Phenotypic Correlation between Egg Quality Indices in 85-Weeks-Old Layer Chicken Genotypes

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Research Article

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ABSTRACT

Phenotypic correlations between egg quality indices were evaluated in aged Shaver Brown (SB) and Nigerian Heavy Ecotype Native (HEN) hens. Studied traits were egg, yolk, albumen and shell weights (EW, YW, AW and SW); Egg Length (EL), Surface Area (ESA), Volume (EV), Specific Gravity (ESG) and Shape Index (ESI); Egg, Yolk and Albumen diameters (ED, YD and AD); Yolk and Albumen Heights (YH and AH); Yolk, Albumen and shell ratios (YR, AR and SR) and indexes (YI, AI and SI); Y/A ratio and Haugh Unit (HU); Shell Thickness (ST), Volume (SV), and Density (SD). Pearson's correlation method was employed for the analysis and none zero coefficients were interpreted as perfect (0.95-1.00), near perfect (0.94-0.85), very strong (0.84-0.75), strong (0.74-0.65), moderate (0.64-0.45), weak (0.44-0.25), or very weak (0.24-0.10). EW correlated perfectly with ESA, EV, ESG and SV in both genotypes; moderately with SW, SR, YW and AW in HEN eggs but near perfectly with AW, strongly with SR, and moderately with ST, SI, YW, AH and AI in SB. YW correlated moderately with HU, SV and SR, and weakly with AW, AH, AD, AI, SD, and SI in HEN eggs while in SB eggs, it had moderate correlations with HU, and weak correlations with AW, SV, SR, and SI. AW was moderately correlated with SV and weakly correlated with Y/A ratio, SW, and SR in HEN eggs but near perfectly with SV, strongly with SR, and moderately with ST and SI in SB eggs. Genotypic differences in strength and/or direction of correlation between egg quality traits could be due to differences in degree and direction of genetic selection for egg traits between genotypes. Therefore, phenotypic correlation could guide non-invasive determination and genetic improvement of egg quality traits in domestic chickens.

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Keywords: Layer chicken genotypes; Egg quality traits; Phenotypic correlation; Strength of correlation; Aged laying hens

INTRODUCTION

The financial return from egg production enterprise depends on rate of lay and the quality of eggs produced [1]. Egg quality refers to egg characteristics which determine consumer acceptance and the nutritional and reproductive roles of eggs and these include external (whole egg) and internal (egg component) qualities [2,3].

Environmental and genetic factors as well as their interactions influence egg quality. Environmental factors include season, ambient temperature, humidity, duration of storage, diet, nutritional status of hen; health and disease, management practices, and husbandry system while genetic factors include species, breed or genotype of bird, extent and direction of genetic selection and selective breeding [4,5]. Egg quality vary widely between ecological zones, farms, management systems, and within and between laying cycles; necessitating continuous evaluation of egg quality within each enterprise [6].

The age of the laying flock is of particular interest in evaluating egg quality. Whereas egg weight increases with age of hen, egg quality decreases [7]. Aged hens lay eggs with higher proportion of yolk, lower proportion of albumen, and thinner shell than younger layers and this is attributed to increased egg size and egg surface area with age [8]. The negative impacts of aging stress and stress due to artificial control measures may also contribute to decreased egg quality *via* changes in ovarian regulatory hormones secretion, damage to follicular cells, and lowered oocyte quality [9-11].

Egg qualities are genetically and phenotypically interrelated due to genetic, and genetic x environment interactions. These interrelationships are also influenced by genetic and environmental factors and this probably accounts for the variation in direction and strength of phenotypic correlations reported between egg quality indices for different genotypes such as in layer chickens, Japanese quail and guinea fowl [12-15]. Egg quality interrelationships could hence characterize laying flock genetics, husbandry system and production environment. Within each genotype and production enterprise, accurate prediction of egg component characteristics and quality enables effective egg production management, keeps production and egg quality within market specifications, and permits effective egg utilization for industrial and/or hatchery operations. In addition, the correlations among egg quality indices could permit non-invasive determination of some difficult-to-measure traits using easier-to-measure counterparts, give significant information for genetic evaluation of flocks, and for predicting the consequences of selection on particular traits on other traits of economic importance [13,15]. The phenotypic correlations between egg quality indices have been extensively reported however, most reports are limited to few of the indices, to hens in their first laying cycle, and with little emphasis on the strength of association between traits. This article attempts a more detailed analysis of the phenotypic correlation between whole egg, yolk, albumen, and eggshell quality traits in aged domestic chicken genotypes with emphasis on the strength of association between traits.

MATERIALS AND METHODS

The study was conducted in a flock of 85 weeks old Shaver brown (SB) and Nigerian Heavy Ecotype Native (HEN) hens made up of 40 birds/genotype. The SB is a commercial layer hybrid popularly reared in the study environment due to its easy adaptation and high rate of egg production while the HEN is a local chicken ecotype which had undergone three generations of within flock multi-trait selection for improved egg production [16]. The birds were 65 weeks in lay at the commencement of the study and were housed in individual cages equipped with feed troughs and water nipples. They were fed a layer ration containing 16.5% crude protein and 2600 kcal ME/kg at 125 g/bird/day. The feed was divided into two portions and fed at 08:30 h and 14:00 h. Water was given *ad libitum*. The study lasted for 21 days during which egg production was recorded. Egg quality measurement was performed on 120 eggs (80 from SB and 40 from HEN) collected within the last 5 days of the study period. Determined egg quality indices in Table 2 were used to evaluate the inter-egg quality phenotypic correlations using the Pearson correlation analysis in SPSS version 20.

Interpretation of correlation coefficients (r)

Zero correlation coefficient was interpreted as lack of phenotypic relationship between traits. Non-zero coefficients were interpreted as perfect (0.95-1.00), near perfect (0.85-0.94), very strong (0.75-0.84), strong (0.65-0.74), moderate (0.45-0.64), weak (0.25-0.44), or very weak (0.10-0.24).

RESULTS

The composition of layer diet fed to the experimental birds is presented in Table 1 while the procedures for determination of the various egg quality indices were as described in Table 2. The guide for interpretation of correlation coefficients (r) is provided in Table 3.

Table 1. Composition of layer diet fed to aged Shaver brown (SB) and Heavy Ecotype Native (HEN) hens.

Composition			
Proximate of major ingredients			
Ingredients	Crude protein (%)	Metabolizable energy (kcal/kg)	Ingredient composition (%)
Maize	9	3430	43
Wheat offal	17	1870	18
Soy bean cake	44	2400	17.5
Palm kernel cake	18	2800	9
Fish meal	50	2700	2.5
Bone meal	-	-	3
Lysine	-	-	0.25
Methionine	-	-	0.25
Vitamin premix	-	-	0.25
Salt	-	-	0.25
Oyster shell	-	-	6
Total	-	-	100
Calculated	-	-	-
Crude protein (%)	-	-	16.5
Kcal ME/kg	-	-	2600

Table 2. Egg quality parameters and procedures for their determination in Shaver Brown (SB) and Heavy Ecotype Native (HEN) hens.

