Quality Characteristics, Phenotypic correlations and Principal Component Analysis of Indigenous Free Range Chicken Eggs in Lusaka, Zambia

Simushi LISWANISO[1], Ning QIN[2], Xuesong SHAN[3], Ignatius Musenge CHIMBAKA[4], Xue SUN[5], Rifu XU[6*]
[1,2,3,4,5,6]Department of Animal Breeding, Genetics and Reproduction Collage of Animal Science and Technology, Jilin Agricultural University, Changchun 130118, Jilin, P.R China.
[1]Department of Livestock Development, Mulungushi House. Lusaka. Republic of Zambia.
[1,2,4,5,6]Modern Agricultural Technology International Cooperative Joint Laboratory of the Ministry of Education, Changchun 130118, P. R. China

Abstract— *The aim of this study was to characterize indigenous chicken eggs and create an inventory that will set a base for designing breeding programs to improve egg quality traits. 338 eggs of mixed breeds of indigenous chickens from small scale farmers in Lusaka were collected and used in this study. A number of external and internal traits were measured manually. The eggs had a weight of 49±0.44g with a length of 54.55mm and 40.31mm wide. Other traits measured included egg shell weight and length, with the egg shell accounting for 12.78% of the total weight of the egg. The egg albumin and egg yolk weighed 26.21g and 16.55g respectively. The egg weight positively correlated with all the traits studied. A principal component analysis on these traits extracted three principal components that accounted 75.80%. The diversity shown by these eggs shows a huge potential for improvements of egg quality characteristics through proper selection and breeding.*

Keywords— egg quality, indigenous chickens, egg shape index, principal component analysis, Lusaka.

I. INTRODUCTION

Eggs are a biological structure intended for reproduction found in female animals. They protect and provide diet to the developing embryo. Even after hatching, eggs remain a source of nutrition for few more days. Some animals produce eggs external to their bodies like birds while others produce eggs inside their bodies. In developing countries, eggs as the most important protein source to man cannot be overemphasized because eggs contain multiple essential nutrients. As a major product from poultry, eggs are composed of egg albumin, egg yolk and the shell in 58, 31 and 11 percentages. More than half of the egg protein is in the albumin while most of the vitamins and all fats are in the egg yolk (Abanikannda *et al.* 2007)

The egg quality depends mainly on consumer preference with respect to various traits that include freshness, mass, cleanliness, egg weight, volume, shell quality and color, yolk index, and shell thickness (Narushin 1997). In the recent past, the trait that has drawn so much attention from researchers is the egg shape (Nedomova *et al.* 2009; Duman *et al.* 2016) which is mainly determined by shape index. The shape index (SI) of the egg is the quotient of the width and the length of the egg. It is the standard by which eggs are graded. Eggs with shape index of less than 72 are classified as sharp, those with SI between 72 and 76 are classified as standard eggs while round eggs have egg index of above 76. Unusually sharp and round eggs can never be graded in AA (top grade) or A (second to AA) this is because they are difficult to pack in cartons and can easily break during freight than those classified as standard eggs (Galic *et al.* 2019).

The indigenous chicken egg farming in Zambia is still a developing one like in any other developing country. And there is very limited commercialization in this sector with only 0.5% of the total population of indigenous chickens being under commercialized production systems (MFL 2019). Chances of developing this sector are so limited due to among many reasons the poor genetic potential of indigenous chickens. Indigenous chickens will lay between 20 and 80 eggs per. This is very low compared to the commercial counterparts that will lay up to 300 eggs per year (Guèye 2000; Wong *et al.* 2017; Dumas *et al.* 2018). This can however, be improved by design of proper breeding programs.

