0.31	19.90±0.86	11.14±0.42	11.29±0.81	9.32±0.41	5.04±0.15	2.70±0.41	4.51±0.23
Arbor acre x 16 birds/m ²		13.12±0.44	21.48±1.21	11.82±0.59	11.69±0.26	8.63±0.58	4.97±0.21	2.60±0.16	4.32±0.33
Arbor acre x 18 birds/m ²		14.29±0.44	18.82±1.21	11.11±0.59	11.12±0.26	9.12±0.58	4.35±0.21	2.64±0.16	3.87±0.33
Cobb-500 x 16 birds/m ²		14.04±0.44	19.88±1.21	12.33±0.59	10.88±0.26	9.30±0.58	4.61±0.21	3.05±0.16	3.92±0.33
Cobb-500 x 18 birds/m ²		13.39±0.44	18.38±1.21	11.35±0.59	11.75±0.26	9.28±0.58	5.04±0.21	2.79±0.16	5.10±0.33
Marshall x 16 birds/m ²		13.49±0.44	20.33±1.21	11.64±0.59	11.52±0.26	9.01±0.58	4.66±0.21	2.72±0.16	4.21±0.33
Marshall x 18 birds/m ²		12.64±0.44	19.48±1.21	10.65±0.59	11.06±0.26	9.62±0.58	5.43±0.21	2.68±0.16	4.80±0.33
p-values (Strain)		0.27	0.68	0.56	0.88	0.70	0.21	0.18	0.38
p-values (Density)		0.77	0.11	0.08	0.81	0.46	0.27	0.53	0.12
p-values (Density * Strain)		0.07	0.75	0.96	0.02	0.85	0.01	0.62	0.07

Means of the same column with no superscripts are statistically similar ($p>0.05$); $\pm$ SEM= Standard Error Mean; BCK= Back weight; BS= Breast weight; TH= Thigh weight; DS= Drumstick weight; WG= Wing weight; HD= Head weight; NK= Neck weight; SHK= Shank weight

Table 3: Non-Carcass cut parts as percentages of live weight of three broiler strains raised at two stocking densities

Strains	Density	HRT (%)	LIV (%)	LNG (%)	INT (%)	PRO (%)	GIZ (%)
Arbor Acre		1.10±0.12	2.0±0.098	0.57±0.027	6.88±0.47	0.49±0.026	1.9±0.072
Cobb-500		0.96±0.12	2.00±0.098	0.63±0.027	7.12±0.47	0.58±0.026	1.999±0.072
Marshall		0.88±0.12	2.10±0.098	0.58±0.027	6.95±0.47	0.52±0.026	1.99±0.072
	16 birds/m ²	0.99±0.09	2.11±0.08	0.61±0.02	7.05±0.38	0.53±0.02	1.94±0.06
	18 birds/m ²	0.97±0.09	2.00±0.08	0.58±0.02	6.92±0.38	0.53±0.02	1.99±0.06
Arbor acre x 16 birds/m ²		1.07±0.16	2.16±0.139	0.53±0.038	6.75±0.66	0.48±0.036	1.83±0.102
Arbor acre x 18 birds/m ²		1.13±0.16	1.98±0.139	0.61±0.038	7.01±0.66	0.50±0.036	1.98±0.102
Cobb-500 x 16 birds/m ²		1.15±0.16	2.17±0.139	0.73±0.038	7.72±0.66	0.58±0.036	1.94±0.102
Cobb-500 x 18 birds/m ²		0.78±0.16	1.83±0.139	0.54±0.038	6.53±0.66	0.58±0.036	2.06±0.102
Marshall x 16 birds/m ²		0.77±0.16	2.02±0.139	0.57±0.038	6.68±0.66	0.52±0.036	2.04±0.102
Marshall x 18 birds/m ²		0.10±0.16	2.18±0.139	0.58±0.038	7.22±0.66	0.52±0.036	1.94±0.102
p-values (Strain)		0.43	0.76	0.18	0.93	0.09	0.61
p-values (Density)		0.84	0.32	0.34	0.81	0.87	0.50
p-values (Density * Strain)		0.20	0.21	0.01	0.34	0.97	0.42

Means of the same column with no superscripts are statistically similar ($p>0.05$); $\pm$ SEM= Standard Error Mean; HRT= Heart weight; LIV= Liver weight; LNG= Lung weight; INT= Intestine weight; PRO= Proventriculus weight; GIZ= Gizzard weight

