Egg quality characteristics and phenotypic correlations among egg quality traits in the naked neck, normal and dwarf strains of Tswana chickens raised under intensive management system

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Abstract**—** *Strains found among Tswana chicken population include the naked neck, dwarf, frizzled, rumpless and normal-feathered (normal). Internal and external egg quality characteristics and phenotypic correlations among egg quality traits in different strains of Tswana chickens under intensive management have never been evaluated. The study was conducted to determine the internal and external egg quality characteristics of the naked neck, normal and dwarf strains of Tswana chicken. A total of 200, 185 and 175 eggs were collected from the naked neck, normal and dwarf strains, respectively, for external and internal egg quality analysis. No significant differences in albumin height, albumen pH and yolk pH were found between the strains. The naked neck strain however produced eggs with the highest egg weight, albumen weight, albumen content, egg volume and egg surface area and the lowest yolk content. The dwarf strain had the lowest egg weight, albumin weight, egg volume, and egg surface area and the highest egg shell thickness.All the three strains of Tswana chicken produced eggs of acceptable quality. The naked neck strain however had the best egg quality characteristics, followed by the normal strain and lastly the dwarf strain. Of the three strains, the naked neck strain had the strongest correlation coefficients among external and internal egg quality characteristics and between external and internal egg quality characteristics. Egg weight was positively and highly correlated with other egg quality traits such as egg length, egg width, egg volume, egg surface area, albumen weight and yolk weight in the three strains of Tswana chicken. Selection for higher egg weight is likely to lead to the greatest improvements in other egg quality characteristics (both internal and external) in the naked neck than in the normal and dwarf strains.*

Keywords**—** ***Internal Egg Traits, External Egg Traits, Tswana Chickens, Intensive System, Botswana***

I. INTRODUCTION

Indigenous Tswana chickens are mainly raised under low input and low output free range production system providing food security, protein nutrition, and women empowerment to most rural families in Botswana. Indigenous chickens are well known for their adaptation superiority in terms of resistance to endemic diseases and other harsh environmental conditions (Nwakpu *et. al*., 1999) hence their popularity with small scale subsistence farmers. The increasing demand for poultry products from indigenous Tswana chickens is offering an opportunity for medium scale to large scale production of Tswana chickens. The profitability and long term sustainability of these medium and large scale Tswana chicken enterprises will however depend on the production of good quality eggs by indigenous Tswana chickens. According to Stadelman (1977) egg quality is the characteristics of an egg that affect its acceptability to consumers and is most important price contributing factor in both table and hatching eggs. Some of the factors influencing egg quality include breed/strain/variety, temperature, relative humidity, rearing practice and season (Rajkumar et. al., 2009).

The indigenous Tswana chicken population exhibit great phenotypic variation due to lack of selection in both qualitative and quantitative traits, and strains found within the Tswana chicken population include normal-feathered (normal), naked neck, frizzled, dwarf and the rumpless. These strains represent an important genetic resource that need to be characterized in various traits of economic importance and conserved for future breed developments. Some strains of Tswana chickens such as the dwarf, frizzled, rumpless and naked neck occur at a relatively low frequency in the Tswana chicken population and are at risk of extinction even before they have been characterized in various traits of economic importance. Compared to exotic chicken breeds, there is less information on egg quality traits and phenotypic correlations among various egg quality traits indifferent strains of indigenous Tswana Chickens. The objectives of this study were therefore to evaluate the internal and

external egg quality traits and to determine phenotypic correlations among the various egg quality traits in the naked neck, normal and dwarf strains of indigenous Tswana chicken.

II. MATERIALS AND METHODS

2.1 Location and duration of study

The study was conducted at Botswana College of Agriculture, Content Farm, Sebele, Gaborone, in the Southern part of Botswana from the beginning of November 2014 to the end of January 2015.Environmental temperature during the study period ranged from 20°C to 40°C and averaged 34°C.

2.2 Housing and management

30 females and 3 males of the naked neck strain, 30 females and 3 males of the dwarf strain, 30 females and 3 males of the normal strain of Tswana chickens were housed separately according to strain in separate deep litter houses. The chickens were fed commercial starter crumbs from day old to 4 weeks of age and thereafter were fed commercial grower pellets. Water was provided *ad libitum* throughout the study period. Chickens were raised under natural light (~12hr light and ~12hr dark periods) throughout the study period.

2.3 Collection of eggs

A total of 200, 185 and 175 eggs were collected from the naked neck, normal and dwarf strains of Tswana chickens, respectively, for laboratory analysis of both external and internal egg quality characteristics. The chickens providing the eggs were of the same age (hatched on the same day using an artificial incubator) and egg collection occurred when the hens were between 28 and 38 weeks of age.