In order to breed towards improving the quality of eggs, there is need for breeders to understand the available phenotypes and the relationships that exist between egg quality characteristics. Studies on Several intraspecific variations in egg composition have been conducted (Hill 1995; Dzialowski & Sotherland 2004). Intraspecific variations in egg traits have been attributed to numerous factor amongst them size and nutritional standing of hen, feed handiness, heritability, order of laying and a blend of these factors (Schreiber & Lawrence 1976; Abanikannda & Leigh 2007). In order to make sense of these relationships and make informed decisions, as breeders we find ourselves in situations where we deal with large numbers of correlated traits and this data would be complex to handle. Principal component analysis (PCA) a multivariate analysis procedure becomes handy to analyze these data. PCA analyses data where observations are described by numerous inter-correlated quantifiable reliant variable (Abdi & Williams 2010). The fundamental theory of PCA is that it reduces the dimensionality of data sets with a huge quantity of related variables at the same time holding as much disparity as there can be of the existing in the data. This is attained by changing to a different set of variables, (the principal components, PCs) which are not correlated but organized so much that the highest of the dissimilarity extant in the original variables is maintained in the first few components (Jolliffe 2005). PCA has been used several times to study variations in egg traits (Sarica *et al.* 2012; Bing-Xue *et al.* 2013; Ukwu *et al.* 2017).

This study aimed at characterizing indigenous chicken eggs in Lusaka, Zambia and use PCA to analyze these characteristics. The results of this study would serve as an inventory of the egg production genetic potential possessed by these chickens on which decisions on the designing of breeding programs as well as selection and breeding would be based.

II. MATERIALS AND METHODS

2.1 Description of site

The study was conducted in Lusaka district in Zambia's Lusaka province in August 2018. Lusaka approximately covers 360 km^2 of area sitting on 15°25′S and 28°17′E. Lusaka has a high altitude with humid subtropical climate. Its coolest month is July whose mean temperatures drop to 14.9 °C. Their summer is very hot and has relatively warm winters. The hottest month is October whose daily mean temperatures go up to 32 °C.

2.2 Data Collection

A total 338 fresh eggs were collected from Lusaka west area in Lusaka district, a place with a concentration of small scale poultry production. These were less than 3 days old from day of laying. The breeds used were of mixed breeds and there is limited documentation on their characterizations if any exist.

2.3 Collection of parameters

The following traits were measured using the standard procedures (Monira *et al.* 2003; Fayeye *et al.* 2005).

Egg length (mm): Through the use of digital Vernier calipers this was measured as the distance between the broad end and the narrow end.

Egg width (mm): A Vernier caliper was used to measure the distance across the middle of the egg.

Egg weight (g): Individual eggs were weighed on a digital scale with accuracy of 0.01g

Shell weight (g): After carefully opening the eggs from the narrow end to allow its contents come out without mixing, the shell was weighed together with the membrane on an electronic scale with 0.01 accuracy.

Shell thickness (mm)**:** A micrometer gauge was made use of to quantify the thickness of the egg shell. The shell thickness was taken at the narrow end, the middle and broad end with their average recorded as thickness of the shell**.**

Albumin weight (g) and yolk weight (g): The fresh eggs were opened at the sharp end enough to allow passage of both the yolk and egg albumin ensuring they don't mix. The yolk and albumin were carefully separated into pre weighed petri dishes. The variance between the heaviness of the unfilled and the weight of the petri dish containing the albumin or yolk was the weightiness of the albumin and yolk respectively.

Yolk height (mm): The height of the yolk was taken using depth gauge of the digital Vernier calipers.

Yolk width (mm): The yolk's width was also taken at the widest horizontal circumference using digital Vernier calipers.

Egg surface area (cm^2) was computed as $S=4\pi r^2$. Radius (r) was calculated as ¼ (length + width) of the egg.

Yolk index: The ratio of the height of the yolk to the yolk width was taken as the yolk index.

Yolk ratio was estimated as yolk weight as the percentage of full weight of the egg.

Egg shape index (%): The quotient (multiplied by 100) of the egg width (W) and egg length (L) was taken as the shape index of the egg as below.