Table 4 presents the effects of strain, density, and Strain x density interaction on the proximate composition of breast muscle. All proximate composition parameters were significantly influenced by the factors. Arbor Acre had the highest values in moisture (MC) and carbohydrate (CHO) contents, followed by Cobb-500, while Marshall had the highest values in crude protein (CP), crude fat (CF), and ash. The density effect indicated that the group of 16 birds per m² was better in MC and CHO, while the group of 18 birds per m² was better in CP, CF, and ash. Interaction effects were higher in MC, CP, and CHO at 16 birds per m², and CF and ash at 18 birds per m² in Arbor Acre. In Cobb-500, the interaction effects were higher in MC and CHO at 16 birds per m², and CP, CF, and ash at 18 birds per m². In Marshall, MC was higher in 16 birds per m², while CP, CF, ash, and CHO were better in 18 birds per m².

Table 4: Proximate composition of Breast muscle of three broiler strains raised at two stocking density

Strains	Density	MC (%)	CP (%)	CF (%)	Ash (%)	CHO (%)
Arbor Acre		72.60±0.017 ^a	22.52±0.008 ^c	2.20±0.006 ^c	0.85±0.018 ^b	0.83±0.020 ^a
Cobb-500		72.71±0.017 ^b	23.06±0.008 ^b	2.32±0.006 ^b	1.23±0.018 ^a	0.68±0.020 ^b
Marshall		71.09±0.024 ^c	23.31±0.008 ^a	2.72±0.006 ^a	1.26±0.018 ^a	0.63±0.020 ^b
16 birds/m ²		72.73±0.014 ^a	23.09±0.007 ^b	2.25±0.005 ^b	1.06±0.015 ^b	0.85±0.016 ^a
18 birds/m ²		72.19±0.014 ^b	22.83±0.007 ^a	2.57±0.005 ^a	1.17±0.015 ^a	0.57±0.016 ^b
Arbor acre x 16 birds/m ²		72.45±0.024 ^a	23.51±0.011 ^a	2.11±0.008 ^b	0.74±0.026 ^b	1.19±0.028 ^a
Arbor acre x 18 birds/m ²		71.74±0.024 ^b	21.54±0.011 ^b	2.30±0.008 ^a	0.96±0.026 ^a	0.47±0.028 ^b
Cobb-500 x 16 birds/m ²		72.89±0.024 ^a	22.66±0.011 ^b	2.24±0.008 ^b	1.21±0.026 ^b	1.00±0.028 ^a
Cobb-500 x 18 birds/m ²		72.53±0.024 ^b	23.47±0.011 ^a	2.40±0.008 ^a	1.25±0.026 ^a	0.36±0.028 ^b
Marshall x 16 birds/m ²		72.87±0.024 ^a	23.13±0.011 ^b	2.40±0.008 ^b	1.24±0.026 ^b	0.37±0.028 ^b
Marshall x 18 birds/m ²		71.31±0.024 ^b	23.50±0.011 ^a	3.03±0.008 ^a	1.29±0.026 ^a	0.89±0.028 ^a
p-values (Strain)		0.00	0.00	0.00	0.00	0.00
p-values (Density)		0.00	0.00	0.00	0.00	0.00
p-values (Density * Strain)		0.00	0.00	0.00	0.03	0.00

a,b,ab,c=Means of the same column with different superscripts are statistically different (p<0.05); ±SEM= Standard Error

Mean; MC= Moisture content; CP = Crude protein; CF= Crude fat; CHO= Carbohydrate concentration

The results presented in Table 5 show significant effects of strain, density, and their interaction on the proximate composition of drumstick muscle in broiler chickens. Arbor Acre exhibited the highest moisture content (MC) and carbohydrate (CHO) levels, followed by Marshall in MC and Cobb-500 in CHO. On the other hand, Cobb-500 had superior values in crude protein (CP) and ash compared to Marshall, with the least values in CHO. Marshall showed the highest values in crude fat (CF), followed by Arbor Acre, while Cobb-500 had the lowest CF values. The density effect favoured the group with 18 birds per m² in MC, CP, CF, and ash, whereas the group with 16 birds per m² had higher CHO content. Interaction effects were more pronounced in CHO at 16 birds per m² and in MC, CP, CF, and ash at 18 birds per m², especially in Arbor Acre. Cobb-500 showed significant interaction effects in CF and CHO at 16 birds per m², and in MC, CP, and ash at 18 birds per m². However, Marshall generally performed better with 18 birds per m², except for CHO.

