Original Article

Morphometric measurements and carcass characteristics of Black Australorp, Naked Neck, and Rhode Island Red crossbreds under alternative production systems

Medições morfométricas e características de carcaça de Black Australorp, Naked Neck e Rhode Island Red crossbreds sob sistemas de produção alternativos

M. Usman[a]* , H. M. Ishaq[b] , A. Mahmud[a] , E. Bughio[c] , M. Azhar[d] , M. M. Saleem[e] , M. F. Riaz[a] , H. A. Raza[a] , M. Hussain[a] , H. R. A. Latif[a] and S. Ahmad[a]*

[a]University of Veterinary and Animal Sciences, Faculty of Animal Production and Technology, Department of Poultry Production, Lahore, Pakistan

[b]Bahauddin Zakariya University, Faculty of Veterinary Sciences, Department of Livestock and Poultry Production, Multan, Pakistan

[c]Shaheed Benazir Bhutto University of Veterinary and Animal Sciences, Faculty of Animal Production and Technology, Department of Poultry Production, Sakrand, Pakistan

[d]Poultry Research Institute, Rawalpindi, Pakistan

[e]University of Veterinary and Animal Sciences, College of Veterinary and Animal Sciences, Narowal, Pakistan

Abstract

The present trial explained the effect of alternative production systems on growth, morphometric and carcass traits of four different chicken genotypes. The second generation of two genotypes RNN (Rhode Island Red × Naked Neck) and BNN (Black Australorp × Naked Neck) obtained by two self-crosses (RNN × RNN = RR and BNN × BNN = BB) and two reciprocal crosses (RNN × BNN = RB and BNN × RNN = BR) were evaluated in three alternative production systems (conventional cages, enriched cages, and aviary). At the 6th week of age after sexing, a total of 600 birds, comprising 150 from each crossbred with a total of 300 pullets and 300 cockerels were divided into conventional cages, enriched cages, and aviary systems having 200 birds in each.Birds were organized into 3×4 factorial arrangements under Completely Randomized Design (3 production systems × 4 genotypes × 2 sexes × 25 birds = 600 birds). Regarding genotypes, RB and BR males showed higher (p < 0.01) carcass yield, drumstick weight, breast weight, and thigh weight than BB and RR genotypes. Females of BR genotype showed higher (p < 0.01) breast weight, thigh weight and drumstick weight. As far as production systems are concerned, higher (p < 0.01) liver weight, heart weight, breast weight, intestinal weight, drumstick weight, and thigh weight were observed in the males reared in enriched cages compared with conventional cages and aviary system. Females reared in enriched cages showed higher (p < 0.01) heart weight, breast weight, intestinal weight, drumstick weight, and thigh weight when compared with those reared in conventional cages and aviary. It is concluded that chickens (both sexes) of BR and RB genotypes had better morphological measurements and carcass traits than those of RR and BB genotype chickens. Among alternative production systems, chickens reared in enriched cages had better traits than those of reared in conventional cages and aviary during the growing phase.

Keywords: crossbred chickens, alternative production systems, carcass traits, morphometric, measurements.

Resumo

O presente estudo explicou o efeito de sistemas alternativos de produção sobre o crescimento, características morfométricas e carcaças de quatro genótipos de frango diferentes. A segunda geração de dois genótipos RNN (Rhode Island Red × Naked Neck) e BNN (Black Australorp × Naked Neck) obtida por duas autocruzes (RNN × RNN = RR e B ANN × BNN = BB) e duas cruzes recíprocas (RNN × BNN = RB e BNN × RNN = BR) foi avaliada em três sistemas de produção alternativos (gaiolas convencionais, gaiolas enriquecidas e aviário). Na 6ª semana de idade após o sexo, um total de 600 aves, compostas por 150 de cada raça cruzada com um total de 300 pullets e 300 galos, foi dividido em gaiolas convencionais, gaiolas enriquecidas e sistemas aviários com 200 aves em cada. As aves foram organizadas em 3×4 arranjos fatoriais sob projeto completamente randomizado (3 sistemas de produção × 4 genótipos × 2 sexos × 25 aves = 600 aves). Em relação aos genótipos, os machos RB e BR apresentaram maior rendimento de carcaça (p < 0,01), peso da baqueta, peso mamário e peso da coxa do que os genótipos BB e RR. As fêmeas do genótipo BR apresentaram maior (p < 0,01) peso mamário, peso da coxa e peso da baqueta. No que diz respeito aos sistemas de produção, maior (p < 0,01) peso hepático, peso cardíaco, peso mamário, peso intestinal, peso da baqueta e peso da coxa foram observados nos machos criados em gaiolas enriquecidas em comparação

com gaiolas convencionais e sistema aviário. As fêmeas criadas em gaiolas enriquecidas apresentaram maior (p < 0,01) peso cardíaco, peso mamário, peso intestinal, peso da baqueta e peso da coxa quando comparadas com as criadas em gaiolas convencionais e aviárias. Conclui-se que as galinhas (ambos os sexos) dos genótipos BR e RB apresentaram melhores medidas morfológicas e traços de carcaça do que os de frangos genótipos RR e BB. Entre os sistemas de produção alternativos, as galinhas criadas em gaiolas enriquecidas tinham características melhores do que as criadas em gaiolas convencionais e aviárias durante a fase de cultivo.

Palavras-chave: galinhas de raça cruzada, sistemas de produção alternativos, traços de carcaça, morfométrica, medidas.

1. Introduction

Native chicken breeds in traditional extensive production systems are integral part of the poultry production in developing countries (Ghayas et al., 2020). These chickens are famous for better adaptability to the local environment (Batool et al., 2018) and their perpetuate role in breaking the vicious cycles of nutritional scarcities in developing countries (Terfa et al., 2019). However, due to unplanned and haphazard crossing in village farming systems, the traits of economic importance in these birds are not feasible for enough profit generation. Such quantitative characteristics like, body weight, growth and egg production can be value-added by improving genetics and housing conditions (Ndegwa and Kimani 1997; Okeno et al., 2011; Havenstein et al., 2003 a, b). Selection and crossbreeding are the most accurate and adapted methods to get genetically superior chickens in successive generations **(**Bungsrisawat et al., 2018**)**. These practices may result in changes in morphometric and carcass traits (Bungsrisawat et al., 2018; Ahmad et al., 2019). For example, Keel bone structure is significantly influenced by genetic background and husbandry systems (Eusemann et al., 2020). In a previous study, body weight and breast meat yield in 16 week old Betong chickens were found to be highly inheritable traits (heritability = 0.45 and 0.50 respectively) that showed the potential of such traits for enhanced meat yield from the selected birds (Bungsrisawat et al., 2018).

Crossing the indigenous germplasm with exotic breeds can result in the improvement of production performance, carcass and reproductive traits and better acclimatization to local environment (Adebambo et al., 2011; Khawaja et al., 2013). Genetic manipulations for enhanced production may result in modification of overall physiology of chicken's body as observed in commercial broilers (Tallentire et al., 2016; Hartcher and Lum, 2020) and layers (Rowland et al., 2019). To maintain the physiological status of genetically selected birds, one should also make suitable changes to the rearing system that can help the birds to perform according to the genetic potential by maintaining their metabolic physiology (Preisinger, 2005).