The formula is Egg shape index = $\frac{egg\ width}{egg\ length}$ x 100 (Markos *et al.* 2017).

2.4 Statistical Analysis

Means, standard error of the mean and coefficients of deviation of egg measurements in Lusaka were evaluated by means of the descriptive statistic of Minitab 18. Pearson correlation coefficients amongst these egg traits were determined. And the correlation matrix remained the main data necessary for Principal component analysis (PCA). To assess the legitimacy of the factor scrutiny of the number sets, Bartlett's test of sphericity was computed. The appropriateness of the statistics set to do analysis was additionally confirmed by KMO (Kaiser-Meyer-Olkin) extent of sampling competence which tested if the correlations between variables stayed trivial. A KMO quantity of 0.60 and higher was taken as adequate (Eyduran *et al.*, 2010). Then Principal Component Analysis for egg quality traits was performed using Minitab 18 statistical software.

III. RESULTS AND DISCUSSION

3.1 Egg quality traits

Table 1 shows the descriptive statistics of the egg quality traits of indigenous chickens in Lusaka, Zambia. The eggs weighed 49.72±0.44g, with a length of 54.55±0.17mm and a width of 40.31±12mm. The egg radius was 2.37±0.01mm and the surface area was 70.79±0.37cm^2. The eggs in this study had shells with a mean weight of 6.34±0.05g, a thickness of 0.36±0.01mm and a shell ratio of 12.78±0.06%. The albumins in this study had recorded a mean weight of 26.21±0.30g. The eggs had egg yolks with a height, width and weight of 15.77±0.30mm, 40.27±0.30mm and 16.55±0.22g respectively. The egg shape index was found to be 73.96±0.23% with the yolk index recording 39.39±0.67%.

TABLE 1
DESCRIPTIVE STATISTICS OF EGG QUALITY TRAITS OF INDIGENOUS CHICKENS IN LUSAKA.

Variable	Mean	SE Mean	COV
External traits			
Length (mm)	54.55	0.17	4.13
Width (mm)	40.31	0.12	3.9
Weight (g)	49.72	0.44	11.85
Radius (mm)	2.37	0.01	3.48
surface area (cm^2)	70.79	0.37	7.05
Internal traits			
Shell weight (g)	6.34	0.05	11.68
Shell thickness (mm)	0.36	0.01	10.55
Shell ratio (%)	12.78	0.06	6.6
Albumen weight (g)	26.21	0.3	15.46
yolk height (mm)	15.77	0.3	25.79
Yolk width (mm)	40.27	0.3	10.04
Yolk weight (g)	16.55	0.22	17.93
Egg shape index (%)	73.96	0.23	4.18
Yolk index (%)	39.39	0.67	23

The weight of the eggs in this study was found to be higher than the 46.5g in Kenyan indigenous chickens (Wambui *et al.* 2018), 45.89g in Malawian chickens (Gongolo & Tanganyika 2018), and 48.21g in Botswana (Kgwatalala *et al.* 2016) but lower than the one found in Turkey (Duman *et al.* 2016) and the 57.78g obtained in India (Rath *et al.* 2015). According to Shalev and Pasternak (1993) egg weight is affected to a large extent by the environment and feed restriction. Parental average weight also plays a vital role (Abudabos *et al.* 2017) but the genetic effect also cannot be ruled out. The egg length in this study was similar to what Rath et al (2015) and Kgwatalala et al. (2016) reported. Other studies have provided results of eggs width comparable to what was obtained in the present study (Abanikannda & Leigh 2007; Kgwatalala *et al.* 2016; Gongolo & Tanganyika 2018). From the shape index it can interpreted that the eggs in Lusaka were standard eggs and would get a good grading as it falls within the 72-76 range for standard eggs (Duman *et al.* 2016). Standard eggs fit well in trays during packaging and freight. The shell weight in this study agrees with that found in other studies (Kgwatalala *et al.* 2016) but higher than obtained in Malawian chickens (Gongolo & Tanganyika 2018). The shell thickness in this flock concurs with that obtained by Nonga et al (2010) but is higher than what other researchers reported (Rath *et al.* 2015). These differences could be due to the differences in breeds used and nutritional strategies employed. Eggs with a shell thickness of atleast 0.33mm stand up to 50% chances of withstanding standard handling without breaking during packaging and transportation (Stadelman 1995). The shell ratio in this study was higher than the ones obtained in leghorns (Sreenivas *et al.* 2013; Rath *et al.* 2015). The yolk height in our study is lower compared to the one obtained in the naked neck, normal feathered and dwarf chickens of Botswana, and the white leghorns (Rath *et al.* 2015; Kgwatalala *et al.* 2016). In comparison to other studies, the current findings on the yolk weight are akin to the ones obtained by Rath et al (2015) but higher than that obtained in the three strains studied by Kgwatalala et al.(2016) and Nonga et al.(2010). From the yolk index obtained in this study which is in the range 0.33- 0.50, a conclusion can be drawn that the eggs from this flock were fresh and of good quality (Ihekoronye & Ngoddy 1985).