Parameter (symbol, unit)	Synonym	Definition/formula, and method (Reference)
Egg Weight (EW, g)	-	Mass of egg taken with digital scale (0.01 g sensitivity)
Egg Length (EL, cm)	Egg major diameter (D)	Distance between broad and pointed ends of egg taken with a vennier caliper (0.01 cm sensitivity).
Egg Diameter (ED, cm)	Egg width, egg minor diameter (d)	Distance across the equator of egg taken with a vennier caliper (0.01 cm sensitivity).
Egg Surface Area (ESA, cm^2)	-	3.9782 x EW0.7056 [17]
Egg Volume (EV, cm^3)	-	0.7608 x EW1.0474 [18]
Egg Specific Gravity (ESG, g/cm^3)	-	EW/EV
Egg Shape Index (ESI)	Egg index, shape index	ED/EL or d/D
Yolk Weight (YW, g)	-	Weight of yolk taken with a sensitive scale (0.01 g sensitivity).
Yolk Diameter (YD, cm)	Yolk width	Average of two measurements taken from two transverse sides of the yolk with a vennier caliper (0.01 cm sensitivity).
Yolk Height (YH, cm)	-	Height of yolk taken from top of its center to the base with a vennier caliper (0.01 cm sensitivity).
Relative yolk weight (%)	Yolk Ratio (YR, %)	YW x 100/EW
Yolk Index (YI)	-	YH/YD
Albumen Weight (AW, g)	-	AW=EW-(YW+SW).
Albumen Height (AH, cm)	-	Height of albumen taken from top of its center to the base.
Albumen Diameter (AD, cm)	Albumen width (cm)	Diameter of albumen taken with a vennier caliper (0.01 cm sensitivity)
Relative albumen weight (%)	Albumen Ratio (AR, %)	AW x 100/EW
Albumen Index (AI)	-	AH/AD
Yolk/Albumen ratio (Y/A)	-	YW/AW
Shell Weight (SW, g)	-	Weight of shell with membrane taken with a digital scale (0.01 g sensitivity)
Shell thickness (ST, mm)	-	Average of shell thickness with membrane taken from the broad end, pointed end, and equator using a micrometer screw gauge (0.01 mm sensitivity).
Shell Volume (SV, cm^3)	-	0.0248 x W1.118 [19]
Shell Density (SD, g/cm^3)	-	SW/(ESA x ST)
Relative shell weight (%)	Shell Ratio (SR, %)	SW x 100/EW
Shell Index (SI, g/cm^2)	Unit Surface Area Shell Weight (USSW)	Shell weight per unit surface area, SW/ESA
Haugh Unit (HU)	Haugh index	100log (AH-1.7EW0.37+7.6) [20]

Table 3. Interpretation of coefficient of phenotypic correlation(r).

Correlation (r)	Strength of association	Inference (considering traits A and B)
0.95 to 1.00	Perfect positive correlation	As A is improved, B improves proportionately.
0.85 to 0.94	Near perfect positive correlation	As A is improved, B improves almost proportionately.
0.75 to 0.84	Very strong positive correlation	Improvement in A leads to substantial improvement in B.
0.65 to 0.74	Strong positive correlation	Improvement in A leads to marked improvement in B.
0.45 to 0.64	Moderate positive correlation	Improvement in A leads to a fair improvement in B.
0.25 to 0.44	Weak positive correlation	Improvement in A leads to a small improvement in B.
0.10 to 0.24	Very weak positive correlation	Improvement in A leads to a minor improvement in B.
0.00	No correlation	Traits are phenotypically independent.
- 0.10 to - 0.24	Very weak negative correlation	Improvement in A leads to a minor loss in B.
- 0.25 to - 0.44	Weak negative correlation	Improvement in A is accompanied by small decrease in B.
- 0.45 to - 0.64	Moderate negative correlation	Improvement in A is accompanied by a fair decrease in B.
- 0.65 to - 0.74	Strong negative correlation	As A is improved, B decreases remarkably.
- 0.75 to - 0.84	Very strong negative correlation	As A is improved, B decreases substantially.
- 0.85 to - 0.94	Near perfect negative correlation	As A is improved, B decreases almost proportionately.
- 0.95 to - 1.00	Perfect negative correlation	As A is improved, B decreases proportionately.

The correlation matrix of whole egg quality parameters is presented in Table 4 for HEN (above diagonal) and SB (below diagonal).

Table 4. Correlation coefficients of whole egg quality parameters in heavy ecotype native (above diagonal) and Shaver brown (below diagonal) hens.

	EW	EL	ED	ESA	EV	ESG	ESI
EW	-	0.560*	0.958**	1.000**	1.000**	-0.994**	0.170
EL	0.708**	-	0.486*	0.555*	0.560*	-0.546*	-0.712**
ED	0.007	0.030	-	0.955**	0.953**	-0.953**	0.258*
ESA	1.000**	0.709**	0.008	-	0.999**	-0.997**	0.176
EV	1.000**	0.706**	0.005	1.000**	-	-0.994**	0.169
ESG	-0.993**	-0.718**	0.049	-0.993**	-0.994**	-	-0.184
ESI	-0.203	-0.267*	0.955**	-0.204	-0.206	0.263*	-

Note: EW: Egg Weight, EL: Egg Length, ED: Egg Diameter, ESA: Egg Surface Area, EV: Egg Volume, ESG: Egg Specific Gravity, ESI: Egg Shape Index, *: Significant at $p \leq 0.05$, **: Significant at $p \leq 0.01$.

Egg Weight (EW) had moderate and strong positive correlation with EL in HEN and SB, respectively, very weak and perfect positive correlation with ED in SB and HEN, respectively, weak correlation with ESI, and perfect correlations with ESA, EV, and ESG in both genotypes. Egg Length (EL) had moderate positive correlations with ED, ESA and EV, moderate negative correlation with ESG and a strong negative correlation with ESI in HEN but very weak positive correlation with ED, strong correlations with ESA, EV and ESG, and weak negative correlation with ESI in SB. Egg Diameter (ED) was perfectly correlated with ESA, EV, and ESG in HEN but very weakly in SB. A weak and perfect positive correlation was observed with ESI in HEN and SB, respectively. Egg Surface Area (ESA) was perfectly correlated with EV and the two traits were perfectly correlated with ESG in both genotypes while very weak correlations were observed for ESI with ESA and EV in both genotypes, with ESG in HEN, and a weak correlation with ESG in SB.

The correlation between whole egg and eggshell quality traits is presented in Table 5 while the correlation of external and internal egg quality traits is presented in Table 6.

Table 5. Correlation of whole egg and eggshell quality traits in Shaver Brown (SB) and Heavy Ecotype Native (HEN) hens.