2.4 Measurement of Parameters

The external egg quality characteristics measured included egg weight (g), egg length (cm), egg width (cm), egg surface area, shell thickness, and egg shape index. Internal egg quality characteristics that were measured included yolk weight (g), yolk width (cm), yolk height (cm), fresh albumin weight, albumen index (%), albumen %, yolk %, yolk index (%) and Haugh unit. Egg weight was measured using an electronic scale, while egg length and width were determined with an electronic vernier calipers calibrated in mm (Fayeye *et. al.*, 2011). The values for egg length and egg weight were used to determine egg shape index which was calculated as the ratio of egg width to egg length multiplied by 100. Shell weight (shell membrane inclusive) was determined by weighing on the electronic scale. Egg shell thickness was determined using a micrometer screw gauge calibrated in mm. Accuracy of shell thickness was ensured by measuring shell thickness at the broad end, middle portion and narrow end of the shell and taking the average of the three measurements. Yolk index was determined as a ratio of the yolk height to the yolk width. Haugh unit was measured according to Haugh (1937).

2.5 Statistical Analysis

External and internal egg quality traits were analyzed using General Linear Models of Statistical Analysis System version 9.2.1 (SAS, 2009) and the model included the fixed effect of strain (Naked neck, normal and dwarf). Correlation coefficients among external and internal and between external and internal egg quality traits were determined using correlation procedure of SAS. Results on various internal and external egg quality traits are presented as least squares means ± SE, and means separation were by pairwise t-test with Scheffe's adjustment to correct for unequal number of eggs among the three strains of Tswana chickens. Differences between means were declared significantly different at $P<0.05$.

III. RESULTS AND DISCUSSION

3.1 External egg quality traits

There were no significant differences in egg weight, egg length, egg shell weight and egg surface area between the naked neck and normal strains of indigenous Tswana chickens (Table 1). The egg weight, egg length, egg shell weight and egg surface area of the naked neck and normal strains of Tswana chickens were however significantly higher than those of their age-matched dwarf counterparts. Similar egg weight between the naked neck and normal strains of Tswana chickens is consistent with Mohammed *et al*. (2005) and Dakpogan *et al*. (2012). Yakubu *et al*. (2008) and Udoh *et al*.(2012) however reported significantly heavier eggs in the naked neck than in the normal strain of Nigerian indigenous chickens. Heavier egg weights in the naked neck and normal strains of Tswana chickens than in the dwarf strain is consistent with Mohammed *et al*. (2005) and Dakpogan *et al*. (2012). According to Alewi *et al.* (2012) body weight and egg weight are positively correlated

and the egg weights of different strains of Tswana chickens reported in this study are consistent with significantly higher body weight in the naked neck and normal strains of Tswana chickens than in the dwarf strain at 20 weeks of age reported by Kgwatalala *et al.* (2012).

TABLE 1
EXTERNAL EGG QUALITY CHARACTERISTICS OF DIFFERENT STRAINS OF TSWANA CHICKENS

	Strains		
Parameter	**Naked neck**	**Normal**	**Dwarf**
Egg weight (g)	49.79^{a}±0.28	48.21^{a}±0.34	41.32^{b}±0.36
Egg length (cm)	5.27^{a}±0.02	5.31^{a}±0.03	5.05^{b}±0.03
Egg width (cm)	4.10^{a}±0.01	4.06^{b}±0.01	3.77^{c}±0.01
Shape index (%)	78.04^{a}±0.31	76.80^{b}±0.38	74.87^{c}±0.39
Shell weight (g)	5.82^{a}±0.16	6.17^{a}±0.19	4.85^{b}±0.20
Shell content (%)	11.72± 0.32	12.84±0.38	11.76±0.41
Shell thickness (mm)	0.38^{b}±0.006	0.41^{a}± 0.007	0.38^{b}±0.007
Egg surface area (cm^3)	67.74^{a}±0.40	67.48^{a}±0.47	59.63^{b}±0.50

Means with different superscripts within a row are significantly different from each other (P≤0.05)