In Pakistan, Rhode Island Red (RIR) and Naked Neck chickens are preferred genotypes among the rural community and in most cases live in scavenging conditions (Sadef et al., 2015). However, Naked Neck chicken is believed to be more suitable because of more adaptability to harsh climate (Melesse et al., 2011). Some rural farmers keep them in indoor cages for more profitability. Although, these conventional cages have some advantages in terms of higher output by enhanced production from the birds, however, there are reports that describe these cages as an unfriendly environment especially from bird welfare point of view. Since the ban from European countries on these cages in 2012 (Appleby, 2003), animal welfare organizations are putting more emphasis on replacement of this system with welfare friendly alternative production systems. Considering such scenarios, efforts were made to mitigate the effect of total confinement of the birds by rearing them in aviary and enriched cages (Leyendecker et al., 2005; Pohle and Cheng, 2009). In an enriched cage, facilities for dust bath, nesting and walk are provided within the cage (Sosnówka-Czajka et al., 2010). But, their potential use in newly developed crossbreds of Naked Neck, RIR and Black Australorp has never been studied earlier. Keeping in mind the expected outcome of genetic structuring and the need for suitable rearing systems, it was hypothesized that the morphometric and carcass traits in Naked Neck chicken crossbreds will differ under aviary, conventional cage and enriched cage systems.

2. Material and Methods

The study evaluated the performance of crossbreds of Naked Neck (NN), Black Australorp (BAL) and Rhode Island Red (RIR) under alternative production systems i.e., conventional cages, aviary system, and enriched cages. The study was conducted at the Indigenous Chicken Genetic resource Centre (ICGRC), Department of Poultry Production, UVAS, Ravi Campus Pattoki. This city is located at $73^0 50' 60E$ and $31^0 1' 0N$ with an altitude of 610 ft (186 m) and normally experiences tropical hot and humid climate where the temperature ranges between 12 to 45°C.

2.1. Statement of animal rights

All the procedures performed in this study was in accordance with the ethical standards of the University of Veterinary and Animal Sciences, Lahore, Pakistan and approval was granted by the Animal Ethical Review Committee.

2.2. Population size and experimental design

The present study was a continuation of the previous research, in which the performance of progeny (F1) was taken from Rhode Island Red × Naked Neck (RNN) and Black Australorp × Naked Neck (BNN) was evaluated (Ahmad et al., 2019). In the present study, the second generation (F2) of these crossbreds (BNN and RNN) were evaluated in reciprocal crosses. For this purpose, a total of 200 heterozygous partial feather chickens (discarding homozygous full feathered and homozygous naked neck) comprising 50 birds (10 ♂ × 40 ♀) from each crossbred

of the first generation i.e., Crossbred I (BNN ♂ × BNN ♀), Crossbred II (BNN ♂ × RNN ♀), Crossbred III (RNN ♂ × RNN ♀) and Crossbred IV (RNN ♂ × BNN ♀) were used to take more than 1200 hatching eggs at 33rd week of age (see Figure 1) (Usman et al., 2020). A total of 720-day-old chicks in the second generation, 180 from each Crossbred (BB, BR, RR and RB) hatched at Avian Research and Training Centre (ARTC), UVAS, Lahore was transported to ICGRC, Ravi Campus, UVAS, Pattoki. Birds were fed commercial breeder ration formulated according to the recommendations of Leeson and Summers (2005). Brooding the chicks was carried out under standard management conditions up to 6 weeks of age (WOA). During the brooding phase, birds were vaccinated against Infectious Bronchitis and Newcastle Disease at the 15th day of age according to the local area schedule.

At the 6th week of age after sexing, a total of 600 out of 720 birds, comprising 150 from each crossbred with a total of 300 pullets and 300 cockerels were divided into conventional cages, enriched cages and aviary system having 200 birds in each. Birds were assigned to treatments in a 3×4 factorial arrangements in Completely Randomized Design (3 production systems × 4 genotypes × 2 sexes × 5 replicates × 5 birds = 600 birds).

2.3. Production systems

Chickens reared in enriched cages and aviary systems were provided with perches and dust bathing area. Open sided windowed enclosures ventilated with ceiling fans were used for aviaries and enriched cages. Galvanized round feeders and plastic manual drinkers were used in aviaries and enriched cages (as shown in Table 1). Birds reared in conventional cage system were maintained in environmentally controlled poultry shed equipped with galvanized three-tiered battery cage system, automatic manure belt, automatic water nipple line, and feed trolley (FACCO, Poultry Equipment-C3). The supply of fresh water was ad libitum; chickens were fed commercial formulated diet (as shown in Tables 2,3).

2.4. Housing conditions

The duration of the experiments was 2.5 months (March to May) during which the minimum to maximum temperature and humidity were maintained between the range of 26 to 34°C and 59 to 76%, respectively, inside open sided enclosures. In environmentally control houses the minimum and maximum temperature and humidity ranged between 19 to 28°C and 64 to 79%, respectively. Chickens reared in enriched cages and aviaries were provided with natural day length (see Figure 2). The lighting schedule for the conventional cage system was applied according to Hyline W36 Management Guide (HY-LINE, 2018). Rice husk was used as litter material in both enriched cages and aviaries. Approximately 4 inches depth of bedding material was maintained and racking on daily basis was ensured to maintain desirable better conditions.

2.5. Parameters evaluated

Data were collected for morphometric measurements on weekly basis during the rearing phase from 7 to 16 weeks.
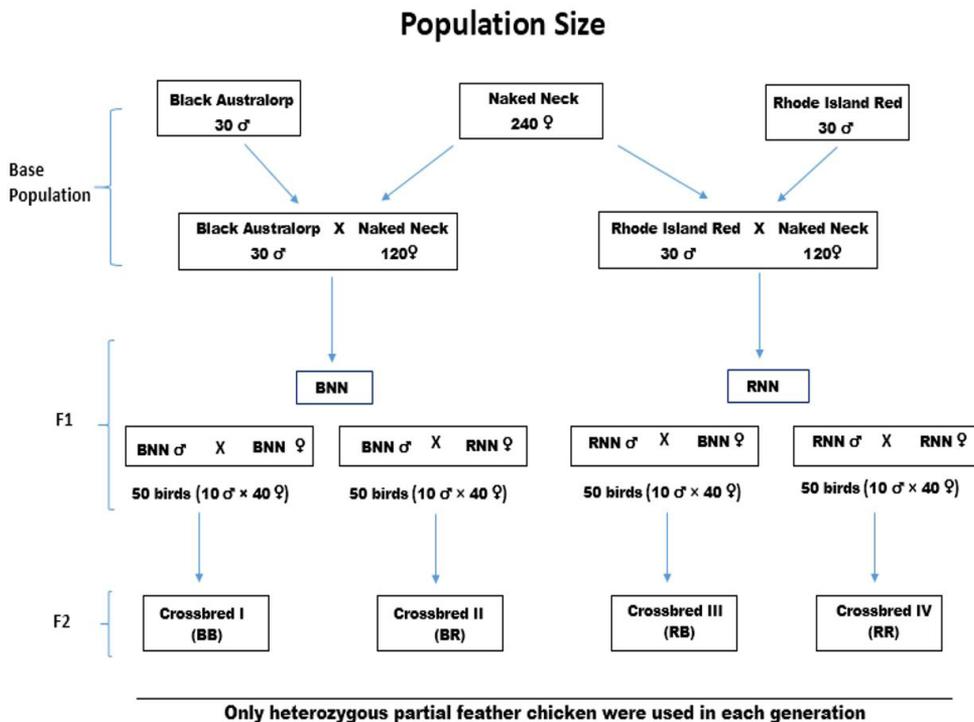