	EW	EL	ED	ESA	EV	ESG	ESI
SB	-	-	-	-	-	-	-
SW	0.000	-0.027	-0.184	-0.004	0.000	0.034	-0.152
ST	-0.500*	-0.410*	-0.058	-0.502*	-0.500*	0.508*	0.070
SV	1.000**	0.706**	-0.007	1.000**	1.000**	-0.993**	-0.203
SD	0.009	0.033	-0.101	0.007	0.009	0.005	-0.097
SR	-0.674**	-0.507*	-0.137	-0.678**	-0.674**	0.695**	0.032
SI	-0.544*	-0.414*	-0.156	-0.547*	-0.544*	0.569*	-0.012
HEN	-	-	-	-	-	-	-
SW	0.456*	-0.032	0.492*	0.459*	0.455*	-0.461*	0.408*
ST	0.125	-0.190	0.251	0.126	0.125	-0.128	0.352*
SV	1.000**	0.561*	0.953**	0.999**	1.000**	-0.993**	0.168
SD	-0.335*	-0.297*	-0.347*	-0.335*	-0.335*	0.335*	0.047
SR	-0.483*	-0.530*	-0.410*	-0.483*	-0.483*	0.485*	0.211
SI	-0.234	-0.428*	-0.163	-0.232	-0.234	0.231	0.300*

Note: SW: Shell Weight, ST: Shell Thickness, SV: Shell Volume, SD: Shell Density, SR: Shell Ratio, SI: Shell Index, CFF: Compression Fracture Force, *: significant at p ≤ 0.05, **: significant at p ≤ 0.01.

In SB, EW, EL, ESA, EV and ESG had zero to very weak correlations with SW and SD, weak to moderate correlations with ST and SI, strong to perfect correlations with SV, and moderate to strong correlations with SR while ED and ESI were very weakly correlated with all eggshell quality traits shown in Table 5. In HEN, EW, ED, ESA, EV, and ESG correlated moderately with SW and SR, very weakly with ST and SI, weakly with SD, and perfectly with SV while EL correlated very weakly with SW and ST, moderately with SV and SR, and weakly with SD and SI. Egg Shape Index

(ESI) had moderate positive correlation with SW, weak positive correlation with ST and SI, and very weak positive correlations with SV, SD, and SR. For external and internal egg quality traits, Table 6 shows that in SB, EW had moderate positive correlations with YW, AH, and AI, near perfect positive correlation with AW, weak correlations with YH and AR, and very weak correlations with other traits. Egg Length (EL) was weakly correlated with YR and AR, moderately correlated with AW (0.533), strongly correlated with AH and AI, and very weakly correlated with other traits. Egg Diameter (ED) had weak correlations with YH, YI, Y/A ratio, AD, and AI, and very weak correlations with other traits while ESA, EV, and ESG were, respectively, moderately correlated with YW, AH, and AI, weakly correlated with YH and AR, near perfectly correlated with AW (0.850, 0.853, and –0.854, respectively) and very weakly correlated with other traits. Egg Shape Index (ESI) had weak correlation with all yolk and albumen traits except YW, AH, AI and HU for which very weak correlations were observed. In HEN, EW, ESA, and EV moderately and positively correlated with YW and AW, weakly correlated with YD and AH, and very weakly correlated with other traits. Egg length (EL) had strong positive correlations with YW and AW, moderate correlation with YD (0.642), YR (0.472), and YI (-0.517), weak correlations with YH, AD, AR, AI, and HU, and very weak correlations with Y/A ratio and AH while ED was moderately and positively correlated with YW, AW and AH, weakly correlated with YD and very weakly correlated with other traits. The correlation of ESA and EV with YW and AW were moderate (0.568 and 0.569, respectively) and (0.586 and 0.590, respectively) but weak with YD (0.387, respectively) and AH (0.398 and 0.396, respectively). Observed correlations with other yolk and albumen traits in this genotype were very weak.

Table 6. Correlation coefficients between external and internal egg quality traits in Shaver Brown (SB) and Heavy Ecotype Native (HEN) hens.

Breed/trait	EW	EL	ED	ESA	EV	ESG	ESI
SB	-	-	-	-	-	-	-
YW	0.459*	0.095	0.147	0.459*	0.459*	-0.470*	0.107
YD	0.12	0.134	0.343*	0.122	0.119	-0.112	0.298*
YH	0.370*	0.077	-0.251*	0.366*	0.371*	-0.364*	-0.270*
YR	-0.177	-0.391*	0.158	-0.176	-0.176	0.160	0.261*
YI	0.188	0.02	-0.370*	0.184	0.189	-0.189	-0.370*
Y/A	-0.06	-0.239	0.249*	-0.059	-0.060	0.050	0.307*
AW	0.852**	0.533*	-0.169	0.850**	0.853**	-0.854**	-0.326*
AH	0.470*	0.695**	0.164	0.472*	0.470*	-0.489*	-0.057
AD	0.025	0.190	0.393*	0.026	0.024	-0.022	0.316*
AR	-0.264*	-0.305*	-0.345*	-0.267*	-0.263*	0.247*	-0.249*
AI	0.500*	0.646**	-0.044	0.501*	0.501*	-0.521*	-0.239
HU	0.035	0.084	-0.139	0.03	0.036	-0.029	-0.159
HEN	-	-	-	-	-	-	-
YW	0.569*	0.692**	0.547*	0.568*	0.569*	-0.569*	-0.331*
YD	0.387*	0.642**	0.376*	0.387*	0.387*	-0.387*	-0.390*
YH	0.048	-0.339*	0.017	0.045	0.049	-0.037	0.378*
YR	0.060	0.472*	0.064	0.061	0.059	-0.068	-0.489*
YI	-0.194	-0.517*	-0.214	-0.198	-0.193	0.21	0.390*
Y/A	0.140	0.198	0.115	0.143	0.139	-0.157	-0.129
AW	0.589*	0.679**	0.601**	0.586*	0.590*	-0.573*	-0.278*
AH	0.396*	0.235	0.510*	0.398*	0.396*	-0.396*	0.096
AD	0.172	-0.265*	0.178	0.179	0.171	-0.199	0.427*
AR	-0.172	0.315*	-0.119	-0.177	-0.172	0.189	-0.476*
AI	0.137	0.282*	0.224	0.135	0.137	-0.123	-0.163
HU	-0.027	-0.416*	0.018	-0.025	-0.028	0.023	0.443*

Note: YW: Yolk Weight, YD: Yolk Diameter, YH: Yolk Height, YR: Yolk Ratio, YI: Yolk Index, Y/A: Yolk Albumen Ratio, AW: Albumen Weight, AH: Albumen Height, AD: Albumen Diameter, AR: Albumen Ratio, AI: Albumen Index, HU: Haugh Unit, *: Significant at $p \leq 0.05$; **: Significant at $p \leq 0.01$.

EGG Specific Gravity (ESG) was moderately and negatively correlated with YW and AW, weakly and negatively correlated with YD and AH, and very weakly correlated with other traits. Egg shape Index (ESI) had weak correlations with all yolk and albumen traits except YR and AR for which moderate negative correlations were observed, and Y/A ratio, AH and AI for which very weak correlations were observed.

In HEN, Yolk Weight (YW) had strong positive correlations with YD and Y/A ratio, weak correlation with YH (-0.398), very strong correlation with YR (0.853), and a moderate correlation with YI (-0.610) (Table 7). Yolk Diameter (YD) had very strong and near perfect negative correlations with YH and YI, respectively, and strong and moderate positive correlations with YR and Y/A ratio, respectively. Yolk Height (YH) had a moderate and a weak negative correlation with YR and Y/A ratio, respectively, and a near perfect positive correlation with YI. Yolk Ratio (YR) correlated strongly with YI (-0.646), and very strongly with Y/A ratio (0.815) while YI had a weak negative correlation with Y/A ratio**.**

Table 7. Correlation coefficients for yolk quality traits in heavy ecotype native (above diagonal) and Shaver brown (below diagonal) hens.