According to Yousif and Eltayeb (2011) the lower egg weight in the dwarf than in the naked neck and normal strains may be due to the negative effect of sex-linked dwarf gene on production performance. Missohou *et al.* (2002) reported a 9% reduction in egg weight of layers by dwarf genes. Similar egg length between the naked neck and normal strains of Tswana chickens is contrary to Dakpogan *et al*. (2012) and Yakubu *et al*. (2008) who reported significantly longer eggs in the naked neck than in the normal strain of Benin and Nigerian indigenous chickens, respectively. Contrary to our present findings, Yousif and Eltayeb (2011) and Dakpogan*et al.* (2012) reported significantly longer eggs in the dwarf than in the naked neck and normal strains, respectively. Similar shell weight between the naked neck and normal strains of Tswana chickens is consistent with Yakubu *et al*. (2008). The higher egg shell weight in the naked neck and normal strains than in the dwarf strain reported in the current study is consistent with Yousif and Altayeb (2011) and Yeasmin and Howlider (2011) in Sudanese and Bangladesh indigenous chickens. Significantly higher egg surface area in the normal than in the dwarf strain of Tswana chickens is consistent with Yeasmin and Howlider (2011) who found a larger shell surface area in the normal than in the dwarf strain of Bangladesh indigenous chickens. Iqbal *et al.* (2012) however reported non-significant differences in egg surface area between four varieties of indigenous Aseel chicken in Pakistan.

The egg shell content (expressed as a ratio of eggshell weight to total egg weight) did not differ significantly between the three strains of Tswana chickens. Yeasmin and Howlider (2011) also reported similar egg shell content or egg shell percentage between the normal and dwarf strains of Bangladesh native chickens. There was no significant difference in eggshell thickness between the naked neck and the dwarf strains but the eggshell thickness of the two strains were significantly lower than that of the normal strain. Similar egg shell thickness between the naked neck and dwarf strains of Tswana chickens is consistent with Mohammed *et al*. (2005) in Sudanese chickens. Yousif and Altayeb (2011) however reported significantly higher egg shell thickness in the naked neck than in the dwarf strain in Sudanese native chickens. Significantly higher eggshell thickness in the normal than in the naked neck strain is contrary to Yakubu *et al*. (2008) and Mohammed *et al*. (2005) who reported the opposite. According to Alewi *et al.* (2012) egg shell thickness is an important bio-economic trait that layer chicken breeders incorporate in their breeding programmes to reduce egg shell breakages. Eggs of the normal strain of Tswana chickens are therefore less likely to be prone to shell breakages than those of their naked neck and dwarf counterparts.

Egg width and egg shape indices differed significantly between the naked neck, normal and dwarf strains with the naked neck strain exhibiting the highest values for both egg width and egg shape index and the dwarf strain exhibiting the lowest values in the two egg quality parameters. Egg width and egg shape index in the normal strain were intermediate to those of the naked neck and dwarf strains. Higher egg width in the naked neck than normal and dwarf strains of Tswana chickens is consistent with Yakubu *et al*. (2008) and Yousif and Altayeb, (2011). Dakpogan *et al*. (2012) however reported similar egg width between the naked neck, normal and dwarf strains of Benin indigenous chickens. Higher egg shape indices in the

naked neck than the normal strain and in the normal than the dwarf strain are consistent with Yakubu *et al*. (2008) and Yeasmin and Howlider (2011).Iqbal *et al.* (2012) however reported no significant differences in egg width and egg shape indices between four varieties of indigenous Aseel chicken of Pakistan. According to Zeidler (2002) shape indices of 70-74 are considered normal shape indices for commercial layers while the shape index of 75 is regarded as the most satisfactory when eggs are to be packaged in specialized containers for transportation (Smith, 1990). The dwarf strain of Tswana chicken therefore has the best shape index while the naked neck and normal strains produced more rounded eggs (higher indices) that are likely to be more prone to breakages.

3.2 Internal egg quality traits

The absolute albumen weight differed significantly among the three strains of indigenous Tswana chickens (Table 2). The naked neck strain had the highest albumin weight and the dwarf strain the lowest albumin weight. There was however no significant difference in albumen content (expressed as a proportion of albumin weight to total egg weight) between the normal and dwarf strains of Tswana chickens. The albumen content of the naked neck strain was however significantly higher than those of the normal and dwarf strains. Significantly higher albumen weight in the naked neck than both normal and dwarf strains of Tswana chickens is consistent with Yakubu *et al*. (2008) and Yousif and Altayeb (2011). Yeasmin and Howlider (2011) also reported higher fresh albumin weight in the normal than dwarf strain of Bangladesh indigenous chicken. According to Harms and Hussein (1993), albumen weight is more closely related to egg weight than yolk weight and the higher albumin weight and albumen content in the naked neck than in the normal and dwarf strains of Tswana chickens is consistent with the egg sizes of the three strains. Eggs containing a large proportion of albumen are regarded as being of high quality (Peters *et. al.*, 2007)and the naked neck strain of Tswana chicken therefore produces the highest quality eggs than the normal and dwarf strains. There were no significant differences in albumin height and albumin pH between the naked neck, normal and dwarf strains of Tswana chickens. Similar albumin height between the three strains of Tswana chickens is contrary to Yakubu *et al*. (2008) and Yousif and Altayeb (2011) who reported significantly higher albumin height in the naked neck than normal and naked neck than dwarf strains, respectively. Peters *et al.* (2007) also reported significantly higher albumen pH in the normal than in the naked neck strains of local Nigerian chickens.