3.2 Phenotypic correlations between egg quality traits

Table 2 displays the Pearson correlation coefficients of different egg traits with respect to each other. In this study Egg weight recorded a strong to moderate positive correlation with all the traits studied. Egg width and shell weight had the highest correlation coefficient with r =0.829 and 0.835 respectively. Egg shape index and yolk index had the lowest correlation coefficients to egg weight with r =0.071 and 0.281 respectively. The correlation between yolk height and yolk index (r =0.936) was the highest in this study. Egg shell index and egg length showed a strong negative relationship (r =0.556).

TABLE 2
CORRELATION MATRIX OF EGG QUALITY TRAITS OF INDIGENOUS CHICKENS IN LUSAKA.

	Egg weight	Egg length	Egg width	Shell weight	shell thickness	Albumin weight	yolk height	yolk width	Yolk weight	Egg shape index
Egg Length	0.721									
Egg width	0.829	0.468								
Shell weight	0.835	0.598	0.737							
Shell thickness	0.494	0.229	0.381	0.582						
Albumin weight	0.405	0.237	0.554	0.244	0.054					
Yolk height	0.481	0.353	0.073	0.434	0.342	-0.151				
Yolk width	0.503	0.242	0.503	0.459	0.284	0.197	0.096			
Yolk weight	0.739	0.524	0.651	0.676	0.24	0.038	0.481	0.353		
Egg Shape Index	0.071	-0.556	0.473	0.105	0.131	0.279	-0.261	0.237	0.099	
Yolk Index	0.281	0.244	-0.113	0.256	0.244	-0.213	0.936	-0.246	0.32	-0.33

The positive relationship of the weight of the egg with all the other measured traits agrees with what was found in similar studies (Abanikannda & Leigh 2007). This positive relation between egg weight, length, width, shell weight and thickness of the shell, albumin weight, yolk height, and yolk width as well as yolk weight suggests that selection for breeding for any of these traits would result in associated improvement in the other traits. This is suggestive that their action is more or less additive in nature, implying a combined effect. This study established a negative relationship between egg shape index and egg length confirming that the determination of egg shape index is more of a function of egg width (Mróz *et al.* 2014). The egg shape index and the egg weight were highly correlated. This is for the reason that the heavier part of the egg (egg albumin) occupies the broader (wider) part of the egg which explains a heavier egg. This finding agrees with other studies by Duman et al.(2016). The findings of Shi et al (2009) also agree with those of the current study. However, the outcomes of the present study disputes the conclusions of Alkans et al. (2010) who found a significantly negative association between the egg weight and the shape index of the egg.