Figure 1. Breeding plan for Crossbreeding of Naked Neck, Black Australorp and Rhode Island Red Chickens.
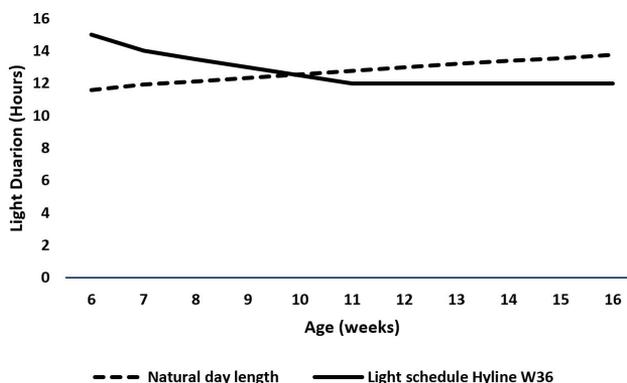
Figure 2. Lighting schedule for experimental birds.

Table 1. Physical characteristics of alternative production systems.

Specifications	Conventional cage (Separate for each sex)	Enriched cage (Separate for each sex)	Aviary (Straight run)
Dimensions (Length × Depth × Height) (cm)	60.9 × 76.2 × 60.9	91.4 × 91.4 × 91.4	304.8 × 304.8 × 304.8
Stocking Density	5 birds/ cage	5 birds/cage	50 birds / aviary
Floor space per bird (cm²)	931.9	1672	1858
Dimensions of Dust bathing Area (Length × width) (cm)	------------------------	55 × 25.3	137 × 137
Dust bathing Space/bird (cm²)	------------------------	276	376
Perches			
Number	------------------------	1	2
Material	------------------------	Wooden	Wooden
Shape	------------------------	Round	Round
Diameter (cm)	------------------------	1.8	4.2
Length (cm)	------------------------	121.9	304.8
Height from floor (cm)	------------------------	45.7	91.4

Table 2. Weekly feed allowance (g / bird) during growing phase.

Age (weeks)	Daily feed allowance (g)
7	24
8	28
9	30
10	30
11	34
12	36
13	38
14	38
15	40
16	42

Measurements taken included body, keel, drumstick and shank length, wing spread and drumstick, and shank circumference. All measurements were taken using a measuring tape. Body weight was measured by using an electronic weighing balance (Weigh South WBT-602 made in China). The carcass traits were measured at the end of the growing phase (16 weeks) by Halal slaughtering of 96 birds (48 cockerels and 48 pullets; 4 birds from each treatment group) randomly picked from the population. Carcass traits measured were drumstick, thigh, breast, wings, and giblets weight (gizzard, liver, and heart) (Raphulu et al., 2015).

2.6. Statistical analysis

Effect of production systems and genotype on morphometric measurements and carcass traits were evaluated by two-way ANOVA technique. General Linear Model of SAS was used (SAS software version, 9.1). Production systems and genotype were considered as main effects and their interaction was also tested. Tukey's Kramer test (Tukey, 1953) was employed to compare treatment means at a significance level of p ≤ 0.05. The following statistical model was used:

$$Y_{ijk} = \mu + P_i + G_j + (P \times G)_{ij} + \epsilon_{ijk} \qquad (1)$$

Table 3. Nutrition value and composition of experimental ration during growing phase.

Nutritive value	Grower (7-16 weeks)
CP (%)	14
ME (Kcal/Kg)	2850
Ca (%)	0.87
Av. P (%)	0.38
Lysine (%)	0.70
Methionine (%)	0.30
Na (%)	0.19
Feed Ingredient (%)	
Corn	61.55
Soybean Meal	31.70
Soybean Oil	3.00
DCP	1.70
NaCl	0.30
Methionine	0.12
Total	100

Where,

Y_{ijk} = Observation of dependent variable recorded on i^{th} Production System and j^{th} Genotype

μ = Population mean

P_i = Effect of ith Production System (i = 1, 2, 3)

G_j = Effect of jth Genotype (j = 1, 2, 3, 4)

$(P \times G)_{ij}$ = Interaction between production system and Genotype

ϵ_{ijk} = Residual error of kth observation on i^{th} Production system and j^{th} genotype NID ~ 0, σ^2

3. Results

3.1. Body weight and morphometric measurements

Comparing growth and morphometric measurements (as shown in Tables 4, 5) of different genotypes, chickens (both sexes) of RB and BR genotypes showed higher (p < 0.01) BW and keel length when compared with BB and RR chicken genotypes. Drumstick length and drumstick circumference of males were higher (p < 0.0001) in both RB and BR genotypes than those of BB and RR genotypes. However, drumstick circumference of females was higher (p < 0.05) in RB and BR genotypes followed by RR and BB genotypes. Drumstick length remained the same (p > 0.05) among the females of different genotypes. Shank length of both sexes was observed to be higher (p < 0.05) in RB genotype than those of RR, BB and BR genotypes. Wing span of males was observed to be higher (p = 0.05) in RB and BR genotypes than those of RR and BB genotypes. However, the difference in wing span of females was not significant (p > 0.05) among different genotypes. Although not significant (p > 0.05), differences were observed in body length and shank circumference of both males and females.

The body weight of chickens (both sexes) reared in enriched cage system was higher (p < 0.05) followed by those reared in conventional cages and aviary system. Drumstick length and drumstick circumference of males reared in enriched cage system were higher (p < 0.05) followed by those reared in conventional cages and aviary system. Non-significant differences (p > 0.05) were observed on drumstick length of females among different production systems whereas drumstick circumference was observed to be higher (p < 0.05) in enriched cage system followed by conventional cage and aviary systems. Wing span of males reared in the aviary system was higher (p < 0.05) than those reared in conventional cages and aviary system. Non-significant differences (p > 0.05) were observed among different production systems in terms of body length, shank length, and shank circumference of both sexes. Keel length of females was observed to be higher (p < 0.05) in the enriched cage system followed by conventional cage and aviary systems.

The body weight and shank length of males were higher (p < 0.05) in RB and BR genotypes reared in the enriched cage system when compared with other interaction groups. Males of RB genotype reared in enriched cage system showed higher (p < 0.05) drumstick circumference and drumstick length compared with other interaction groups. Males of BR genotype reared in the aviary system showed higher (p < 0.05) wingspread than other interaction groups. Although not significant (p > 0.05), differences in interaction means of body length, keel length, and shank circumference of males were observed. Moreover, similarities (p > 0.05) in body length, shank length, shank circumference, drumstick length, drumstick circumference, and wing spread of females were observed among different interaction groups. Body weight of females from RB and BR genotypes reared in the enriched cage system was observed to be higher (p < 0.05) when compared with other interaction groups. Keel length of females from RB genotypes reared in the enriched cage system was observed to be significantly higher (p < 0.05) than other interactions.