TABLE 2
INTERNAL EGG QUALITY CHARACTERISTICS OF DIFFERENT STRAINS OF TSWANA CHICKENS

	Strains		
Parameter	**Naked neck**	**Normal**	**Dwarf**
Albumin weight (g)	30.26^{a}±0.31	27.75^{b}±0.36	24.24^{c}±0.39
Albumin content (%)	60.71^{a}±0.49	57.50^{b}±0.59	58.63^{b}±0.62
Albumin height (mm)	6.39±0.24	6.00±0.28	6.44±0.30
Albumin pH	8.79±0.03	8.78±0.04	8.85±0.04
Yolk weight (g)	13.71^{a}±0.17	14.28^{a}±0.21	12.24^{b}±0.22
Yolk content (%)	27.57^{a}±0.31	29.66^{b}±0.37	29.61^{b}±0.39
Yolk height (cm)	1.67^{b}±0.03	1.74^{ab}±0.04	1.82^{a}±0.05
Yolk width (cm)	3.72^{a}±0.03	3.50^{b}±0.04	3.65^{a}±0.05
Yolk index	0.45^{b}±0.01	0.50^{a}±0.01	0.50^{a}±0.01
Yolk pH	6.42±0.02	6.46±0.03	6.40±0.03
Edible portion (g)	43.97^{a}±0.30	42.03^{b}±0.36	36.47^{c}±0.38
Edible Content (%)	88.28±0.32	87.16±0.38	88.24±0.41
Egg volume (cm^3)	53.20^{a}±0.42	52.58^{a}±0.51	43.13^{b}±0.54
Haugh unit	81.05^{b}±1.38	78.44^{b}±1.71	88.88^{a}±1.83
Age at first egg (days)	140^{a}±2.38	141^{a}±2.71	148^{b}±2.83

Means with different superscripts within a row are significantly different from each other (P≤0.05)

There was no significant difference in absolute yolk weight between the naked neck and normal strains of Tswana chickens. The two strains however had significantly higher absolute yolk weight than the dwarf strain. The yolk content of the naked neck strain (27.57±0.31%) was significantly lower than those of the normal and dwarf strains of Tswana chickens. There was no significant difference in yolk content between the normal and dwarf strains (29.66±0.37 and 29.61±0.39%, respectively). Similar yolk weight between the naked neck and normal strain of Tswana chickens is contrary to Yakubu *et al*. (2008) who found significantly higher yolk weight in the naked neck than normal strain in Nigerian indigenous chickens. Significantly higher yolk weight in the naked neck than in the dwarf strain of Tswana chickens is however consistent with Yousif and Altayeb (2011) in Sudanese native chickens. The lower yolk content in the naked neck than in the dwarf and normal strains of Tswana indicate that eggs of naked neck chickens might be relatively healthier with lower total saturated fat and cholesterol content which are mostly found in the egg yolk.

There were no significant differences in yolk height between the naked neck and normal strains and between the normal and dwarf strains of Tswana chickens. Udoh *et al*. (2012) also reported a non-significant difference in yolk height between the naked neck and normal-feathered Nigerian local chickens. Yakubu *et al*.(2008) however, reported significantly higher yolk height in the naked neck than in the normal strain in Nigerian indigenous chickens. The yolk height of the dwarf strain was however significantly higher than that of the naked neck strain (1.82±0.05 and 1.67±0.03cm, respectively) which contradicts Yousif and Altayeb (2011) who reported the opposite in Sudanese native chickens. There was no significant difference in yolk width between the naked neck and dwarf strains but the yolk widths of the two strains were significantly higher than that of the normal strain. Significantly higher yolk width in the naked neck than in the normal strain of Tswana chickens is consistent with Yakubu *et al*. (2008). Yousif and Altayeb (2011) to the contrary reported significantly higher yolk width in the naked neck than in the dwarf strain of Sudanese native chickens. The yolk index did not differ between the normal and dwarf strains of Tswana chickens but the two strains had significantly higher yolk index than the naked neck strain. Yeasmin and Howlider (2011) also reported similar yolk index between the normal and dwarf strains in Bangladesh native chickens. Significantly higher yolk index in the normal than naked neck strain of Tswana chickens is however contrary to Yakubu *et al*. (2008) and Udoh *et al.* (2012) who found similar yolk index between the naked neck and normal strain in Nigerian indigenous chickens. The yolk indices of the three strains of Tswana chickens ranged from 0.45 to 0.50 which is higher than the egg yolk indices range of 0.35-0.38 for the indigenous Kadaknath chicken breed of India reported by Fayeye*et al.* (2005). The yolk indices of the three strains of Tswana chicken were however within the range of 0.33-0.50 required of good quality eggs (Ihekoronye and Ngoddy, 1985). Egg yolk pH did not differ significantly between the three strains of Tswana chickens but unlike the albumin, the egg yolk was acidic.