3.3 Principal component analysis

The Eigen values, communalities and percentage of variation of extracted components are shown in Table 3. Bartlett's test was conducted to determine the rightness of the data for PCA. The Bartlett's test was highly significant (P=0.00) indicating suitability of the data for PCA. Next the Kaiser-Meyer-Olkin (KMO) sampling competence was completed and got 0.68 this was above 0.60 at which any value above is considered an adequate sample (Eyduran *et al.* 2010). Three principal components were extracted and these had Eigen values of 6.40 (PC1), 2.51 (PC2) and 1.70 (PC3). These Eigen values showed amounts of variance accounted for by each factor. They each accounted for 45.73% (PC1), 17.96% (PC2) and 12.11% (PC3) of the total variability. Cumulatively the three factors accounted for 75.80% of the total variance. PC1 was characterized by high positive loading on egg weight, Egg length, egg width, egg radius, shell weight , yolk weight and egg surface area . PC1 had moderate loadings on shell thickness, albumin weight, and yolk height and yolk width. Low loadings of PC1 were observed on shell index, yolk index and shell ratio. The second factor (PC2) had low loadings on egg weight, egg length, egg radius, shell weight, shell thickness, yolk width, yolk weight, egg surface area, and shell ratio. However PC2 had moderate to high loadings on egg width, albumin weight, yolk height, shell index and. PC3 had high loading on shell ratio and moderately on egg length and shell thickness and low loadings on the rest of the traits studied. The large Communalities recorded here ranging from 0.43 to 0.97 indicated that the majority of variation was accounted for by the factor solutions. In a study to analyze egg quality traits of eggs of ISA brown layer chickens in Nigeria, Ukwu et al.(2017) extracted three principal factors that accounted for 85.80% of the total variance. In another study of egg quality traits in Chinese native duck breeds, Bin-Xue et al (2013) extracted two factors that accounted for 65.32% of the total variance. However, this study extracted three components. PC1 which seemed to be a description of external Egg quality traits and PC2 which was a description of internal egg traits. Just like in the findings of Ukwu et al. (2017), PC3 in this study was a description of egg shell quality.

TABLE 3
EIGEN VALUES, PERCENTAGE OF TOTAL VARIANCE, ROTATED COMPONENT MATRIX AND COMMUNALITIES OF EGGS OF INDIGENOUS CHICKENS IN LUSAKA.

	PC1	PC2	PC3	Communalities
Egg weight	0.97	0.02	0.02	0.94
Egg Length	0.80	-0.26	-0.45	0.91
Egg width	0.84	0.47	0.11	0.94
Egg radius	0.95	0.05	-0.26	0.96
shell weight	0.87	-0.02	0.37	0.90
Shell thickness	0.50	-0.08	0.52	0.53
albumin weight	0.40	0.54	-0.28	0.52
Yolk height	0.46	-0.75	0.24	0.83
Yolk width	0.51	0.37	0.19	0.44
Yolk weight	0.77	-0.12	0.14	0.63
Shell index	-0.01	0.69	0.56	0.78
yolk index	0.26	-0.86	0.19	0.83
egg surface area	0.95	0.05	-0.26	0.97
Shell ratio	-0.15	-0.06	0.63	0.43
Eigen value	6.40	2.51	1.70	
% variance	45.73	17.96	12.11	
Cumulative % Variance	45.73	63.68	75.80	

As far as the consumption of eggs is concerned, eggs have been accepted world over as a main ingredient of the human diets as a staple food in some cases. Zambia is no exception as it is also in the baking industry. With the rising in populations comes increased demand for food eggs inclusive. The Zambian egg industry is not yet up to speed with the rising in demand. There is recently a growing trend for people to fancy indigenous chicken eggs. But the quantity and quality of these eggs are still yet to improve. Egg quality is those characteristics of an egg that would influence the acceptability to buyers and is the most vital price determinant in both hatching and table eggs (Kgwatalala *et al.* 2016). Several factors influence the quality of eggs. These could be the breed, relative humidity, management, temperature and the season (Rajkumar *et al.* 2009). But to uphold this quality of eggs, unceasing genetic appraisal of diverse egg quality characters has become vital in modern market oriented production (Rath *et al.* 2015). Understanding the egg quality traits and how they relate to each is a basis for formulation of sound breeding. This study has created an inventory of egg quality traits as prevalent in Lusaka, Zambia and also analyzed how these relate to each other. Based on these traits, plans of how to improve egg quality traits can now be exploited.