Table 6 further demonstrates the effects of strain, density, and their interaction on the proximate composition of thigh muscle. All proximate composition parameters were affected by strain, density, and their interaction, except for MC, which showed no strain effect. Marshall exhibited the highest values in CP, CF, and ash, followed by Cobb-500, while Arbor Acre had the least values, although ash content was similar between Arbor and Cobb-500. In CHO content, Arbor Acre had the highest values, followed by Cobb-500 and Marshall with the least values. The density effect favoured the group with 16 birds per m² in CF and CHO, while the group with 18 birds per m² had higher values in MC, CP, and ash. Interaction effects were more pronounced in CP and CHO at 16 birds per m², whereas at 18 birds per m², they were higher in MC, CF, and ash in Arbor Acre. In Cobb-500, the interaction effect was higher in CHO alone at 16 birds per m² and in CP, CF, and ash at 18 birds per m². Marshall showed higher CF and CHO values at 16 birds per m², while MC, CP, and ash were higher at 18 birds per m².

Table 5: Proximate composition of drumstick muscle of three broiler strains raised at two stocking densities

Strains	Density	MC (%)	CP (%)	CF (%)	Ash (%)	CHO (%)
Arbor Acre		69.55±0.01 ^a	22.08±0.008 ^c	1.82±0.016 ^b	1.06±0.009 ^c	5.41±0.035 ^a
Cobb-500		69.06±0.01 ^c	22.89±0.008 ^a	1.52±0.016 ^c	1.52±0.009 ^a	5.03±0.035 ^b
Marshall		69.41±0.01 ^b	22.75±0.008 ^b	7±0.016 ^a	1.12±0.009 ^b	4.43±0.035 ^c
16 birds/m ²		68.42±0.008 ^b	22.30±0.007 ^b	0.013 ^b	1.05±0.007 ^b	6.40±0.029 ^a
18 birds/m ²		70.26±0.008 ^a	22.86±0.007 ^a	1.90±0.013 ^a	1.42±0.007 ^a	3.51±0.029 ^b
Arbor acre x 16 birds/m ²		68.92±0.014 ^b	21.65±0.012 ^b	1.59±0.022 ^b	1.03±0.013 ^b	6.83±0.050 ^a
Arbor acre x 18 birds/m ²		70.19±0.014 ^a	22.52±0.012 ^a	2.05±0.022 ^a	1.10±0.013 ^a	3.99±0.050 ^b
Cobb-500 x 16 birds/m ²		67.90±0.014 ^b	22.61±0.012 ^b	1.91±0.022 ^a	1.02±0.013 ^b	6.57±0.050 ^a
Cobb-500 x 18 birds/m ²		70.21±0.014 ^a	23.17±0.012 ^a	1.12±0.022 ^b	2.02±0.013 ^a	3.49±0.050 ^b
Marshall x 16 birds/m ²		68.43±0.014 ^b	22.66±0.012 ^b	2.01±0.022 ^b	1.09±0.013 ^b	5.82±0.050 ^a
Marshall x 18 birds/m ²		70.39±0.014 ^a	22.89±0.012 ^a	2.54±0.022 ^a	1.16±0.013 ^a	3.04±0.050 ^b
p-values (Strain)		0.00	0.00	0.00	0.00	0.00
p-values (Density)		0.00	0.00	0.01	0.00	0.00
p-values (Density * Strain)		0.00	0.00	0.00	0.00	0.05

a,b,c= Means of the same column with different superscripts are statistically different (p<0.05); ±SEM= Standard Error Mean; MC=

Moisture content; CP = Crude protein; CF= Crude fat; CHO= Carbohydrate concentration

Table 6: Proximate composition of Thigh muscle of three broiler strains raised at two stocking densities