	YW	YD	YH	YR	YI	Y/A
YW	-	0.731**	-0.398*	0.853**	-0.610*	0.735**
YD	0.518*	-	-0.819**	0.662**	-0.941**	0.476*
YH	0.082	-0.506*	-	-0.540*	0.950**	-0.280*
YR	0.790**	0.680**	-0.384*	-	-0.646**	0.815**
YI	-0.174	-0.819**	0.906**	-0.542*	-	-0.429*
Y/A	0.793**	0.764**	-0.384*	0.946**	-0.597*	-

Note: *: Significant at $p \leq 0.05$; **: Significant at $p \leq 0.01$.

In SB, YW had a moderate positive correlation with YD, very weak correlations with YH and YI, and very strong positive correlations with YR and Y/A ratio. Yolk Diameter (YD) was moderately and negatively correlated with YH, strongly and positively correlated with YR, and very strongly correlated with YI (-0.819) and Y/A ratio (0.764). Yolk Height (YH) had weak negative correlations with YR and Y/A ratio, and a near perfect positive correlation with YI. Yolk Ratio (YR) had a moderate negative correlation with YI and a perfect positive correlation with Y/A ratio while YI was moderately and negatively correlated with Y/A ratio.

The correlation of yolk and albumen quality indices (Table 8) shows that YW had a weak positive correlation with AW, very weak correlations with AH, AD, AR and AI, very strong positive correlation with Y/A ratio and a moderate negative correlation with HU in SB eggs. Yolk Diameter (YD) was moderately and negatively correlated with AW, AH, AR, AI, and HU, moderately and positively correlated with AD and very strongly correlated with Y/A ratio (0.764). Yolk Height (YH) had strong positive correlation with AW, very strong positive correlations with AH and AI, moderate correlation with AD (-0.531) and HU (0.616), and weak negative correlation with Y/A ratio.

Table 8. Correlation coefficients of yolk and albumen quality indices in Shaver Brown (SB) and Heavy Ecotype Native (HEN) hens.

Breed/trait	AW	AH	AD	AR	AI	Y/A	HU
SB	-	-	-	-	-	-	-
YW	0.251*	-0.197	0.006	-0.145	-0.127	0.793**	-0.469*
YD	-0.427*	-0.480*	0.438*	-0.441*	-0.479*	0.764**	-0.457*
YH	0.690**	0.834**	-0.531*	0.101	0.805**	-0.384*	0.616*
YR	-0.302*	-0.587*	0.247*	-0.031	-0.492*	0.946**	-0.696**
YI	0.656**	0.760**	-0.555*	0.318*	0.750**	-0.597*	0.611**
HEN	-	-	-	-	-	-	-
YW	0.381*	0.252*	-0.441*	-0.059	0.400*	0.735**	-0.545*
YD	0.309*	0.013	-0.580*	0.003	0.351*	0.476*	-0.803**
YH	-0.088	0.091	0.682**	-0.121	-0.359*	-0.280*	0.801**
YR	0.073	0.043	-0.639**	0.014	0.392*	0.815**	-0.660**
YI	-0.193	-0.013	0.628**	-0.031	-0.392*	-0.429*	0.814**

Note: *: Significant at p<0.05; **: Significant at p<0.01.

Yolk Ratio (YR) was weakly correlated with AW and AD, moderately and negatively correlated with AH and AI, perfectly correlated with Y/A ratio (0.946) and strongly correlated with HU (-0.696). Yolk Index (YI) had strong positive correlation with AW, very strong positive correlation with AH and AI, moderate correlation with AD (-0.555), Y/A ratio (-0.597), and HU (0.611), and weak positive correlation with AR. In HEN, YW was weakly correlated with AW, AH, AD, and AI, very weakly correlated with AR, strongly correlated with Y/A ratio (0.735), and moderately correlated with HU (-0.545). Yolk Diameter (YD) had weak correlations with AW and AI, very weak correlations with AH and AR, moderate correlation with AD (-0.580) and Y/A ratio (0.476), and very strong negative correlation with HU. Yolk Height (YH) was very weakly correlated with AW, AH and AR, strongly and positively correlated with AD, weakly and negatively correlated with AI and Y/A ratio, and very strongly correlated with HU (0.801). Yolk Ratio (YR) had very weak correlations with AW, AH and AR, moderate negative correlation with AD, weak positive correlation with AI, very strong positive correlation with Y/A ratio, and strong negative correlation with HU while YI correlated very weakly with AW, AH and AR, moderately and positively with AD, weakly and negatively with AI and Y/A ratio, and very strongly and positively with HU.

The correlation of yolk and eggshell indices (Table 9) shows that in SB eggs, YW had weak correlations with SV, SR, and SI, and very weak correlations with other traits. Yolk Diameter (YD) had a weak positive correlation with SR, and very weak correlations with other traits.

Table 9. Correlation coefficients of yolk and eggshell quality indices in Shaver Brown (SB) and Native Heavy Ecotype (HEN) hens.

Breed/trait	SW	ST	SV	SD	SR	SI
SB	-	-	-	-	-	-
YW	-0.122	0.224	0.353*	-0.108	-0.383*	-0.363*
YD	0.080	0.199	-0.223	0.012	0.261*	0.244
YH	0.306*	-0.629**	0.629**	0.374*	-0.417*	-0.296*
YR	-0.217	0.319*	-0.293*	-0.254*	0.129	0.062
YI	0.147	-0.481*	0.540*	0.220	-0.388*	-0.305*
HEN	-	-	-	-	-	-
YW	-0.011	-0.077	0.569*	-0.369*	-0.537*	-0.424*
YD	-0.265*	-0.048	0.387*	-0.517*	-0.630**	-0.578*
YH	0.531*	0.127	0.050	0.427*	0.497*	0.557*
YR	-0.309*	-0.170	0.059	-0.252*	-0.362*	-0.381*
YI	0.411*	0.074	-0.192	0.519*	0.609**	0.606**
Note: *: Significant at $p \leq 0.05$; **: Significant at $p \leq 0.01$.						

Yolk Height (YH) had weak correlations with SW, SD, SR, and SI, and moderate correlations with ST and SV (-0.629 and 0.629, respectively). Yolk Ration (YR) was weakly correlated with SW, ST, SV, and SD but very weakly correlated with other traits while YI had very weak correlations with SW and SD, moderate correlations with ST and SV, and weak correlations with SR and SI. In HEN eggs, YW had moderate correlations with SV and SR (0.569 and -0.537, respectively), weak correlations with SD and SI, and very weak correlations with SW and ST. Weak correlations were observed for YD with SW and SV, very weak correlation with ST, and moderate negative correlations with SD, SR, and SI. Yolk Height (YH) correlated moderately and positively with SW, SR, and SI, weakly with SD, and very weakly with ST and SV. The correlation between YR and SW, SD, SR, and SI were weak while very weak correlations were observed with other traits. YI correlated very weakly with ST and SV, weakly with SW, and moderately and positively with SD, SR, and SI.