IV. CONCLUSION

This study successfully reported the genetic inventory of indigenous chickens with regards to egg quality traits. These plus the further analysis reported here of the relationships between these traits forms a good base for designing a sound breeding for improvement of these traits.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

[1] Abanikannda O. & Leigh A. (2007). Allometric relationships between composition and size of chicken table Eggs. *Internal journal of Poultry Science,* 6: 211-217.

[2] Abanikannda O., Olutogun O., Leigh A. & Ajayi L. (2007) Statistical modeling of egg weight and egg dimensions in commercial laye0000-0001-6006-9948rs. *Internal journal of Poultry Science,*6: 59-63.

[3] Abdi H. & Williams L. (2010). Principal component analysis. WIREs Comp Stat 2: 433–459.

[4] Abudabos A., Aljumaah R.s., Algawaan A.S., Al-Sornokh H. & Al-Atiyat R. (2017). Effects of Hen Age and Egg Weight Class on the Hatchability of Free Range Indigenous Chicken Eggs. *Brazilian Journal of Poultry Science,* 19: 33-40.

[5] Alkan S., Karabag K., Galic A., Karsli T. & Balcioglu M.S. (2010). Effects of selection for body weight and egg production on egg quality traits in Japanese quails (Coturnix coturnix japonica) of different lines and relationships between these traits. *Kafkas Universitesi Veteriner Fakultesi Dergisi*, 16: 239-244.

[6] Bing-Xue D., Jian-Zhou S., Jin-Bing Z., Wan-Li G., Yun W. & Xue-Ying C. (2013) Principal component analysis on egg quality characteristics of native duck breeds in China. *Journal of Animal and Veterinary Advances,* 12: 1286-8.

[7] Duman M., Sekeroglu A., Yildirim A., Eleroglu H. & Camci O. (2016). Relation between egg shape index and egg quality characteristics. *European Poultry Science,* 80: 1-9.

[8] Dumas S.E., Lewis D. & Travis A.J. (2018). Small- scale egg production centres increase children's egg consumption in rural Zambia. *Maternal & child nutrition,* 14: e12662.

[9] Dzialowski E.M. & Sotherland P.R. (2004). Maternal effects of egg size on emu Dromaius novaehollandiae egg composition and hatchling phenotype. *Journal of Experimental Biology,* 207: 597-606.

[10] Eyduran E., Topal M. & Sonmez A.Y. (2010). Use of factor scores in multiple regression analysis for estimation of body weight by several body measurements in brown trouts (Salmo trutta fario). *International Journal of Agriculture and Biology,* 12: 611–615.

[11] Fayeye T., Adeshiyan A. & Olugbami A. (2005). Egg traits, hatchability and early growth performance of the Fulani-ecotype chicken. *Livestock Research for Rural Development,* 17.

[12] Galic A., Filipovic D., Janjecic Z., Bedekovic D., Kovacev I., Copec K. & Pliestic S. (2019). Physical and mechanical characteristics of Hisex Brown hen eggs from three different housing systems. *South African Journal of Animal Science,* 49, 468-476.

[13] Gongolo J. & Tanganyika J. (2018). Evaluation of Physical Egg Quality Characteristics of Free Range Indigenous Malawian Normal Feathered and Frizzled Chicken. *International Journal of Avian & Wildlife Biology,* 3: 00046.

[14] Guèye E. (2000). The role of family poultry in poverty alleviation, food security and the promotion of gender equality in rural Africa. *Outlook on agriculture,* 29: 129-136.