The absolute weights of the edible portion of the egg (albumin weight plus yolk weight) differed significantly among the three strains of Tswana chickens. The naked neck strain had the highest absolute weight of the edible portion of the egg (43.97±0.30g) and the dwarf strain had the lowest (36.47±0.38g). The edible content (expressed as a ratio of albumin plus egg yolk weight to total egg weight) however, did not differ significantly between the naked neck, normal and dwarf strains of Tswana chickens. There was no significant difference in egg volume between the naked neck and normal strains of Tswana chickens (53.20±0.42 and 52.58±0.51cm^3, respectively) but the egg volumes of the two strains were significantly higher than that of the dwarf strain (43.13±0.54cm^3). Iqbal*et al.* (2012) reported non-significant differences in egg volume between four varieties of indigenous Aseel chicken of Pakistan. The egg volumes of indigenous Tswana chickens ranged from 43.13-53.20 cm^3 which is higher than egg volumes of 35.87-40.32cm^3 reported by Iqbal *et al.* (2012) in the four varieties of indigenous Aseel chicken of Pakistan. There was no significant difference in Haugh unit between the naked neck and normal strains of Tswana chickens (81.05±1.38 and 78.44±1.71%) but the two strains had significantly lower Haugh unit than the dwarf strain (88.88±1.83%). Contrary to our findings, Yakubu *et al*. (2008) reported significantly higher Haugh unit inthe naked neck than in the normal strain of Nigerian native chickens. Yousif and Altayeb (2011) also reported significantly higher Haugh unit in the naked neck than in the dwarf Sudanese native chickens. There was no significant difference in age at first egg between the naked neck and normal strains but the age at first age was delayed by about a week in the dwarf strain. To the contrary, Yousif and Eltayeb (2011) reported age at first egg of 163.90±1.55 and 184.90±1.71 in Sudanese native dwarf and naked neck chickens, respectively, under improved traditional production system. The higher age at first egg in the dwarf than in the normal and naked neck strains of Tswana chickens is consistent with Garces *et al.* (2001) who associated the dwarf gene with delayed sexual maturity as well as the production of fewer and lighter egg.

3.3 Phenotypic Correlations among External Egg Quality Traits in Tswana Chickens

High and significant (P<0.05) positive correlations were observed between egg weight and other external egg quality traits such as egg surface area, egg length and egg width in the dwarf, naked neck and normal strains of Tswana chickens (Table 3). The correlation between egg weight and shell weight was significant (P<0.05) but weak in the dwarf and normal strain (0.407 and 0.334, respectively) while there was no significant correlation between egg weight and shell weight in the naked neck strain (r=0.093).