Strains	Density	MC (%)	CP (%)	CF (%)	Ash (%)	CHO (%)
Arbor Acre		71.05±0.137	20.71±0.021 ^c	1.12±0.008 ^c	1.08±0.006 ^b	6.31±0.021 ^a
Cobb-500		71.59±0.137	21.73±0.021 ^b	1.23±0.008 ^b	1.08±0.006 ^b	4.38±0.021 ^b
Marshall		71.40±0.137	21.93±0.021 ^a	1.73±0.008 ^a	1.12±0.006 ^a	3.83±0.021 ^c
16 birds/m ²		70.86±0.112 ^b	20.99±0.017 ^b	1.11±0.006 ^b	1.04±0.005 ^b	6.01±0.017 ^a
18 birds/m ²	70	71.82±0.112 ^a	21.92±0.017 ^a	1.95±0.006 ^a	1.14±0.005 ^a	3.35±0.017 ^b
Arbor acre x 16 birds/m ²		.32±0.194 ^b	20.72±0.029 ^a	1.02±0.011 ^b	1.05±0.008 ^b	6.93±0.030 ^a
Arbor acre x 18 birds/m ²		71.78±0.194 ^a	20.71±0.029 ^b	1.22±0.011 ^a	1.11±0.008 ^a	5.70±0.030 ^b
Cobb-500 x 16 birds/m ²		71.58±0.194	20.95±0.029 ^b	1.21±0.011 ^b	1.02±0.008 ^b	5.26±0.030 ^a
Cobb-500 x 18 birds/m ²		71.60±0.194	22.52±0.029 ^a	1.26±0.011 ^a	1.14±0.008 ^a	3.50±0.030 ^b
Marshall x 16 birds/m ²		70.69±0.194 ^b	21.31±0.029 ^b	1.11±0.011 ^a	1.06±0.008 ^b	5.84±0.030 ^a
Marshall x 18 birds/m ²		72.10±0.194 ^a	22.56±0.029 ^a	1.36±0.011 ^b	1.19±0.08 ^a	2.82±0.030 ^b
p-values (Strain)		0.08	0.00	0.00	0.00	0.00
p-values (Density)		0.00	0.00	0.00	0.00	0.00
p-values (Density * Strain)		0.02	0.00	0.00	0.05	0.00

a,b,ab,c=Means of the same column with different superscripts are statistically different ($p<0.05$); Means of the same column with no superscripts are similar different ($p>0.05$); $\pm$ SEM= Standard Error Mean; MC= Moisture content; CP = Crude protein; CF= Crude fat; CHO= Carbohydrate concentration

Tables 7, 8, and 9 provide insights into the correlations between live weight, carcass traits, and offal components for Arbor Acre, Cobb-500, and Marshall at different stocking densities (16 birds per m² and 18 birds per m²).

In Arbor Acre at 16 birds per m², several strong correlations were observed. The bled value was highly positively correlated with eviscerated weight and highly negatively correlated with neck size. Plucked weight showed positive correlations with bled and eviscerated weights. However, live weight had negative correlations with wing size, back size with drumstick, and heart size with lung. At 18 birds per m², thigh size was strongly positively correlated with gizzard size and moderately positively correlated with shank size. On the contrary, live weight showed strong negative correlations with wing size, while liver size had negative correlations with eviscerated and intestinal values. In Cobb-500 at 16 birds per m², notable correlations included strong negative correlations between thigh size and wing size, intestine size with proventriculus and shank sizes, and proventriculus with shank size. Bled weight was positively correlated with wing size, and live weight had negative correlations with neck size. At 18 birds per m²,

significant positive correlations were observed between plucked weight and gizzard size, as well as between shank size and neck and head sizes. However, negative correlations were found between breast and wing sizes, as well as between head and lung sizes.

In Marshall at 16 birds per m², perfect correlation was noted between head size and eviscerated weight. Strong negative correlations were observed between breast and wing sizes, neck and gizzard sizes, and plucked weight and shank size. Furthermore, negative correlations were found between bled and head weights, thigh and wing sizes, heart size and shank size.

Table 7: Correlations between Live Weight, Carcass Traits and Non-Carcass Components in Arbor Acre at 16 Birds per m2 (Above Diagonal) and 18 Birds per m2 (Below diagonal)