Albumen Weight (AW) had very weak correlations with AH, AD, AI and HU, weak negative correlation with Y/A ratio and strong positive correlation with AR in HEN eggs (Table 10).

Table 10. Correlation coefficients for albumen quality parameters in heavy ecotype native (above diagonal) and Shaver brown (below diagonal) hens.

	AW	AH	AD	AR	AI	Y/A	HU
AW	-	0.233	-0.106	0.693**	0.189	-0.336*	-0.165
AH	0.516*	-	-0.022	-0.063	0.763**	0.075	0.455*
AD	-0.283*	-0.527*	-	-0.267*	-0.647**	-0.324*	0.677**
AR	0.357*	-0.069	0.080	-	0.105	-0.550*	-0.150
AI	0.442*	0.925**	-0.799**	-0.131	-	0.231	-0.061
Y/A	-0.388*	-0.528*	0.202	-0.350*	-0.418*	-	-0.396*
HU	0.424*	0.765**	-0.332*	0.220	0.651**	-0.727**	-

Note: *: Significant at $p \leq 0.05$; **: Significant at $p \leq 0.01$.

Albumen Height (AH) had very weak correlations with AD, AR and Y/A ratio, strong positive correlation with AI and moderate positive correlation with HU. Albumen Diameter (AD) correlated weakly with AR and Y/A ratio and strongly with AI (-0.647) and HU (0.677). Albumen Ratio (AR) had very weak correlations with AI and HU, and moderate negative correlation with Y/A ratio. Albumen Index (AI) was very weakly correlated with Y/A ratio and HU while Y/A ratio was weakly correlated with HU (-0.396). In SB eggs, AW was moderately correlated with AH (0.516) but weakly correlated with other albumen traits. AH had very weak correlation with AR, moderate negative correlations with AD and Y/A ratio, and very strong and near perfect positive correlation with AI and HU, respectively. Albumen Diameter (AD) had very weak correlations with AR and Y/A ratio, weak negative correlation with HU, and very strong negative correlation with AI while AR was very weakly correlated with AI and HU, and weakly correlated with Y/A ratio. Albumen Index (AI) had weak negative correlation with Y/A ratio and strong positive correlation with HU while Y/A ratio was strongly and negatively correlated with HU.

For correlation of albumen and eggshell traits (Table 11), AW had very weak correlations with SW and SD, moderate negative correlations with ST and SI, strong negative correlation with SR, and near perfect positive correlation with SV in SB. Albumen Height (AH) was very weakly correlated with SI, weakly correlated with SW and SR, moderately and positively correlated with SV and SD, and strongly and negatively correlated with ST. Albumen Diameter (AD) had very weak correlations with SR and SI, and weak correlations with SW, ST, SV, and SD while AR had very weak correlations with SW, SV, SR and SI, and weak correlations with ST and SD. Albumen Index (AI) had very weak correlation with SI, weak correlations with SW and SR, and moderate correlations with ST, SV and SD (-0.624, 0.543 and 0.511, respectively). Very weak correlations were observed between Y/A ratio and all the eggshell traits while HU was very weakly correlated with SW, SD, SR and SI, and weakly correlated with ST and SV. In HEN, AW correlated moderately with SV, weakly with SW and SR and very weakly with ST, SD and SI. Albumen Height (AH) correlated moderately with SW, weakly with ST and SV, and very weakly with other indices. Albumen Diameter (AD) correlated weakly with SW and SI, and very weakly with other traits. Very weak correlations were observed between AR and AI and all the eggshell indices while HU correlated strongly with SI (0.662), moderately with SW and SR (0.585 and 0.604, respectively), weakly with ST and SD, and very weakly with SV.

Table 11. Correlation coefficients of albumen and eggshell quality indices in Shaver Brown (SB) and Heavy Ecotype Native (HEN) hens.

Breed/trait	SW	ST	SV	SD	SR	SI
SB	-	-	-	-	-	-
AW	0.065	-0.643**	0.875**	0.075	-0.720**	-0.615**
AH	0.274*	-0.663**	0.585*	0.451*	-0.332*	-0.229
AD	-0.298*	0.321*	-0.353*	-0.304*	0.158	0.067
AR	-0.131	0.311*	-0.138	-0.276*	0.064	0.023
AI	0.357*	-0.624**	0.543*	0.511*	-0.263*	-0.148
Y/A	-0.184	0.186	-0.221	-0.16	0.077	0.026
HU	0.146	-0.271*	0.338*	0.139	-0.184	-0.129
HEN	-	-	-	-	-	-
AW	0.290*	-0.01	0.591*	-0.103	-0.242*	-0.099
AH	0.446*	0.309*	0.396*	-0.015	0.079	0.205
AD	0.436*	0.110	0.169	0.227	0.239	0.332*
AR	-0.038	-0.128	-0.171	0.193	0.151	0.104
AI	0.058	0.128	0.138	-0.098	-0.049	-0.022
Y/A	-0.182	-0.062	0.138	-0.262*	-0.327*	-0.312*
HU	0.585*	0.277*	-0.028	0.441*	0.604**	0.662**

Note: *: significant at $p \leq 0.05$; **: significant at $p \leq 0.01$.

The correlations between eggshell quality indices (Table 12) shows that in HEN eggs, SW had weak and very strong positive correlations with ST and SI, respectively, and moderate positive correlations with SV, SD, and SR. Shell Thickness (ST) had very weak correlations with SV and SR, and weak correlations with SD and SI (-0.390 and 0.289, respectively). Shell Volume (SV) was very weakly correlated with SI, weakly correlated with SD, and moderately and negatively correlated with SR. Shell Density (SD) had very strong positive correlations with SR and SI while SR was perfectly and positively correlated with SI.

Table 12. Correlation coefficients for egg shell quality traits in heavy ecotype native (above diagonal) and Shaver brown (below diagonal) hens.

	SW	ST	SV	SD	SR	SI
SW	-	0.347*	0.455*	0.477*	0.552*	0.757**
ST	-0.181	-	0.124	-0.390*	0.222	0.289*
SV	0.141	-0.838**	-	-0.335*	-0.483*	-0.234
SD	0.830**	0.531*	0.221	-	0.783**	0.768**
SR	0.486*	0.634*	-0.795**	0.306*	-	0.963**
SI	0.648**	0.511*	-0.661**	0.454*	0.981**	-

Note: *: Significant at $p \leq 0.05$; **: Significant at $p \leq 0.01$.

In SB, SW was very weakly correlated with ST and SV, moderately, strongly, and very strongly positively correlated with SR, SI, and SD, respectively. Shell Thickness (ST) had very strong negative correlation with SV and moderate positive correlations with SD, SR and SI. Shell Volume (SV) correlated very weakly with SD, strongly with SI (-0.661), and very strongly with SR (-0.795). Shell Density (SD) had a weak correlation with SR and a moderate correlation with SI while SR was perfectly correlated with SI (0.981).