[15] Hill W.L. (1995). Intraspecific variation in egg composition. *The Wilson Bulletin,* 107: 382-387.

[16] Ihekoronye A.I. & Ngoddy P.O. (1985). Integrated food science and technology for the tropics. *Macmillan.*

[17] Jolliffe I. (2005). Principal component analysis. *2nd ed*.

[18] Kgwatalala P., Molapisi M., Thutwa K., Sekgopi B., Selemoge T. & Nsoso S. (2016). 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. *Agriculture Journal and Environmental Journal,* 8: 96-105.

[19] MFL. (2019).The livestock and aquaculture census report. p. 19. *MINISTRY OF FISHERIES AND LIVESTOCK OF THE REPUBLIC OF ZAMBIA,* Lusaka, Zambia.

[20] Monira K., Salahuddin M. & Miah G. (2003). Effect of breed and holding period on egg quality characteristics of chicken. *International Journal of Poultry Science,***2:** 261-263.

[21] Mróz E., Stępińska M. & Krawczyk M. (2014). Morphology and chemical composition of turkey eggs. *The Journal of Applied Poultry Research,* 23, 196-203.

[22] Narushin V. (1997). The avian egg: geometrical description and calculation of parameters. *Journal of Agricultural Engineering Research,* 68: 201-205.

[23] Nedomova S., Severa L. & Buchar J. (2009). Influence of hen egg shape on eggshell compressive strength. *International Agrophysics,* 23: 249-256.

[24] Nonga H., Kajuna F., Ngowi H. & Karimuribo E. (2010). Physical egg quality characteristics of free-range local chickens in Morogoro municipality, Tanzania. *Livestock Research for Rural Development,* 22, 1-19.

[25] Rath P.K., Mishra P.K., Mallick B.K. & Behura N.C. (2015) Evaluation of different egg quality traits and interpretation of their mode of inheritance in White Leghorns. *Veterinary World*, 8: 449.

[26] Rajkumar U., Sharma R., Rajaravindra K., Niranjan M., Reddy B., Bhattacharya T. & Chatterjee R. (2009) Effect of genotype and age on egg quality traits in naked neck chicken under tropical climate from India. Int. J. Poult. Sci 8, 1151-5.

[27] Sarica M., Onder H. & Yamak U.S. (2012). Determining the most effective variables for egg quality traits of five hen genotypes. *International Journal of Agriculture and Biology,* 14: 235-40.

[28] Schreiber R.W. & Lawrence J.M. (1976). Organic material and calories in Laughing Gull eggs. *The Auk*, 93: 46-52.

[29] Shalev B. & Pasternak H. (1993). Increment of egg weight with hen age in various commercial avian species. *British Poultry Science*, 34: 915-924.

[30] Shi S., Wang K., Dou T. & Yang H. (2009). Egg weight affects some quality traits of chicken eggs. *Journal of Food, Agriculture and Environment,* **7**: 432-4.

[31] Sreenivas D., Prakash M.G., Mahender M. & Chatterjee R.N. (2013). Genetic analysis of egg quality traits in White Leghorn chicken. *Veterinary World,* 6: 263.

[32] Stadelman W. (1995). Quality identification of shell eggs. *Egg science and technology*, 39-66.

[33] Ukwu H., Abari P. & Kuusu D. (2017) Principal component analysis of egg quality characteristics of ISA Brown layer chickens in Nigeria. *World Scientific News,* 70: 304-311.

[34] Wambui C., Njoroge E. & Wasike C. (2018) Characterisation of physical egg qualities in indigenous chicken under free range system of production in Western Kenya. *Livestock Research for Rural Development*, 30: 7.

[35] Wong J., de Bruyn J., Bagnol B., Grieve H., Li M., Pym R. & Alders R. (2017) Small-scale poultry and food security in resource-poor settings: A review. *Global Food Security,* 15:43-52.