3.2. Carcass traits

Significant differences were observed in carcass traits of different genotypes reared in alternative production systems (as shown in Tables 6, 7, 8, 9). Both RB and BR genotype chickens showed significantly higher (p < 0.01) carcass yield % (in male and females) than BB and RR genotypes. Males of RB and BR genotypes showed higher (p < 0.01) breast weight, drumstick weight, and thigh weight whereas females of the RB and BR genotypes showed higher (p < 0.05) heart weight compared with BB and RR genotypes. Males of RB genotype showed higher (p < 0.01) heart weight, intestinal length, and intestinal weight than that of BR, RR and BB genotypes. Gizzard weight was found to be higher (p < 0.05) in BR genotype chickens (in both males and females). Females of BR genotype chickens showed higher (P< 0.05) breast weight, intestinal length, wing weight, drumstick weight, and thigh weight. BB chickens showed lowest (males, p < 0.01 and females, p < 0.05) liver weight in both sexes. Although not significant (p >0.05), differences were observed in the

Table 4. Effect of Production system, genotype and their interaction on male morphometric measurements at 16th week of age.

Production system	Genotype	BW	BL	DC	DL	KL	SC	SL	WS
CC		1420.05±8.44[b]	62.10±1.26	7.86±0.20[ab]	11.36±0.16[ab]	10.54±0.22	3.96±0.09	9.40±0.25	8.88±0.20[b]
AV		1376.86±6.87[c]	58.05±2.33	7.47±0.20[b]	11.07±0.20[b]	10.30±0.16	3.74±0.07	9.61±0.13	9.63±0.20[a]
EC		1453.52±11.94[a]	63.85±1.41	8.20±0.21[a]	11.80±0.17[a]	10.69±0.17	3.91±0.09	9.81±0.24	9.08±0.17[b]
P-value		<0.0001	0.0599	0.0060	0.0064	0.2955	0.1699	0.3693	0.0187
	RB	1453.61±12.93[a]	63.73±1.65	8.52±0.19[a]	11.99±0.20[a]	10.89±0.22[a]	4.02±0.13	10.01±0.25[a]	9.42±0.07[a]
	RR	1398.93±8.74[b]	60.33±1.15	7.42±0.21[b]	11.12±0.07[b]	10.21±0.16[b]	3.78±0.09	9.29±0.24[b]	9.07±0.28[ab]
	BR	1447.64±11.80[a]	62.53±2.82	8.41±0.17[a]	11.72±0.19[a]	10.89±0.20[a]	3.95±0.10	9.91±0.24[ab]	9.54±0.24[a]
	BB	1367.02±8.00[c]	58.73±0.23	7.04±0.18[b]	10.81±0.25[b]	10.04±0.20[b]	3.72±0.04	9.21±0.20[b]	8.75±0.24[b]
P-value		<0.0001	0.2994	<.0001	<.0001	0.0047	0.1244	0.0389	0.0505
CC	RB	1424.77±15.63[bcd]	60.00±1.64	8.57±0.21[abc]	11.75±0.32[abc]	10.94±0.59	3.95±0.30	9.78±0.69[ab]	9.39±0.11[ab]
CC	RR	1433.76±17.86[bc]	59.80±1.15	7.45±0.28[def]	11.12±0.08[bcd]	10.20±0.29	4.03±0.17	8.92±0.58[b]	8.15±0.40[c]
CC	BR	1446.57±17.62[b]	66.00±3.34	8.48±0.08[abc]	11.69±0.34[bc]	10.96±0.37	4.06±0.16	9.24±0.45[b]	9.18±0.42[abc]
CC	BB	1374.66±12.93[de]	62.60±2.99	6.95±0.40[ef]	10.88±0.42[cd]	10.04±0.48	3.81±0.11	9.65±0.30[ab]	8.82±0.44[bc]
AV	RB	1392.81±13.04[cde]	65.60±3.44	8.01±0.40[abcd]	11.51±0.32[bc]	10.64±0.23	3.88±0.14	9.64±0.20[ab]	9.41±0.22[ab]
AV	RR	1375.76±12.65[de]	59.60±2.56	7.19±0.50[def]	10.95±0.12[cd]	10.03±0.33	3.62±0.12	9.70±0.32[ab]	9.71±0.56[ab]
AV	BR	1393.79±11.64[cde]	57.40±6.91	7.91±0.33[bcde]	11.46±0.31[bc]	10.59±0.38	3.77±0.20	9.81±0.19[ab]	10.09±0.50[a]
AV	BB	1345.14±15.64[e]	49.60±2.11	6.78±0.21[f]	10.37±0.62[d]	9.94±0.31	3.69±0.05	9.29±0.37[b]	9.31±0.21[ab]
EC	RB	1537.96±23.68[a]	65.60±2.97	8.97±0.22[a]	12.71±0.19[a]	11.08±0.34	4.24±0.22	10.62±0.15[a]	9.47±0.00[ab]
EC	RR	1388.36±11.99[cde]	61.60±2.33	7.62±0.38[cdef]	11.29±0.16[bcd]	10.40±0.28	3.70±0.15	9.26±0.29[b]	9.37±0.21[ab]
EC	BR	1502.57±23.51[a]	64.20±3.81	8.85±0.29[ab]	12.02±0.36[ab]	11.12±0.34	4.03±0.20	10.69±0.37[a]	9.37±0.26[ab]
EC	BB	1380.61±12.27[de]	64.00±2.70	7.37±0.29[def]	11.18±0.14[bcd]	10.14±0.32	3.67±0.06	8.69±0.31[b]	8.13±0.43[c]
p-value		<0.0001	0.0545	<.0001	0.0012	0.2005	0.3030	0.0184	0.0111

Superscripts on means within columns differ significantly at probability ≤ 0.05; Values explains Mean ± Standard Errors; RR= RNN × RNN while RNN = Rhode Island Red × Naked Neck, BB = BNN × BNN while BNN = Black Australorp × Naked Neck, RB = RNN × BNN, BR = BNN × RNN, EC = Enriched cages, AV= Aviary, CC = Conventional cages; BW= body weight (g), BL= Body length (cm), DC= Drumstick circumference (cm), DL= Drumstick length (cm), KL= Keel length (cm), SC= Shank circumference (cm), SL= Shank length (cm), WS= Wing span (cm).

wings weight of males and intestinal length of females among different genotypes.

Chickens reared in enriched cage system had higher (p < 0.01) breast weight, drumstick weight, thigh weight, and heart weight than those reared in the aviary and conventional cage system. Carcass yield was found to be higher (p < 0.01) in males reared in the aviary and enriched cages than those reared in conventional cages. Carcass yield and wings weight of females were highest (p < 0.05) in the aviary system followed by enriched and conventional cages. Gizzard weight was found to be higher (p < 0.01) in both sexes reared in conventional cages than those reared enriched and conventional cages. Liver weight of females was higher (p < 0.01)in the enriched and conventional cage than that of the aviary system while the liver weight of males was higher (p < 0.01)in chickens reared in enriched cages followed by conventional cages and aviary system. Although not significant (p > 0.05), differences were observed in the intestinal length of chickens reared in different production systems.