TABLE 3
PHENOTYPIC CORRELATIONS AMONG EGG QUALITY TRAITS IN THE DWARF, NAKED NECK AND NORMAL STRAINS OF TSWANA CHICKEN

STRAIN	TRAIT	EW	EL	EWD	ESI	AWT	YWT	EC	SWT	STH	ESA	EV
DF	EW	1.000	0.647 *	0.625*	-0.112	0.901*	0.700*	0.984*	0.407*	-0.171	0.801*	0.788*
NN		1.000	0.807*	0.801*	-0.122	0.892*	0.703*	0.987*	0.093	-0.641**	0.898*	0.891*
NR		1.000	0.634*	0.722*	0.074	0.907*	0.764*	0.979*	0.334*	-0.142	0.790*	0.789*
DF	EL		1.000	0.264*	-0.693*	0.572*	0.560**	0.676**	0.066	-0.245*	0.824**	0.666**
NN			1.000	0.604*	-0.555*	0.688**	0.590**	0.784**	0.151	-0.579**	0.907**	0.830**
NR			1.000	0.473*	-0.521**	0.635**	0.424*	0.644**	0.106	-0.114	0.853**	0.740**
DF	EWD			1.000	0.509**	0.629**	0.340*	0.621**	0.222	-0.081	0.764**	0.894**
NN				1.000	0.326	0.767**	0.562*	0.828**	-0.137	-0.675**	0.884**	0.945**
				1.000	0.504**	0.720**	0.559**	0.760**	-0.005	-0.202	0.863**	0.941**
NR	ESI				1.000	-0.036	-0.255*	-0.140	0.105	0.160	-0.165	0.072
NN					1.000	-0.012	-0.122	-0.066	-0.347*	-0.052	-0.153	0.002
NR					1.000	0.071	0.122	0.100	-0.105	-0.078	-0.002	0.184
DF	AWT					1.000	0.369*	0.911**	0.239*	-0.208	0.752**	0.755**
NN						1.000	0.362*	0.894**	0.024	-0.507*	0.777**	0.785**
NR						1.000	0.481**	0.944**	0.043	-0.223	0.793**	0.795**
DF	YWT						1.000	0.719**	0.133	-0.275*	0.576**	0.527**
NN							1.000	0.726**	-0.138	-0.546*	0.645**	0.637**
NR							1.000	0.743**	0.276*	-0.223*	0.571**	0.581**
DF	EC							1.000	0.238*	-0.278*	0.818**	0.798**
NN								1.000	-0.068	-0.644**	0.899**	0.901**
NR								1.000	0.137	-0.254*	0.820**	0.825**
DF	SWT								1.000	0.450**	0.175	0.205
NN									1.000	0.050	0.004	-0.053
NR									1.000	0.434**	0.051	0.020
DF	STH									1.000	-0.210	-0.174
NN										1.000	-.707**	-0.722**
NR										1.000	-0.196	-0.212
DF	ESA										1.000	0.971**
NN											1.000	0.988**
NR											1.000	0.982**
DF	EV											1.000
NN												1.000
NR												1.000

DF,NN,NR,EW,EL,EWD,ESI,AWT,YWT,EC,SWT,STH,ESA,EV= Dwarf, Naked Neck, Normal Feathered, egg weight, egg length, egg width, egg shape index, albumen weight, yolk weight, egg content, shell weight, shell thickness, egg surface area, egg volume, respectively. * represent sig. diff (p<0.05).

The Naked Neck strain had the highest correlation coefficient between egg weight and egg surface area and egg length and while the Dwarf strain had the highest correlation coefficient between egg weight and egg width. Significant positive

correlations between egg weight and egg length and egg width in the different strains of Tswana chickens are consistent with Yousif and Eltayeb (2011) and Yakubu *et al.* (2008). The correlation coefficients between egg weight and egg width in the different strains of Tswana chicken reported in the current study are higher than the correlation coefficient between the same traits reported by Yousif and Eltayeb (2011) in dwarf and naked neck strains of Sudanese chickens (0.45 and 0.53, respectively). The correlation coefficients between egg weight and egg length and egg width in Tswana chickens are also higher than those reported between the two traits in Nigerian naked neck and normal-feathered chickens (Yakubu et. al., 2008).

Negative correlations were recorded between egg weight and shell thickness in all the three strains of Tswana chickens and between egg weight and egg shape index in the Dwarf and Naked Neck strains. A significant negative correlation between egg weight and shell thickness was found only in the Naked Neck strain (r= -0.641), otherwise all the correlations between egg weight and shell thickness and egg shape index were weak and non-significant. Yakubu *et al*. (2008) also reported a weak correlation between egg weight (r=0.23) and egg shape index in free range naked neck and normal-feathered Nigerian indigenous chickens. Negative association between egg weight andegg shape index has also been reported in other poultry species (Ozcelik 2002; Nowaczewski et al., 2008). To the contrary, Bernacki and Heller (2003) reported a significant positive correlation between egg shape index and egg weight suggesting that heavier eggs are more rounded in shape. A negative correlation coefficient between egg weight and eggshell thickness suggests that heavier eggs are thin-shelled and more prone to breakages than lighter eggs probably due to the increased surface area for shell deposition in heavier or larger eggs compared to smaller or lighter eggs in the uterus. Strong, significant and positive correlation coefficients between egg weight and other egg quality parameters indicate that selection for higher egg weight (current grading and pricing of chicken eggs based on egg weight) in Tswana chickens might lead to simultaneous positive improvements in egg surface area, egg length and egg width but might negatively affect egg shell thickness which might lead to large eggs that are highly susceptible to breakages.