DISCUSSION

The correlation between egg quality indices reveals the direction and strength of association between traits and this enables improvement and prediction of some egg quality variables using easier-to-determine counterparts [21,22]. In the present study, strength of phenotypic correlation were used to assess the degree of association between egg quality traits in two layer chicken genotypes. The moderate to perfect correlations between EW, EL, ESA, EV and ESG in SB, and EW, EL, ED, ESA, EV and ESG in HEN were consistent with previous studies [23,24]. The near perfect negative correlation between EW and ESG was in concord with Brunelli and de Almeida and this could be attributed to the reduced shell thickness as egg size increases [25,26]. The perfect positive correlations between EW, ESA and EV indicate a proportionate direct relationship between these traits and that they can be predicted from one another [27]. The very weak correlation of EW with ESI in the two breeds agrees with Shi et al [28]. The result indicates minor influence of EW on ESI. Duman et al also reported a very weak correlation (r=0.18) between EW and ESI. EL and ED were very poorly correlated in SB in agreement with Alkan at al [29, 30]. This could be due to the 'rounder' shape of eggs from this breed while the moderate positive correlation between the two traits in HEN agrees with Guni et al and this could be attributed to the more elongated or 'pointer' shape of HEN eggs [31-33]. The perfect positive correlation of ED with ESA and EV in HEN were in agreement with Tyasi et al. The moderate to perfect negative correlation of ESG with geometrical egg traits (EL and ESA in SB, and EL, ED and ESA in HEN) agrees with Inca et al and this could be attributed to the reduced shell thickness as these traits increase in value. ESI was very weakly correlated with ESA and EV in SB, and ESA, EV and ESG in HEN in agreement with previous studies and this indicates that changes in the values of these traits have very minimal influence on ESI [34,35]. The weak to strong negative correlation of ESI with EL, and positive correlations with ED in both genotypes agrees with Inca et al. EL and ED determine ESI however; ED seems to have greater influence on ESI in SB eggs (r=0.955 for ED versus-0.267 for EL) while EL was more important in HEN eggs (r=-0.712 for EL versus 0.258 for ED).

The very weak to zero correlation of SW with EW, ED, ESA, EV, ESG, and ESI in SB and EL in both genotypes could mean different genetic background for SW and these traits especially in SB. The results agreed with the very weak correlations reported between SW and EW, EL, ED, and ESI by previous studies [36]. The moderate positive correlation between SW and EW, ED, ESA, EV, and ESI in HEN agreed with Tyasi et al [37]. Thus selection for higher EW, EL, ED, ESA, EV or ESI in this genotype will lead to moderate improvement in SW but decreased ESG. The weak to moderate negative correlation of ST and SI with EW, EL, ESA, and EV, respectively and the moderate positive correlation with ESG in SB indicate that improvement in EW, EL, ESA, or EV in this genotype would lead to a moderate negative response in ST and SI while improvement in ST and SI would enhance ESG. The weak to very weak correlation of ST and SI with all whole egg quality traits in HEN indicate poor phenotypic relationship with these traits probably because the HEN has not been subjected to intensive genetic selection for egg quality traits. These results agreed with previous studies [38]. The moderate to perfect positive and moderate to strong negative correlations of EW, EL, ESA, and EV in SB, and EW, EL, ED, ESA, and EV in HEN with SV and SR, respectively, and the moderate to strong positive and perfect negative correlations of ESG with SR and SV, respectively in both genotypes were expected. Selection for higher egg size implies higher EL, ED, ESA, EV, and SV but reduced ESG and SR due to thinner eggshell. A very strong negative correlation of EW with SR (-0.780) was reported by Alkan and Turker [39] while weak and very weak negative correlations were reported by other studies [24,36,37]. The weak to very weak correlations of SD with whole egg quality traits in SB and HEN indicate very poor phenotypic relationships between the traits in these genotypes.

The weak correlation of EW, ESA, EV and ESG with YH and AR in SB, and YD and AH in HEN; the moderate correlations with YW, AH and AI in SB, and YW and AW in HEN; and the near perfect correlation with AW in SB agreed with Inca et al. These results indicate that changes in EW, ESA, EV and/or ESG would lead to weak correlated responses in YH, YD, AH and AR in both genotypes, moderate responses in YW, AH and AI in SB, and in YW and AW in HEN, and proportionate response in AW in SB. The reported very weak correlation of EW, ESA, EV and ESG with YD, YR, YI, Y/A, AD and HU, respectively in SB, and YH, YR, YI, Y/A, AD, AR, AI and HU, respectively in HEN indicate that EW, ESA, EV and ESG do not have strong relationship with these yolk and albumen quality traits. The results agreed with Inca et al, who reported weak to very weak correlation coefficients for EW and very weak to zero correlation coefficients for ESG with albumen and yolk quality traits. The mostly negative correlation of ESG with yolk and albumen indices in the present study indicate that improvement in albumen and yolk quality parameters would reduce ESG (according to the strength of correlation) probably due to reduction in eggshell thickness that accompanies increases in egg size. The moderate to strong positive correlation of EL with AW, AH and AI in SB; and YW, YD, YI and AW in HEN as well as the moderate positive correlation of ED with YW, AW and AH in HEN indicate that improvement in EL and/or ED would lead to higher albumen and yolk contents. The results partly agree with Kgwatalala et al who reported strong positive correlation of EL and ED with YW and AW [40]. Apart from AW, AH and AI in SB and YW, YD, YI, AH and AW in HEN, other yolk and albumen traits were poorly correlated with EL and ED in the two genotypes and this agreed with Tunsisa and Reda [41]. Similarly, apart from YR and AR which were moderately and negatively correlated with ESI in HEN, other albumen and yolk quality parameters were weakly to very weakly correlated with ESI indicating poor phenotypic relationship between the traits and this agreed with Vekic et al and Yahaya et al [42]. Alkan et al and Inca et al however, reported very weak correlations for ESI with YR (r=-0.172 and 0.13, respectively) and AR (0.144 and -0.17, respectively) contrary to the results from the present study. The results in the present study suggest that albumen and yolk proportions will be reduced by improvement in ESI. The best ESI in chickens is ‘standard’ (ESI=72-76%) which corresponds to the oval shape of chicken eggs. To maintain this ‘standard’ egg shape requires keeping ED and EL optimal or balanced and this in turn constrains albumen and yolk sizes.

The moderate to very strong positive correlation of YW with YD, YR and Y/A ratio and the very weak correlation with YH and YI in both breeds were in agreement with Tyasi et al [24]. The results indicate that improvement in YW will result in moderate to high correlated response in YD, YR, and Y/A ratio but very minimal impact on YH and YI. A change in YW will be more directly reflected in YD than in YH while a change in YR will directly affect Y/A ratio. Yolk Height (YH) mainly reflects yolk quality. The moderate to very strong negative correlation of YD with YH as well as the strong positive correlation with YR in both genotypes indicates that yolk increases in size through increase in YD (lateral dimension) than YH (vertical dimension) and that improvement in YD reflects improvement in yolk size which increases YR. The results were however, contrary to Inca et al. These workers reported weak to very weak correlation coefficients for YD with YH and YR. The reported very strong to near perfect negative correlation of YD with YI was supported by Tunsisa and Reda who reported moderate to very strong negative correlation between YD and YI while the moderate to very strong positive correlation between YD and Y/A ratio disagrees with the weak correlation coefficient reported by Olawumi and Ogunlade for the same traits [43]. The observed weak to moderate negative correlation of YH with YR and weak negative correlation with Y/A ratio in both genotypes partly agreed with Alkan et al. This study reported very weak correlation of YH with YR and Y/A ratio (-0.137 and -0.139, respectively). The reported near perfect to perfect positive correlation of YH with YI in both genotypes was expected from the expression for determination of YI. The result agreed with the strong to very strong positive correlations reported by previous studies [30,38,40]. The observed moderate to strong negative correlations between YR and YI in the genotypes partly disagreed with Vekic et al who reported very weak negative correlations between the traits (-0.23) while the very strong to perfect positive correlations of YR with Y/A ratio in the genotypes agreed with the findings of Tyasi et al [24].