Significant interactions (p < 0.05) between genotype and production systems of males and females were observed in most of the carcass traits except intestinal length in which similar (p > 0.05) means (in males and females) of interactions were found. RB and BR genotypes chickens (both sexes, p <0.01) in the enriched cage system showed higher breast weight. Higher gizzard weight was observed in chickens (both sexes p < 0.05) of BB genotype in conventional cages. Heart weight and intestinal weight of RB genotype chickens (both sexes) were higher (p < 0.05) in the enriched cage system. Carcass yield % of males from RB genotype was higher (p <0.01) in the aviary system while carcass yield % of females were higher (p <0.01) in RB and BR genotypes in an aviary system. Drumstick and thigh weight of BR males were observed to be higher (p < 0.01) in enriched cages. Wings and thigh weight of females were higher (p < 0.05) in the BR genotype in conventional cages. Drumstick weight of females from RB and BR genotype reared in enriched cages and BR genotype in conventional cages were higher (P < 0.05) than other interaction groups.

4. Discussion

The present study elaborates the genetic potential of different crossbred genotypes under production systems.

Table 5. Effect of Production system, genotype and their interaction on female morphometric measurements at 16th week of age.

Production system	Genotype	BW	BL	DC	DL	KL	SC	SL	WS
CC		1081.89±14.53[b]	56.70±1.31	7.17±0.22[ab]	10.32±0.39	7.93±0.19[ab]	3.28±0.08	8.09±0.22	7.85±0.25
AV		1041.55±8.09[c]	54.80±1.60	6.76±0.21[b]	10.06±0.26	7.62±0.14[b]	3.13±0.14	8.30±0.22	8.23±0.32
EC		1120.70±16.71[a]	57.90±1.29	7.60±0.21[a]	10.63±0.21	8.18±0.18[a]	3.15±0.13	8.01±0.25	8.02±0.12
P-value		0.0001	0.3128	0.013	0.3966	0.04	0.6282	0.6264	0.5775
	RB	1121.70±21.16[a]	56.40±1.42	7.61±0.23[a]	10.84±0.30	8.32±0.21[a]	3.40±0.18	8.76±0.31[a]	8.24±0.30
	RR	1046.76±8.67[b]	55.53±1.03	6.94±0.28[ab]	10.07±0.24	7.58±0.15[b]	3.15±0.11	7.91±0.31[b]	7.99±0.16
	BR	1130.35±19.32[a]	57.80±2.21	7.50±0.16[a]	10.69±0.52	8.26±0.19[a]	3.22±0.12	8.20±0.17[ab]	8.11±0.34
	BB	1028.44±7.05[b]	56.13±1.74	6.64±0.25[b]	9.74±0.16	7.48±0.18[b]	2.98±0.13	7.67±0.17[b]	7.79±0.31
P-value		<0.0001	0.7994	0.009	0.0850	0.001	0.2458	0.0274	0.7359
CC	RB	1144.02±39.14[ab]	53.00±1.18	7.53±0.34	10.74±0.51	8.33±0.51[abc]	3.45±0.14	8.49±0.54	7.76±0.42
CC	RR	1031.66±13.10[d]	56.20±2.15	6.99±0.52	10.18±0.48	7.58±0.22[abcd]	3.45±0.18	8.44±0.46	7.70±0.20
CC	BR	1128.25±33.60[abc]	60.00±3.34	7.65±0.17	10.72±1.50	8.33±0.32[abc]	3.17±0.12	7.99±0.32	8.42±0.56
CC	BB	1026.00±12.36[d]	57.60±2.99	6.5±0.52	9.66±0.26	7.47±0.34[bcd]	3.07±0.21	7.46±0.36	7.55±0.74
AV	RB	1040.37±16.48[d]	58.00±3.14	7.19±0.38	10.44±0.74	8.09±0.15[abcd]	3.34±0.49	9.17±0.26	9.29±0.56
AV	RR	1032.96±11.78[d]	54.40±1.36	6.54±0.51	9.74±0.22	7.23±0.28[d]	3.06±0.17	8.20±0.66	7.87±0.29
AV	BR	1064.56±22.28[cd]	55.00±4.84	7.01±0.36	10.48±0.71	7.83±0.28[abcd]	3.05±0.12	7.83±0.24	8.02±0.90
AV	BB	1028.65±12.43[d]	51.80±2.92	6.29±0.39	9.57±0.28	7.31±0.24[cd]	3.06±0.30	8.01±0.35	7.75±0.65
EC	RB	1174.33±41.60[a]	58.20±2.37	8.12±0.46	11.33±0.28	8.53±0.37[ab]	3.39±0.28	8.61±0.76	7.67±0.21
EC	RR	1077.03±18.34[bcd]	56.00±2.07	7.30±0.50	10.29±0.53	7.93±0.24[abcd]	2.94±0.19	7.09±0.37	8.40±0.29
EC	BR	1198.23±37.42[a]	58.40±3.65	7.85±0.18	10.89±0.36	8.63±0.34[a]	3.45±0.33	8.77±0.22	7.91±0.25
EC	BB	1030.66±12.46[d]	59.00±2.70	7.14±0.38	9.99±0.35	7.66±0.42[abcd]	2.83±0.21	7.56±0.10	8.08±0.14
p-value		<0.0001	0.6797	0.07	0.6875	0.034	0.6881	0.0588	0.5173

Superscripts on different means within columns differ significantly at probability ≤ 0.05; Values explains Mean ± Standard Errors; RR= RNN × RNN while RNN = Rhode Island Red × Naked Neck, BB = BNN × BNN while BNN = Black Australorp × Naked Neck, RB= RNN × BNN, BR = BNN × RNN, EC= Enriched cages, AV= Aviary, CC = Conventional cages; BW= body weight (g), BL= Body length (cm), DC= Drumstick circumference (cm), DL= Drumstick length (cm), KL= Keel length (cm), SC= Shank circumference (cm), SL= Shank length (cm), WS= Wing span (cm).

Table 6. Effect of Production system and genotype on male carcass traits at 16th week of age.

Trait	Production System			P-value	Genotype				p-value
	CC	AV	EC		RB	RR	BR	BB	
DW	687.72±8.17	713.95±11.49	711.57±12.00	0.0923	733.70±13.66[a]	697.81±10.12[bc]	715.79±11.41[ab]	670.35±7.49[c]	0.0010
CY	55.86±0.40[b]	58.70±0.64[a]	57.83±0.62[a]	0.0004	59.13±0.84[a]	56.61±0.47[b]	58.25±0.55[a]	55.85±0.63[b]	0.0004
LW	24.22±1.22[ab]	21.66±0.98[b]	27.20±1.40[a]	0.0039	27.27±1.17[a]	24.58±1.17[a]	24.79±1.96[a]	20.80±1.18[b]	0.0088
HW	5.85±0.36[c]	6.95±0.35[b]	8.04±0.32[a]	0.0001	7.92±0.48[a]	6.03±0.37[c]	7.38±0.37[ab]	6.46±0.49[bc]	0.0017
GW	21.37±1.24[a]	17.21±1.31[b]	15.28±1.09[b]	0.0016	15.26±1.32[b]	18.88±2.00[ab]	16.81±1.29[b]	20.87±1.17[a]	0.0237
BW	113.55±3.79[b]	118.27±2.76[b]	143.04±4.29[a]	0.0001	136.41±4.90[a]	118.55±4.55[b]	133.19±5.57[a]	111.64±4.55[b]	0.0001
IW	44.68±1.03[b]	47.04±1.00[b]	52.67±1.78[a]	0.0001	50.92±2.03[a]	46.53±1.53[bc]	50.25±1.79[ab]	44.82±1.24[c]	0.0075
IL	150.12±5.85	139.37±4.75	146.00±7.42	0.3853	164.00±5.51[a]	140.91±7.78[b]	143.91±7.30[b]	131.83±4.00[b]	0.0073
WW	59.61±1.33[b]	69.61±1.01[a]	65.97±1.43[a]	0.0001	65.05±1.98	65.49±1.58	66.59±1.95	63.13±2.06	0.4228
DMW	112.81±2.36[b]	116.63±2.78[b]	130.26±2.48[a]	0.0001	125.26±3.19[a]	117.46±2.83[b]	125.41±3.63[a]	111.48±3.47[b]	0.0004
TW	132.13±2.43[b]	135.72±2.91[b]	149.59±2.68[a]	0.0001	144.74±3.28[a]	136.81±2.91[b]	144.71±3.87[a]	130.33±3.52[b]	0.0006