	LW	BLW	PLW	EVW	BKW	BSW	THW	DS	WGW	HDW	NKW	HTW	LVW	LGW	INW	PRO	GIZ	SHK
LW	1	-.708	-.831	-.662	-.913	.424	.544	.810	-.965*	.332	.574	-.842	.197	-.713	.272	-.753	.423	.834
BLW	.647	1	.979*	.995**	.567	.291	-.391	-.430	.856	-.451	-.983*	.540	-.591	.344	-.870	.599	.026	-.206
PLW	.940	.451	1	.967*	.717	.129	-.412	-.590	.943	-.493	-.932	.628	-.557	.432	-.761	.712	-.137	-.388
EVW	.515	-.207	.499	1	.549	.370	-.303	-.425	.828	-.515	-.993**	.458	-.663	.252	-.901	.617	.006	-.139
BKW	.001	.759	-.232	-.657	1	-.346	-.168	-.978*	.889	-.618	-.455	.569	-.399	.418	-.174	.932	-.743	-.787
BSW	.198	.646	-.145	-.037	.745	1	.515	.323	-.173	-.425	-.461	-.608	-.709	-.723	-.716	-.013	.294	.841
THW	.253	-.477	.542	.493	-.883	-.859	1	-.022	-.451	-.565	.269	-.905	-.511	-.942	.084	.137	-.429	.527
DS	.826	.154	.809	.905	-.471	.009	.504	1	-.782	.697	.331	-.404	.438	-.260	.072	-.949	.865	.736
WGW	-.991**	-.695	-.886	-.516	-.082	-.326	-.136	-.813	1	-.476	-.759	.745	-.414	.572	-.505	.809	-.366	-.663
HDW	.184	-.582	.457	.579	-.949	-.833	.985*	.522	-.078	1	.494	.221	.924	.424	.460	-.860	.695	.028
NKW	.883	.828	.672	.374	.368	.635	-.216	.646	-.936	-.260	1	-.387	.679	-.183	.944	-.548	-.088	.028
HTW	-.752	-.807	-.758	.156	-.369	-.075	-.081	-.279	.716	.072	-.640	1	.281	.972*	-.108	.278	.024	-.794
LVW	-.225	.456	-.219	-.951*	.729	.087	-.445	-.729	.233	-.569	-.119	-.453	1	.498	.730	-.693	.369	-.252
LGW	.825	.543	.620	.689	.068	.571	-.073	.823	-.883	-.055	.917	-.338	-.499	1	.081	.083	.111	-.780
INW	-.119	.399	-.032	-.876	.546	-.146	-.183	-.611	.163	-.329	-.147	-.565	.961*	-.527	1	-.351	-.260	-.302
PRO	-.317	-.074	-.080	-.735	.079	-.606	.224	-.590	.409	.107	-.526	-.308	.740	-.786	.865	1	-.783	-.516
GIZ	.195	-.542	.484	.509	-.915	-.867	.997**	.485	-.081	.995**	-.267	-.002	-.484	-.098	-.231	.198	1	.531
SHK	.384	-.414	.625	.662	-.895	-.735	.977*	.670	-.284	.978*	-.056	-.082	-.593	.130	-.347	.021	.974*	1

*. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed); LW = Live weight, BLW = Bled weight, PLW = Plucked weight, EVW = Eviscerated weight, BKW = Back weight, BSW = Breast weight, THW = Thigh weight, DS = Drumstick weight, WGW = Wing weight, HDW = Head weight, NKW = Neck weight, HTW = Heart weight, LVW = Liver weight, LGW = Lung weight, INW = Intestinal weight, PRO = Proventriculus weight, GIZ = Gizzard weight, SHK = Shank weight

Table 8: Correlations between Live Weight, Carcass Traits and Non-Carcass Components in Cobb-500 at 16 Birds per m² (Above Diagonal) and 18 Birds per m² (Below diagonal)