The weak positive correlation between YW and AW in both genotypes indicates that improvement in YW will be accompanied by slight improvement of AW. It has been observed that increase in egg size with age in hens is essentially due to increase in yolk size and slight increase in albumen content [38]. This might also explain the observed moderate to strong negative correlation of YW and YD with HU in both genotypes. In addition, both albumen and yolk occupy the broad region of the egg. Therefore, the bigger the yolk, the lesser would be the albumen and hence albumen quality reflected in lowered HU. The observed strong positive correlation of YH and YI with HU in the two genotypes indicates strong positive association between yolk quality and albumen quality. YH and YI are indices of yolk quality; as such, factors that reduce YH and YI would equally reduce HU. The very weak negative correlation between YW and SW in both genotypes as well as the very weak positive and negative correlations with ST in HEN and SB, respectively indicate that improvement in YW would have very minor influence on SW and ST as this would depend on the response of shell deposition to increased egg size. The findings were supported by Kgwatalala et al in naked neck and dwarf native chickens and Yahaya et al in Noiler chickens. The reported weak to moderate positive correlations of YW with SV as well as the negative correlations with SD, SR, and SI in both genotypes indicate that increase in YW would result to increase in SV probably due to larger egg size while SD, SR and SI would decrease probably due to the thinning of the shell following increase in egg size. Tyasi et al reported very weak negative correlation between YW and SR in agreement with the present study [24]. The reported very weak to weak positive correlation of YD with SW, ST, and SI in SB as well as the weak negative correlations with SW and ST in HEN indicate minor influence of YD on these eggshell traits while the moderate negative correlation of YD with SR and SI in HEN indicate that improvement in yolk size would reduce the proportion of shell in this genotype. Guni et al reported very low positive correlation values for YD with SW and ST as were observed in SB in the present study. The weak and moderate positive correlations between YH and SW in SB and HEN, respectively were contrary to Yahaya et al but agreed with Inca et al. The observed moderate negative correlation of YH with ST in SB partly disagreed with the very weak negative correlations reported by Tunsisa and Reda while the very weak positive correlation between the traits in HEN was supported by inca et al. Yahaya et al however, reported a moderate positive correlation between the traits in unimproved Nigerian indigenous chicken. The weak negative correlation of YH with SR and SI in SB as against the moderate positive correlations observed between the traits in HEN agreed with Alkan et al. In both genotypes, observed correlations between YR and SW, ST, SR, and SI were generally weak indicating poor phenotypic relationship between YR and these eggshell traits and this agreed with previous reports [6,37,38]. Similarly, apart from the moderate correlation of YI with SV and ST in SB and with SD, SR, and SI in HEN, correlation with other eggshell traits were weak to very weak in both genotypes and this suggests poor phenotypic association between the traits. As was observed in the present study, reported correlation coefficients between yolk and shell traits are highly variable suggesting that egg yolk parameters are unreliable predictors of eggshell traits.

In the present study, moderate and very weak positive correlations were observed between AW and AH in SB and HEN, respectively and this partially agreed with the weak positive coefficients reported by Adeoye et al. The observed weak and strong positive correlations between AW and AR in SB and HEN, respectively and the weak negative correlations with Y/A ratio et al in both genotypes indicate that selection for higher AW will minimally and highly increase AR in SB and HEN, respectively and minimally decrease Y/A ratio in both genotypes. The results were in line with the findings of Olawumi and Ogunlade and Vekic et al. The very weak and moderate positive correlations of AW with AH in HEN and SB, respectively partly agreed with the very weak and weak positive correlations reported by Adeoye et al and Dogara et al [44], respectively. The very weak and weak positive correlations of AW with AI in HEN and SB, respectively agreed with Yahaya et al for Noiler chickens but was contrary to Inca et al who reported a weak negative correlation between the traits. The reported very weak negative correlation of AW with AD and HU in HEN agreed with Tunsisa and Reda but was contrary to the weak positive correlation reported by Vekic et al. The very weak and moderate negative correlations of AH with AD in HEN and SB, respectively agreed with previous studies [38,43]. These results were however, contrary to the very weak positive correlations reported by Alkan et al and Yahaya et al for unimproved Nigerian local chickens. The very weak negative correlation of AH with AR in the two genotypes was in agreement with Inca et al but was contrary to the very weak and weak positive correlations reported by Olawumi and Ogunlade and Alkan et al, respectively. The reported very strong and near perfect positive correlations between AH and AI in HEN and SB, respectively was supported by Inca et al. The results reflect the strong dependence of AI (an index of albumen quality) on AH. Albumen height (AH) and Y/A ratio were positively and very weakly correlated in HEN and this agreed with Inca while the moderate negative correlation between the traits in SB partly agreed with the weak negative correlation reported by Alkan et al. The moderate and very strong positive correlations between AH and HU in HEN and SB, respectively were supported by previous studies [30,38,41]. Very weak positive correlations were however, reported between the traits by Yahaya et al in unimproved Nigerian indigenous chickens and the Noiler. The observed weak negative correlation of AD with AR in HEN concurred with the very weak negative correlation reported by Olawumi and Ogunlade while the very weak positive correlation observed in SB agreed with Alkan et al and Inca et al. The strong and very strong negative correlations between AD and AI in HEN and SB, respectively agreed with Alkan et al while the weak negative correlation with Y/A ratio in HEN agreed with Inca et al and Alkan et al who reported weak and very weak negative correlation, respectively between the traits. These reports were contrary to the very weak positive correlation observed in SB. The strong positive correlation between AD and HU in HEN partially agreed with Yahaya et al who reported very weak positive correlation between the traits but was contrary to Olawumi and Ogunlade who reported weak negative correlation between the traits as was observed in SB in the present study. The very weak positive and negative correlations for AR with AI and HU, respectively in HEN agreed with the weak positive correlation (0.255) reported between AR and AI by Alkan et al and the very weak negative correlation (-0.16) reported between AR and HU by Inca et al. Adeoye et al and Vekic et al reported very weak positive correlations for AR with HU which agreed with values observed in SB. The moderate and weak negative correlations of AR with Y/A ratio in HEN and SB, respectively partly agreed with the perfect and near perfect negative correlations reported by Alkan et al and Inca et al, respectively between the traits. Albumen Index (AI) was very weakly and positively correlated with Y/A ratio in HEN in concord with Inca et al but the traits were weakly and negatively correlated in SB in agreement with Alkan et al while the very weak negative correlation with HU in HEN and strong positive correlation in SB agreed with Yahaya et al and Inca et al, respectively. Alkan et al and Vekic et al reported weak negative correlations between Y/A ratio and HU as was observed in HEN but partially agreed with the strong negative correlation observed in SB. The differences in direction and/or strength of correlation between albumen quality indices in HEN and SB reflect the effect of genotype, genetic interactions, and/or selection history on the traits as were alluded to by previous workers [12,31,42].