Egg length was highly and significantly ($P<0.05$) positively correlated with egg surface and egg volume and weakly but significantly positively correlated with egg width in the dwarf, naked neck and normal-feathered strains of Tswana chickens. Yakubu *et al*. (2008) reported a strong, positive and significant correlation between egg length and egg width (r=0.71) in free range naked neck and normal-feathered Nigerian indigenous chickens. Obike and Azu (2012) also reported moderate and positive correlation coefficients between egg length and egg width in pearl grey and royal purple varieties of helmeted guinea fowl. Egg surface area had high, significant ($P<0.05$) and positive correlation with egg volume in the three strains of Tswana chicken. Significant correlation coefficients between egg length, egg width, egg volume and egg surface are due to the fact that egg length and egg width determine the volume and holding capacity of an egg, which in turn gives an indication of egg surface area and egg weight (Obike and Azu, 2012). Direct selection for either egg length and egg width will thus result in simultaneous improvement in egg volume, egg surface area and egg weight.

A weak, positive and non-significant correlation existed between egg length and egg shell weight and between egg width and egg shell weight in all the three strains of Tswana chickens. Weak correlation coefficients between egg width and egg shell weight observed in the three strains of Tswana chicken are consistent with Yousif and Eltayeb (2011) who also reported weak correlation coefficients between the two traits in Sudanese dwarf and naked neck chickens (r=0.39 and r=0.37, respectively). Significant negative correlations between egg length and egg shell thickness were observed in the dwarf and naked neck strains of Tswana chicken (r= -0.245 and -0.579, respectively) while a weak, negative and non-significant correlation coefficient was observed between egg length and egg shell thickness in the normal strain of Tswana chicken (r=-0.114). A moderate, negative and significant correlation coefficient between egg width and egg shell thickness (r=-0.675) occurred only in the naked neck strain. A negative correlation between egg width and egg shell thickness observed in the naked neck strain of Tswana chicken is consistent with Yousif and Eltayeb (2011) who also reported a negative though very weak correlation coefficient between the two traits in Sudanese naked neck chickens.

Moderate and positive correlations between egg width and egg shape index occurred in all the three strains of Tswana chicken. Moderate correlation coefficients between egg width and egg shape index have also been reported in quail and chickens (kul and Seker, 2004 and Abanikannda *et al.*, 2007). Significant, positive and higher correlation coefficients (0.70-0.76) between egg width and egg shape index have been reported in pearl grey and black varieties of helmeted guinea fowl (Obike and Azu, 2012). Positive correlation coefficients between egg width and egg shape index are to be expected in different poultry species because egg width is the numerator in the calculation of egg shape index (Obike and Azu, 2012). Weak and non-significant correlations occurred between the egg shape index and egg surface area, egg volume, shell weight

and shell thickness in all the three strains of Tswana chickens. Yakubu *et al*. (2008) also reported weak correlation coefficients between egg shape index and shell weight (r=0.16) and shell thickness (r=0.03) in Nigerian free range naked neck and normal-feathered chickens.

3.4 Phenotypic Correlations among External and Internal Egg Quality Traits in Tswana Chicken

Strong, positive and significant correlations occurred between egg weight and other internal egg quality traits such as albumen weight, yolk weight, egg content and egg volume in all the three strains of Tswana chickens. Strong correlation coefficients between egg weight and albumen weight and yolk weight observed in the three strains of Tswana chickens are consistent with Yousif and Eltayeb (2011) who also reported strong, positive correlation coefficients between egg weight and albumen weight (r=0.88 and 0.79 in the dwarf and naked neck) and moderate positive correlation coefficients between egg weight and yolk weight in the dwarf and naked neck Sudanese chickens (r=0.66 and 0.50, respectively). Obike and Azu (2012) also reported significant positive correlation coefficients between egg weight and albumen and yolk weight in pearl grey and black varieties of helmeted guinea fowl. The Normal strain of Tswana chicken had the highest correlation coefficient between egg weight and albumen weight and yolk weight, while the Naked Neck strain had the highest correlation coefficient between egg weight and egg content and egg volume. These results suggest that selecting Tswana chicken for increased egg weight will result in eggs with higher albumen and yolk weight.