	LW	BLW	PLW	EVW	BKW	BSW	THW	DS	WGW	HDW	NKW	HTW	LVW	LGW	INW	PRO	GIZ	SHK
LW	1	0.11	-0.88	0.06	0.43	-0.16	0.77	-0.40	-0.81	0.85	-.964*	-0.53	0.59	0.24	-0.79	0.80	-0.64	0.78
BLW	0.50	1	0.36	-0.13	0.38	-.982*	-0.54	0.54	0.49	0.60	-0.27	0.76	0.68	-0.32	-0.54	0.58	0.21	0.52
PLW	0.92	0.13	1	-0.03	-0.15	-0.29	-.969*	0.69	.982*	-0.51	0.76	0.87	-0.28	-0.46	0.52	-0.51	0.76	-0.53
EVW	0.45	0.87	0.17	1	0.81	0.31	0.19	0.58	-0.16	0.11	-0.24	0.06	-0.57	-0.83	0.44	-0.36	0.63	-0.46
BKW	-0.29	-0.37	-0.26	-0.77	1	-0.24	0.17	0.61	-0.18	0.65	-0.65	0.22	0.02	-0.77	-0.14	0.22	0.42	0.11
BSW	-0.33	-0.51	-0.07	-0.03	-0.59	1	0.49	-0.38	-0.44	-0.61	0.27	-0.67	-0.79	0.13	0.64	-0.67	-0.04	-0.63
THW	0.11	0.37	0.05	0.77	-.977*	0.61	1	-0.65	-.998**	0.35	-0.66	-0.92	0.03	0.36	-0.30	0.29	-0.63	0.31
DS	0.75	0.83	0.45	0.54	0.01	-0.80	-0.09	1	0.65	0.05	0.15	0.85	-0.24	-0.94	0.34	-0.27	0.92	-0.38
WGW	0.39	0.32	0.21	-0.16	0.69	-.964*	-0.75	0.73	1	-0.40	0.69	0.91	-0.10	-0.37	0.36	-0.35	0.66	-0.37
HDW	-0.07	0.33	-0.32	-0.15	0.74	-0.91	-0.69	0.53	0.85	1	-0.93	-0.01	0.74	-0.09	-0.84	0.89	-0.31	0.83
NKW	0.64	0.31	0.67	0.65	-0.89	0.45	0.78	0.17	-0.45	-0.75	1	0.34	-0.55	0.01	0.74	-0.78	0.42	-0.73
HTW	-0.52	0.06	-0.70	-0.32	0.76	-0.63	-0.62	0.11	0.54	0.89	-0.93	1	0.09	-0.60	0.13	-0.09	0.72	-0.16
LVW	-0.86	-0.87	-0.60	-0.77	0.39	0.48	-0.29	-0.91	-0.40	-0.14	-0.55	0.27	1	0.40	-.961*	.953*	-0.58	.960*
LGW	0.11	-0.54	0.43	-0.11	-0.52	0.85	0.43	-0.57	-0.71	-.951*	0.63	-0.87	0.24	1	-0.42	0.34	-0.90	0.45
INW	-0.87	-0.62	-0.67	-0.33	-0.11	0.76	0.25	-0.94	-0.78	-0.43	-0.21	0.03	0.85	0.38	1	-.996**	0.68	-.999**
PRO	-0.28	-0.81	0.10	-0.43	-0.24	0.88	0.20	-0.85	-0.73	-0.82	0.26	-0.58	0.63	0.91	0.66	1	-0.62	.992**
GIZ	0.92	0.12	.992**	0.10	-0.14	-0.17	-0.07	0.49	0.33	-0.21	0.57	-0.61	-0.60	0.35	-0.73	0.03	1	-0.70
SHK	0.63	0.46	0.59	0.77	-0.92	0.37	0.83	0.26	-0.42	-0.66	.985*	-0.85	-0.64	0.50	-0.24	0.12	0.49	1

*. Correlation is significant at the 0.05 level (2-tailed); **. Correlation is significant at the 0.01 level (2-tailed); LW = Live weight, BLW = Bled weight, PLW = Plucked weight, EVW = Eviscerated weight, BKW = Back weight, BSW = Breast weight, THW = Thigh weight, DS = Drumstick weight, WGW = Wing weight, HDW = Head weight, NKW = Neck weight, HTW = Heart weight, LVW = Liver weight, LGW = Lung weight, INW = Intestinal weight, PRO = Proventriculus weight, GIZ = Gizzard weight, SHK = Shank weight

Table 9: Correlations between Live Weight, Carcass Traits and Non-Carcass Components in Marshall at 16 Birds per m² (Above Diagonal) and 18 Birds per m² (Below diagonal)