Superscripts on means within rows differ significantly at probability ≤ 0.05; Values explains Mean ± Standard Errors; RR= RNN × RNN while RNN = Rhode Island Red × Naked Neck, BB= BNN × BNN while BNN = Black Australorp × Naked Neck, RB= RNN × BNN, BR = BNN × RNN, EC= Enriched cages, AV= Aviary, CC = Conventional cages; DW= Dressed weight (g), CY = Carcass yield (%), LW= Liver weight (g), HW = Heart weight (g), GW= Gizzard weight (g), BW= Breast weight (g), IW= Intestinal Weight (g), IL= Intestinal length (cm), WW= Wings weight (g), DMW= Drumstick weight (g), TW= Thigh weight (g).

Table 7. Interaction effect (Production system × genotype) on male carcass traits at 16th week of age.

Trait	CC				AV				EC				p-value
	RB	RR	BR	BB	RB	RR	BR	BB	RB	RR	BR	BB	
DW	687.38 ± 10.19[cd]	689.95 ± 21.73[cd]	706.33 ± 20.62[bcd]	667.22 ± 8.88[d]	765.80 ± 7.16[a]	714.25 ± 15.39[abc]	720.54 ± 16.72[abc]	655.22 ± 3.88[d]	747.93 ± 27.80[ab]	689.23 ± 16.80[cd]	720.50 ± 26.15[abc]	688.6 ± 18.24[cd]	0.0038
CY	55.34 ± 0.63[f]	55.31 ± 0.25[f]	57.96 ± 0.85[cde]	54.81 ± 0.25[f]	61.32 ± 0.36[a]	58.39 ± 0.56[bcd]	59.54 ± 0.77[abc]	55.56 ± 1.14[f]	60.74 ± 0.23[ab]	56.13 ± 0.61[def]	57.26 ± 1.07[cdef]	57.18 ± 1.45[cdef]	0.0001
LW	28.41 ± 1.93[ab]	25.06 ± 1.97[abc]	23.52 ± 2.83[abc]	19.88 ± 1.40[c]	24.55 ± 1.97[abc]	20.97 ± 1.10[bc]	22.80 ± 1.70[bc]	18.31 ± 2.05[c]	28.85 ± 1.93[a]	27.70 ± 1.58[ab]	28.06 ± 5.10[ab]	24.20 ± 1.77[abc]	0.0353
HW	6.08 ± 0.73[de]	4.95 ± 0.45[e]	7.18 ± 0.22[bcd]	5.19 ± 0.92[e]	8.46 ± 0.45[ab]	6.33 ± 0.55[cde]	6.81 ± 0.79[bcde]	6.20 ± 0.59[cde]	9.22 ± 0.22[a]	6.81 ± 0.62[bcde]	8.15 ± 0.75[abc]	7.97 ± 0.35[abcd]	0.0002
GW	18.77 ± 1.32[abc]	22.46 ± 4.19[ab]	19.67 ± 1.41[abc]	24.57 ± 1.60[a]	14.92 ± 0.79[bc]	16.47 ± 4.33[bc]	17.37 ± 2.60[abc]	20.10 ± 1.95[abc]	12.09 ± 3.06[c]	17.71 ± 1.17[abc]	13.39 ± 1.75[c]	17.93 ± 1.05[abc]	0.0366
BW	127.68 ± 3.49[bc]	105.89 ± 6.47[de]	120.33 ± 4.41[bcd]	100.30 ± 7.41[e]	125.71 ± 1.50[bc]	114.35 ± 4.64[cde]	122.93 ± 4.82[bcd]	110.07 ± 7.24[de]	155.84 ± 7.80[a]	135.42 ± 3.17[b]	156.32 ± 5.52[a]	124.56 ± 4.65[bc]	0.0001
IW	46.26 ± 2.78[cd]	43.23 ± 2.16[d]	47.45 ± 1.20[cd]	41.77 ± 0.67[d]	49.30 ± 3.57[bcd]	44.95 ± 0.47[cd]	47.09 ± 1.35[cd]	46.82 ± 1.43[cd]	57.19 ± 2.00[a]	51.40 ± 2.95[abc]	56.22 ± 3.76[ab]	45.87 ± 3.13[cd]	0.0009
IL	168.00 ± 8.70	151.75 ± 19.15	140.75 ± 6.92	140.00 ± 4.96	162.75 ± 8.13	132.75 ± 7.27	134.75 ± 6.20	127.25 ± 6.42	161.25 ± 13.59	138.25 ± 13.56	156.25 ± 20.47	128.25 ± 8.78	0.1624
WW	61.37 ± 1.80[cd]	61.10 ± 3.28[bcd]	60.40 ± 1.82[cd]	55.56 ± 3.30[d]	70.88 ± 2.40[a]	69.42 ± 1.62[ab]	70.29 ± 2.39[a]	67.84 ± 2.16[abc]	62.89 ± 4.13[abcd]	65.94 ± 1.54[abc]	69.07 ± 3.69[ab]	65.98 ± 1.38[abc]	0.003
DMW	119.57 ± 5.65[bcde]	110.31 ± 4.04[de]	116.10 ± 2.47[cde]	105.23 ± 4.14[e]	123.36 ± 4.62[abcd]	114.96 ± 0.92[cde]	123.00 ± 6.12[abcd]	105.22 ± 4.68[e]	132.85 ± 5.29[ab]	127.09 ± 4.59[abc]	137.14 ± 4.98[a]	123.98 ± 3.89[abcd]	0.0001
TW	139.07 ± 5.71[bcde]	129.89 ± 4.39[de]	135.22 ± 2.74[cde]	124.35 ± 4.26[e]	142.97 ± 4.79[abcd]	134.16 ± 1.21[cde]	142.00 ± 6.49[abcd]	123.75 ± 4.95[e]	152.18 ± 5.70[ab]	146.36 ± 4.90[abc]	156.91 ± 5.77[a]	142.89 ± 3.89[abcd]	0.0002

Superscripts on means within rows differ significantly at probability ≤0.05; Values explains Mean ± Standard Errors; RR= RNN × RNN while RNN = Rhode Island Red × RNN while BB= BNN × BNN while BNN = Black Australorp × Naked Neck, RB= RNN × BNN, BR= BNN × RNN, EC= Enriched cages, AV= Aviary,CC= Conventional cages; DW= Dressed weight (g), CY = Carcass yield (%),LW= Liver weight (g), GW= Gizzard weight (g), BW= Breast weight (g), HW = Heart weight (g),IW= Intestinal Weight (g),IL= Intestinal length (cm), WW= Wings weight (g), DMW= Drumstick weight (g),TW= Thigh weight (g).