In the present study, AW had very weak and weak positive correlations with SW in SB and HEN, respectively and these were in line with the findings of Kgwatalala et al and Dogara et al. Yahaya et al however, reported very weak and weak negative correlations between the traits in two Nigeria chicken genotypes. The moderate negative correlation for AW with ST and SI in SB and the very weak negative correlations in HEN indicate that selection for higher AW would fairly reduce ST and SI in SB but would have very minimal effect on these traits in HEN. These results were in concord with Inca et al and Tyasi et al [24]. Alkan and Turker however, reported very weak positive correlation between AW and SI. The near perfect and moderate positive correlations for AW with SV in SB and HEN, respectively and the strong and weak negative correlations with SR, respectively indicate that improvement in AW would highly and moderately increase SV in SB and HEN, respectively but have a proportionate and minor negative influence on SR in SB and HEN, respectively. Improvement in AW could increase SV *via* increased egg size, and concomitantly decrease SR *via* reduced shell thickness. The negative correlations between AW and SR in the two genotypes were supported by Tyasi et al [24] and Veckic et al. The weak and moderate positive correlations between AH and SW in SB and HEN, respectively, the strong negative and weak positive correlations with ST, respectively, and the moderate and weak positive correlations with SV, respectively indicate that a change in AH would lead to a weak to moderate direct response in SW and SV but a negative response in ST. The positive correlations reported for AH with SW agreed with Dogara et al but was contrary to the weak to very weak negative correlations reported by some other studies (Inca; Tunsisa and Reda; Yahaya) [38,40,41] while the negative correlation with ST agreed with Inca et al and Dogara et al but was contrary to Tunsisa and Reda. The moderate positive and very weak negative correlation of AH with SD in SB and HEN, respectively, the weak and very weak negative correlation with SR and SI, respectively in SB, and the very weak positive correlation between the traits in HEN suggest that selection for higher AH would moderately enhance SD in SB, have little or no effect on SD in HEN, and little or no effect on SR and SI in both genotypes. Alkan et al and Inca et al reported very weak negative correlations between AH and SR while Yahaya et al reported very weak negative correlation between AH and SI in unimproved Nigerian indigenous chickens and very weak positive correlation between the traits in Noiler chickens. The reported weak to very weak correlation coefficients between AD and eggshell traits in the two genotypes indicate poor phenotypic relationship between AD and the eggshell traits probably because AD is highly influenced by environmental factors such as ambient temperature, duration of storage, and relative humidity which do not easily alter the studied eggshell traits. Correlation coefficients reported by previous studies for AD with eggshell traits were generally weak to very weak [38,42,44]. Similar to AD, the observed correlation coefficients for AR, Y/A ratio and HU in SB, and AR, AI and Y/A ratio in HEN, with eggshell traits were generally weak to very weak suggesting poor phenotypic association between the albumen traits and the eggshell traits and this agreed with Tyasi et al [24] and Vekic et al. Tyasi et al [37] however, reported moderate positive and negative correlations for AR with SI and SR, respectively contrary to the present study while Yahaya et al reported a moderate positive correlation of HU with ST in unimproved Nigerian indigenous chickens contrary to the weak negative and positive correlations observed in SB and HEN, respectively. The moderate negative correlation of AI with ST in SB was partially in agreement with the weak and very weak negative correlations reported by Inca et al but was in disagreement with the very weak positive correlation reported by Alkan et al. The weak positive and negative correlation of AI with SW and SR, respectively in SB agreed with the very weak positive correlation of AI with SW and weak negative correlation with SR reported by Yahaya et al and Inca et al, respectively. The very weak negative correlation of AI with SI was contrary to Yahaya et al who reported very weak positive correlation between the traits. The weak positive correlation of HU with ST in HEN agreed with Tunsisa and Reda while the moderate to strong positive correlations with SW, SR, and SI in this genotype disagreed with the very weak correlations reported by Dogara et al and Vekic et al.

The observed weak positive and very weak negative correlation of SW with ST in HEN and SB, respectively indicate that increase in SW does not directly translate to thicker eggshell especially with increase in egg size. Kgwatalala et al and Yahaya et al reported weak positive and very weak negative correlation, respectively between the traits while Olawumi and Ogunlade and Inca et al observed strong positive correlations between the traits contrary to the findings of the present study. The moderate positive correlation of SW with SV in HEN and the moderate to very strong positive correlations with SD, SR and SI in both genotypes indicate that improvement in SW will positively influence these traits. The results were in line with Alkan et al with respect to SW and SR in both genotypes but disagreed with Tyasi et al [37] and Yahaya et al. The very weak positive and weak negative correlation of ST with SV and SD, respectively in HEN as well as the strong negative and moderate positive correlation with SV and SD, respectively in SB suggest that improvement in ST would have minimal effect on SV and SD in HEN but would proportionately reduce SV and fairly improve SD in SB. These results suggest that ST is not just a function of the quantity of eggshell. The reported very weak correlation of ST with SR in HEN agreed with Tunsisa and Reda while the weak positive correlation with SI agreed with Olawumi and Ogunlade. The observed moderate positive correlation of ST with SR in SB were in line with Inca et al who reported strong positive correlation between the traits. The very weak, weak, and moderate negative correlation of SV with SI, SD, and SR, respectively in HEN, as well as, the very weak positive correlation with SD and very strong and strong negative correlation with SR and SI, respectively in SB indicate that as SV increases (*via* increases in egg size), SD and SR in HEN, and SI and SR in SB would decrease. It has been reported that unlike in young hens, increase in egg size in aged hens is not accompanied by a proportionate increase in shell deposition [30,38]. The very strong positive correlations of SD with SR and SI in HEN as well as the weak and moderate positive correlations between the traits in SB indicate that improvement in SD would increase SR and SI in the genotypes. In the present study, SR was perfectly and positively correlated with SI in both genotypes in disagreement with the strong negative correlation reported by Tyasi et al [37]and the very weak positive and negative correlations reported by Tyasi et al [34]in two chicken genotypes. As observed for other egg quality traits, the discrepancies in strength and direction of phenotypic correlations between shell quality traits in SB and HEN in the present study could arise from breed differences as well as extent of genetic selection for egg production and quality parameters.

CONCLUSION

The present study observed similar phenotypic correlations between some egg quality traits in HEN and SB eggs but also variations in direction and/or strength of correlations between other egg quality traits in the two genotypes. The discrepancies could be attributed to breed genetic background, variation in inter trait genetic relationships, degree of genetic selection for egg traits and the selection pathways applied to the genotypes. The SB layer is a commercial hybrid derived from highly selected parental lines whereas the heavy ecotype native chicken is essentially unimproved. The genetic underpinnings of egg quality traits in the two genotypes could differ in their associations and interactions.

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