	LW	BLW	PLW	EVW	BKW	BSW	THW	DS	WGW	HDW	NKW	HTW	LVW	LGW	INW	PRO	GIZ	SHK
LW	1	0.10	-0.32	-0.33	-0.44	0.76	0.89	0.42	0.76	-0.28	0.70	-0.90	0.27	0.35	0.26	-0.91	-0.71	-0.90
BLW	0.85	1	0.85	0.84	-0.31	-0.44	-0.35	0.50	0.47	-.966*	0.44	0.30	0.58	-0.07	0.81	-0.50	-0.34	0.34
PLW	0.89	.977*	1	1.00**	-0.39	-0.83	-0.71	0.37	0.85	-0.81	0.32	0.58	0.67	-0.53	0.81	-0.06	-0.23	0.64
EVW	-0.07	-0.09	-0.27	1	-0.39	-0.84	-0.72	0.36	0.86	-0.80	0.31	0.59	0.67	-0.53	0.80	-0.04	-0.23	0.65
BKW	-0.52	-0.77	-0.83	0.66	1	0.15	-0.19	0.66	-0.12	0.53	-0.93	0.42	-0.94	0.67	-0.80	0.46	0.94	0.34
BSW	0.66	0.68	0.55	0.66	-0.06	1	0.94	-0.31	-.998**	0.35	0.09	-0.83	-0.40	0.70	-0.44	-0.50	-0.14	-0.88
THW	0.72	0.41	0.37	0.55	0.20	0.81	1	-0.54	-.954*	0.19	0.39	-.967*	-0.08	0.45	-0.18	-0.63	-0.45	-.986*
DS	-0.60	-0.90	-0.90	0.41	.958*	-0.32	0.03	1	0.36	-0.26	-0.54	0.71	-0.38	0.47	-0.08	0.12	0.63	0.66
WGW	-0.93	-0.59	-0.68	0.13	0.30	-0.47	-0.76	0.32	1	-0.37	-0.11	0.85	0.37	-0.65	0.44	0.48	0.16	0.89
HDW	-.988*	-0.90	-0.91	-0.01	0.54	-0.74	-0.71	0.66	.863	1	-0.66	-0.09	-0.74	0.17	-0.92	0.63	0.57	-0.14
NKW	-0.02	0.25	0.03	0.84	0.21	0.72	0.30	-0.06	.275	0.86	1	-0.58	0.88	-0.37	0.81	-0.75	-.994**	-0.51
HTW	0.36	-0.10	0.09	-0.51	-0.01	-0.31	0.25	0.17	-0.66	0.27	-0.11	1	-0.15	-0.22	0.00	0.65	0.64	.996**
LVW	0.56	0.04	0.17	-0.14	0.14	0.08	0.63	0.21	-0.83	-0.44	-0.55	0.91	1	-0.69	0.95	-0.44	-0.85	-0.06
LGW	0.17	0.23	0.04	0.94	0.37	0.85	0.62	0.09	-0.01	-0.27	0.93	-0.59	-0.19	1	-0.51	-0.32	0.38	-0.30
INW	0.10	0.10	0.29	-.999**	-0.65	-0.64	0.52	-0.41	-0.17	-0.02	-0.85	0.54	0.18	-0.94	1	-0.53	-0.76	0.07
PRO	-0.84	-0.92	-.980*	0.46	0.90	-0.37	-0.23	0.92	0.66	0.85	0.14	-0.19	-0.20	0.16	-0.47	1	0.72	0.64
GIZ	-0.3-	0.05	-0.16	0.74	0.24	0.48	0.01	0.01	0.55	0.16	0.952*	-0.953*	-0.75	0.79	-0.77	0.31	1	0.57
SHK	0.50	-0.07	-0.26	0.53	0.15	0.21	-0.30	-0.01	0.76	0.37	0.82	-.986*	-0.91	0.56	-0.57	0.35	.951*	1

*. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

LW = Live weight, BLW = Bled weight, PLW = Plucked weight, EVW = Eviscerated weight, BKW = Back weight, BSW = Breast weight, THW = Thigh weight, DS = Drumstick weight, WGW = Wing weight, HDW = Head weight, NKW = Neck weight, HTW = Heart weight, LVW = Liver weight, LGW = Lung weight, INW = Intestinal weight, PRO = Proventriculus weight, GIZ = Gizzard weight, SHK = Shank weight

At 18 birds per m², highly significant negative correlations were obtained between eviscerated and intestinal weights, live and head weights, plucked weight and proventriculus size, heart and gizzard sizes, and shank size. Conversely, positive correlations were observed between back and drumstick sizes, gizzard size and neck and shank sizes.

Discussion

The study revealed significant differences in live weight among the strains, with Marshall exhibiting the highest weight and Cobb-500 showing the lowest weight. This finding aligns with prior studies (Amao et al., 2015; Korver et al., 2004; Gonzales et al., 1998), emphasizing the critical role of genotype in determining poultry body weight. The reduced body weight observed at higher stocking densities may be attributed to overcrowding, which restricts space for growth and limits access to feed, potentially leading to nutritional deficiencies, particularly evident in the 18 birds per m² group (Alltane et al., 2018). This trend is consistent with earlier research indicating a decrease in live weight with increasing densities (Hassanein, 2011; Simitzis et al., 2012; Petek et al., 2014; Das and Lacin, 2014). The study also found similarities in the effects of strain, density, and strain x density interactions on bled, plucked, and eviscerated weights as percentages of live weight. This observation is in line with the work of Fernandes et al. (2001) and Oliveira et al. (2004), who reported no significant impact of rearing density on carcass yields in broilers of different genetic strains. These results suggest that increasing housing density from 16 to 18 birds per m² did not lead to a reduction in carcass characteristics in any of the three evaluated strains due to competition or stress resulting from overcrowding.