Table 8. Effect of Production system and genotype on female carcass traits at 16th week of age.

Trait	Production System			P-value	Genotype				p-value
	CC	AV	EC		RB	RR	BR	BB	
DW	552.24±18.67	542.62±8.58	575.60±16.97	0.221	568.81±19.99[ab]	530.64±11.95[b]	602.59±20.29[a]	525.24±7.08[b]	0.0033
CY	55.50±0.37[b]	58.27±0.91[a]	56.88±0.63[ab]	0.0045	58.65±0.94[a]	55.15±0.37[b]	58.25±0.79[a]	55.47±0.61[b]	0.0002
LW	17.76±1.14[a]	14.93±0.78[b]	19.75±1.17[a]	0.0048	19.01±0.97[a]	17.55±1.13[a]	18.72±1.83[a]	14.65±0.85[b]	0.0374
HW	4.30±0.39[b]	4.84±0.25[b]	5.87±0.29[a]	0.0017	5.54±0.41[a]	4.25±0.33[b]	5.60±0.39[a]	4.62±0.39[ab]	0.0146
GW	16.26±0.97[a]	12.50±1.14[b]	11.15±0.91[b]	0.0011	10.56±1.01[b]	13.77±1.45[ab]	13.25±1.43[ab]	15.62±0.95[a]	0.0175
BW	88.51±4.68[b]	87.15±1.68[b]	110.05±5.04[a]	0.0001	100.71±5.77[ab]	89.62±5.22[bc]	106.02±5.69[a]	84.58±3.44[c]	0.0023
IW	35.29±1.51[b]	35.24±0.80[b]	41.11±2.22[a]	0.0149	37.96±2.17	35.84±2.27	40.52±2.01	34.54±1.11	0.1149
IL	116.06±3.63	111.62±2.42	116.25±3.49	0.4859	107.41±4.12[b]	115.00±2.75[ab]	121.75±4.64[a]	114.41±1.72[ab]	0.0541
WW	46.66±1.98[b]	51.96±1.11[a]	50.44±1.17[ab]	0.0338	47.61±1.14[b]	49.70±1.86[ab]	53.12±2.08[a]	48.31±1.72[ab]	0.0993
DMW	84.87±3.58[b]	83.32±2.03[b]	97.05±3.78[a]	0.0042	89.65±5.04[ab]	85.64±3.24[b]	96.59±4.02[a]	81.79±2.76[b]	0.0292
TW	100.27±4.00[b]	97.78±2.16[b]	112.17±4.23[a]	0.0096	104.26±5.49[ab]	100.57±3.56[b]	112.33±4.62[a]	96.47±2.82[b]	0.041

Superscripts on means within rows differ significantly at probability ≤ 0.05; Values explains Mean ± Standard Errors; RR= RNN × RNN while RNN = Rhode Island Red × Naked Neck, BB= BNN × BNN while BNN = Black Australorp × Naked Neck, RB= RNN × BNN, BR= BNN × RNN, EC= Enriched cages, AV= Aviary, CC = Conventional cages; DW= Dressed weight (g), CY = Carcass yield (%), LW= Liver weight (g), HW= Heart weight (g), GW= Gizzard weight (g), BW= Breast weight (g), IW= Intestinal Weight (g), IL= Intestinal length (cm), WW= Wings weight (g), DMW= Drumstick weight (g), TW= Thigh weight (g is the unit of thigh weight).

On a general basis, higher body weight and morphometric traits were observed to be higher in the enriched cage system followed by conventional cage and aviary systems. Higher body weight in the enriched cage system might be ascribed by the provision of dust bathing and perching space thus providing more countenance of natural behaviors and less moving space. This prevents the burning of nutrients when compared with the aviary system in which the active behavior of birds causes more utilization of nutrients. Higher wing spread in the aviary system might be attributed to the higher wing flapping exercises which ultimately affects wings growth and development. Similar findings have been reported by Stadig et al. (2016) who observed lighter body weight of slow growing broilers in a free range system. Contrary findings have been reported by Ahmad et al. (2019) who observed improved morphometric traits due to more exercise in free range and semi intensive systems. As far as genotypes are concerned, BR and RB genotypes showed higher body weight, keel length, drumstick length and circumference, wingspread and shank length compared with RR and BB genotypes on an overall basis. This might be attributed to the additive gene action in RB and BR genotypes as RB and BR genotypes were crossbred of BNN and RNN genotypes which were obtained by cross breeding of Rhode Island Red, Black Australorp and Naked Neck. Rhode Island Red and Black Australorp are considered as heavier breeds because of their higher adult body weights (approximately 3-4 kg). In the previous study, body weight of Naked Neck was improved by crossing with Black Australorp and Rhode Island Red (Ahmad et al., 2019). Results of the present study revealed that body weight further increased in the second generation after crossing in a reciprocal way. Genes from three different breeds might be combined after heterosis and enhanced the effect of additive gene action. Improved morphometric traits from RB and BR genotypes might be due to the higher body weight of these breeds

as improved body measurements are associated with higher body weights. Similar findings have been reported by Ahmad et al. (2019) who observed improvement in body weight and morphometric traits after crossbreeding between Rhode Island Red, Black Australorp and Naked Neck chickens. Fadare (2014) observed differences in morphological traits in the normal feathered, naked neck and frizzled feathered chickens when crossed with Giri-Raja breed. Dissimilarities in morphometric traits among different varieties of Pakistani Aseel breed have also been elaborated by Qureshi et al. (2018).

Comparison of different genotypes in terms of carcass traits revealed that RB and BR genotype chickens showed better carcass yield %, breast weight, drumstick weight and thigh weight. This might be attributed to the faster growth pattern of these genotype chickens as these breeds exhibited higher body weights as well. Higher carcass yield %, breast weight, thigh weight and drumstick weight associated with better meat deposition which might also be concomitant with the wider breasts and substantial thigh muscles of Rhode Island Red and Black Australorp. Differences in carcass parameters are due to developed leg and breast muscle yield in slow growing chicken might be ascribed to larger muscle fibers that if attained by muscle fiber hypertrophy (Tang et al., 2009; Kim et al., 2013). These findings are corresponding to the outcomes of Devatkal et al. (2018) who observed differences in carcass parameters of meat type chickens. Ahmad et al. (2019) reported higher dressed weight, breast weight and carcass yield in the Naked neck and Rhode Island Red crossbreds whereas higher thigh weight and drumstick weight was observed in Naked Neck and Black Australorp crossbreds. Variations in carcass traits among indigenous Thai chicken and crossbreds have also been reported by Jaturasitha et al. (2008). Regarding production systems, chickens reared in enriched cages showed higher breast weight, drumstick weight and thigh weight which reveals

Table 9. Interaction effect (Production system × genotype) on female carcass traits at 16th week of age.