Strong, positive and significant ($P<0.05$) correlations existed between egg length and egg content and egg volume in the three strains of Tswana chickens. There were moderate, positive and significant correlation coefficients between egg length and albumen weight and yolk weight in the three strains of Tswana chickens. Moderate correlation coefficients between egg length and albumen weight observed in the current study are consistent with Yakubu *et al*. (2008) who also reported moderate correlation coefficients between the two traits in the Nigerian free range naked neck and normal-feathered chickens (r=0.52). The naked neck strain had the highest correlation coefficient between egg length and egg content, egg volume, albumen weight and yolk weight compared to the other two strains implying that selection for increased egg weight will result in the greatest improvements in egg length and other internal egg quality traits in the naked neck than in the dwarf and normal strains of Tswana chickens.

Strong, positive and significant correlations also existed between egg width and albumen weight, egg content and egg volume in the three strains of Tswana chickens. Moderate, positive and significant correlation existed between egg width and yolk weight (0.562 and 0.559 in the naked neck and normal strains, respectively) while weak, positive and significant ($P<0.05$) correlation existed between the same traits (r=0.340) in the dwarf strain. Strong, positive correlation coefficients between egg width and albumen weight and yolk weight observed in the three strains of Tswana chickens are inconsistent with Yousif and Eltayeb (2011) who reported weak, positive correlation coefficients between egg width and albumen weight (r= 0.37 and 0.36) and yolk weight (r=0.32 and 0.350) in Sudanese native dwarf and naked neck chickens, respectively. Strong, positive and significant correlations existed between egg surface area and albumen weight, egg content and egg volume in the three strains of Tswana chickens. Moderate, positive and significant correlations also existed between egg surface area and egg yolk in the dwarf, naked neck and normal strains of Tswana chickens.

Egg volume was strongly, positively and significantly correlated with albumen weight and egg content and moderately correlated with yolk weight in the three strains of Tswana chickens. Weak, positive to negative and non-significant correlations existed between egg shape index and egg volume, albumen weight and egg content in the three strains of Tswana chickens. Egg shape index was weakly and non-significantly correlated with yolk weight in the naked neck and normal strains (r=-0.122 and 0.122, respectively) while there was a negative and significant correlation between egg shape index and yolk weight in the dwarf strain (r=-0.255).Weak and non-significant correlation coefficients between egg shape index and albumen weight observed in the three strains of Tswana chickens are consistent with Yakubu *et al.* (2008) who also reported a weak but significant correlation coefficient between the two traits in the Nigerian free range Naked Neck and Normal Feathered (r=0.26).

Shell weight was weakly, positively and significantly correlated with albumen weight in Dwarf strain but was weakly, positively and non-significantly correlated with albumen weight in the naked neck and normal strains. Shell weight was weakly and non-significantly correlated with yolk weight, egg content and egg volume in the naked neck strain. Shell thickness was weakly, negatively and significantly correlated with egg content and yolk weight in all the three strains of Tswana chickens. Weak correlation coefficients between shell thickness and yolk weight and albumen weight observed in all

the strains of Tswana chickens are not consistent with Yakubu *et al*. (2008) who reported a moderate correlation coefficient between shell thickness and yolk weight and albumen weight in Nigerian naked neck and normal strains, respectively.

3.5 Phenotypic Correlations among Internal Egg Quality Traits in Tswana Chickens

Strong, positive and significant correlations occurred between albumen weight and egg content and egg volume in the naked neck, normal and dwarf strains of Tswana chickens. Weak, positive and significant correlation coefficients were observed between albumen weight and yolk weight in the three strains of Tswana chickens. Yousif and Eltayeb (2011) also reported weak, positive and negative correlations between albumen weight and yolk weight (r= 0.25 and -0.11 in the dwarf and naked neck strains, respectively) in Sudanese native chickens. This indicates that selection for improvement in albumen weight might lead to improvement in total edible portion of the egg and this is in agreement with Nonga (2010) who reported that albumen has a major influence on overall interior egg quality. Yolk weight was strongly, positively and significantly correlated with egg content in the three strains of Tswana chickens, but was moderately, positively and significantly correlated with egg volume in all the three strains of Tswana chicken.

IV. CONCLUSION

Naked neck, normal and dwarf strains of Tswana chicken produce eggs of acceptable external and internal qualities. Eggs of the naked neck and normal strains are heavier than those of the dwarf strain. Of the three strains, the naked neck produce the healthiest eggs for human consumption with the highest albumen (protein) weight and content and the lowest yolk (fat) weight and content. Selection for higher egg weight in the three strains of Tswana chicken is likely to lead to improvements in other egg quality traits such as egg length, egg width, egg volume, egg surface area, albumen weight and yolk weight and the greatest improvement in correlated egg quality traits will occur in the naked neck than in the other two strains.

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