In poultry meat production, three crucial factors include quantitative, qualitative, and welfare considerations. Evaluating meat cut parts at the same chronological age across different broiler strains is an accepted method for assessing differences in carcass characteristics (Iman-Rahayu et al., 2008). This study focused on breast, drumstick, and thigh components, which are primary sources of meat, corroborating findings from prior research (Broadbent et al., 1981; Iman Rahayu et al., 2008). The consistency in carcass cut parts implies that the three strains likely invested equally in developing leg and breast muscles. This aligns with reports by Fernandes et al. (2001) and Oliveira et al. (2004), who found no significant impact of rearing density on cut parts' yields in broilers of different genetic strains. Similarly, Rudzani et al. (2017) observed no effects of genotype, stocking density, or their interactions on various cut parts' percentages in Ross 308 and Cobb Avian 48 broilers. However, these results contrast with Hassanein's (2011) findings, which indicated reductions in breast and thigh weights with increased stocking density. Additionally, Rudzani et al. (2017) reported that stocking density significantly influenced breast percentage in Ross 308 and Cobb Avian 48 broilers. Furthermore, Iman Rahayu et al. (2008) noted a decrease in breast percentage with rising stocking density. Heart, liver, and gizzard weights remained similar across the strains, likely due to their essential functions as blood suppliers in birds (Rudzani et al., 2017). These consistent organ weights underscore their critical roles in avian physiology.

The study revealed significant influences of strain, density, and their interaction on all proximate composition parameters. This reaffirms that the genetics of the animal are paramount in shaping

carcass composition (Thaxton et al., 2006; Adeyemo et al., 2016), aligning with the views of Liu et al. (2006) and Iman Rahayu et al. (2008) regarding the importance of genotype, age, diet, and gender in determining poultry meat composition, especially in terms of fat and protein contents.

Notably, crude protein, fat, and ash contents were notably higher in leg muscles of birds housed at 18 birds per m², likely due to reduced activity stemming from higher density. This observation resonates with Vitorović's insights (1992) as cited by Škrbić et al. (2009), suggesting that increased floor space per chicken can influence physical activity, skeletal development, and firmness, particularly in legs, consequently impacting morphometric bone parameters and mechanical characteristics through improved blood supply to long bone epiphyses and adequate mineralization. However, these findings contrast with reports by Abeni and Bergoglio (2001) and Adeyemo et al. (2016), who found no discernible differences in meat composition parameters among birds stocked at varying densities. Additionally, Sogunle et al. (2008) reported higher crude protein, fat, and ash contents in Arbor Acre and Marshall MY breeds compared to the values observed in this study, suggesting potential breed-specific variations in composition. Furthermore, the present study hinted at higher protein content, albeit not explicitly tested, in breast muscles compared to leg muscles (drumstick and thigh), contrary to fat content trends. This disparity could be attributed to variations in muscle fiber types and activities associated with different muscle parts.

Genetic and phenotypic correlations play crucial roles in understanding the genetic parameters of a population, especially in the context of breeding programs (Gaya et al., 2011). In our study, significant correlations were observed among various traits in different strains of broiler chickens housed at different densities. At 16 birds per m², positive relationships were noted between bled and eviscerated weights, as well as between plucked and bled values in Arbor Acre. Similar positive correlations were found between bled and wing weights in Cobb-500, and head and eviscerated weights in Marshall. Conversely, negative correlations were observed between bled and neck, live weight and wing, back and drumstick, and heart and wing in Arbor Acre; thigh and wing, intestine and proventriculus, and shank, live weight and neck, bled and breast, plucked and thigh, and intestine and liver in Cobb-500; and between breast and wing, neck and gizzard, plucked and shank, bled and head, thigh and wing, and heart and shank in Marshall. When the density increased to 18 birds per m², positive correlations were found between thigh and gizzard, and shank values in Arbor Acre; plucked and gizzard, shank, and neck, and head values in Cobb-500; and back and drumstick, gizzard and neck, and shank in Marshall. Conversely, negative correlations were observed between live weight and wing, and liver; and between eviscerated and intestinal values in Arbor Acre; breast and wing, and head and lung in Cobb-500; and between live weight and head, plucked and proventriculus, heart and gizzard, and shank in Marshall. These results indicate a strong phenotypic correlation among body weight, carcass traits, and offal components. This correlation could stem from pleiotropic effects of genes and linkage effects influencing these traits. Consequently, positive phenotypic correlations may translate into positive genetic correlations, allowing selection for one trait to improve the other as a correlated response (El-Labban, 1999; Tougan et al., 2013).

However, traits showing negative correlations cannot be improved simultaneously, necessitating separate improvement efforts that may increase time and costs.

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