Trait	CC				AV				EC				p-value
	RB	RR	BR	BB	RB	RR	BR	BB	RB	RR	BR	BB	
DW	523.28 ± 18.05[b]	512.65 ± 5.60[b]	648.98 ± 48.39[a]	524.06 ± 9.61[b]	550.53 ± 9.54[b]	524.76 ± 6.38[b]	575.40 ± 22.68[ab]	519.79 ± 12.93[b]	632.62 ± 42.68[a]	554.50 ± 34.52[b]	583.38 ± 24.27[ab]	531.88 ± 16.35[b]	0.0034
CY	54.99 ± 0.99[c]	55.05 ± 0.39[c]	57.02 ± 0.73[bc]	54.94 ± 0.32[c]	61.80 ± 0.42[a]	55.27 ± 0.89[c]	61.28 ± 0.24[a]	54.72 ± 1.07[c]	59.18 ± 0.89[ab]	55.14 ± 0.79[c]	56.45 ± 1.27[c]	56.74 ± 1.44[bc]	0.0001
LW	20.02 ± 1.42[ab]	17.05 ± 1.49	20.13 ± 3.41	13.86 ± 1.10	15.94 ± 1.56	14.68 ± 1.35	16.17 ± 2.03	12.93 ± 1.27	21.06 ± 1.04	20.93 ± 1.86	19.86 ± 4.22	17.15 ± 1.41	0.0726
HW	4.17 ± 0.55[cd]	3.25 ± 0.39[d]	6.18 ± 0.64[ab]	3.58 ± 0.71[d]	5.58 ± 0.27[abc]	4.48 ± 0.58[bcd]	4.77 ± 0.52[bcd]	4.55 ± 0.56[bcd]	6.88 ± 0.50[a]	5.03 ± 0.45[bcd]	5.85 ± 0.82[abc]	5.73 ± 0.27[abc]	0.0013
GW	13.53 ± 1.12[abcd]	15.86 ± 3.05[abc]	17.24 ± 1.50[ab]	18.40 ± 1.29[a]	9.83 ± 0.52[cd]	11.86 ± 3.17[bcd]	12.96 ± 2.68[abcd]	15.37 ± 1.75[abc]	8.33 ± 2.24[d]	13.60 ± 1.12[abcd]	9.56 ± 1.78[cd]	13.10 ± 0.76[abcd]	0.0173
BW	94.25 ± 2.16[bc]	75.71 ± 4.35[c]	108.90 ± 10.79[ab]	75.16 ± 5.89[c]	86.55 ± 2.71[bc]	85.23 ± 1.81[c]	91.79 ± 3.28[bc]	85.01 ± 5.01[c]	121.33 ± 1148[a]	107.92 ± 9.75[ab]	117.37 ± 10.80[a]	93.57 ± 3.72[bc]	0.0001
IW	34.67 ± 2.71[bc]	31.48 ± 1.56[c]	43.16 ± 2.47[ab]	31.87 ± 0.61[c]	34.25 ± 2.01[bc]	34.13 ± 1.31[bc]	35.66 ± 1.39[bc]	36.91 ± 1.84[abc]	44.96 ± 4.00[a]	41.91 ± 5.75[ab]	42.73 ± 4.98[ab]	34.83 ± 2.35[bc]	0.0202
IL	106.75 ± 5.55	107.00 ± 2.34	134.50 ± 7.02	116.00 ± 2.85	103.75 ± 4.58	117.50 ± 4.03	111.75 ± 5.17	113.50 ± 4.48	111.7 5 ± 11.15	120.50 ± 5.31	119.00 ± 8.43	113.75 ± 1.79	0.0683
WW	45.52 ± 2.04[bc]	44.07 ± 1.56[bc]	55.04 ± 5.67[a]	42.01 ± 2.62[c]	49.22 ± 2.46[abc]	52.60 ± 2.97[ab]	52.95 ± 2.00[ab]	53.05 ± 1.58[ab]	48.101 ± 1.30[abc]	52.43 ± 3.36[ab]	51.37 ± 3.03[ab]	49.86 ± 1.31[abc]	0.0408
DMW	85.60 ± 5.84[abc]	76.42 ± 3.08[c]	101.21 ± 8.05[a]	76.26 ± 3.34[c]	82.32 ± 4.32[abc]	83.24 ± 2.63[abc]	89.06 ± 3.96[abc]	78.67 ± 4.80[bc]	101.03 ± 12.68[a]	97.27 ± 4.92[ab]	99.48 ± 8.26[a]	90.44 ± 3.41[abc]	0.0239
TW	100.34 ± 6.14[abcd]	90.86 ± 3.17[d]	118.86 ± 9.34[a]	91.04 ± 3.48[d]	96.13 ± 4.61[bcd]	97.97 ± 2.99[abcd]	103.61 ± 4.31[abcd]	93.40 ± 5.15[cd]	116.32 ± 14.03[ab]	112.88 ± 6.01[abcd]	114.51 ± 9.37[abc]	104.96 ± 3.49[abcd]	0.0368

Superscripts on means within rows differ significantly at probability ≤0.05; Values explains Mean ± Standard Errors; RR= RNN × RNN while RNN = Rhode Island Red × Naked Neck, BB= BNN × BNN while BNN = Black Australorp × Naked Neck, BR= RNN × BNN, RB= BNN × RNN, EC= Enriched cages, AV= Aviary,CC = Conventional cages; DW= Dressed weight (g), CY= Carcass yield (%),LW= Liver weight (g), HW = Heart weight (g), GW= Gizzard weight (g), BW= Breast weight (g),IW= Intestinal Weight (g),IL= Intestinal length (cm), WW= Wings weight (g),DMW= Drumstick weight (g),TW= Thigh weight (g).

better development of skeletal muscles and meat yield. This might be attributed to the faster growth as chickens reared in enriched cages unveiled higher body weight. A possible reason behind the faster growth and muscle development of chickens in enriched cages is the activity level. Enriched cage is the compact package with sufficient stocking density for chickens equipped with utensils to express natural behavior in terms of perching and dust bathing for welfare aspects. So, this system restricted the unwanted movements and provided gears necessary to express natural comportment. This resulted in reduced cage stress with the least nutrient utilization on spontaneous activities and ultimately reinforced to enhance growth and muscle development. Association of activity and carcass traits has also been elaborated by Tong et al. (2014) in which they reported a linear increase in breast muscles and linear decrease in leg, thigh and foot yield with increasing free-range duration. Ahmad et al. (2019) reported higher carcass yield in chickens reared in the free range system when compared with intensive and semi intensive system. They explained that this variation might be due to the level of activity in outdoor excess. Improved thigh and breast yield in Ross males, when provided with outdoor access, has been reported (Castellini et al., 2002). Improved carcass traits of chickens given access to outdoor area boost their activity thus enhances comfort and welfare (Martínez-Pérez et al., 2017).

It is concluded that chickens (both sexes) of BR and RB genotypes had better morphological measurements and carcass traits than those of RR and BB genotype chickens. Among alternative production systems, chickens reared in enriched cages had better traits than those reared in conventional cages and aviary during the growing phase.

Acknowledgements

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