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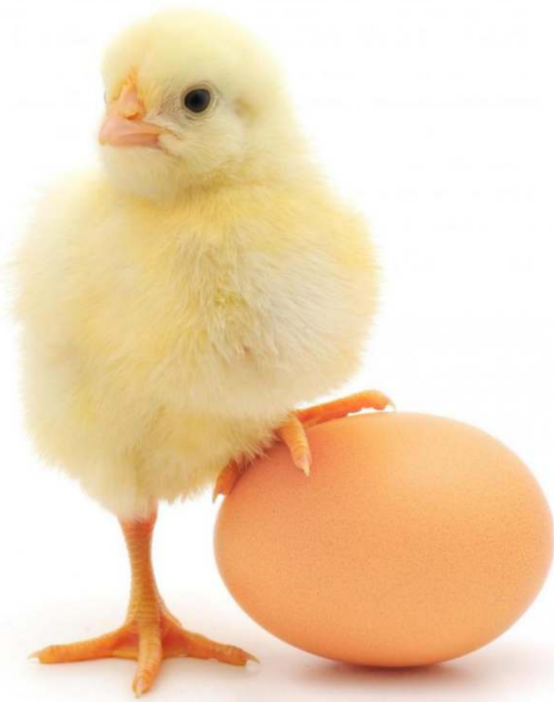

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Allometric Relationships Between Composition and Size of Chicken Table Eggs

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Abstract: This study investigates intraspecific variation in egg sizes and its component measures and it also estimated the allometric relationships between egg components (albumen, yolk and shell) and egg weight in domestic chicken. A total of 299 eggs from Harco Black strain of commercial layers of five distinct age groups were evaluated for egg weight (g), egg length (mm), egg width (mm), albumen weight (g), yolk weight (g) and shell weight (g). The overall mean values obtained for the six variables are respectively 55.64±0.28, 56.09±0.15, 42.40±0.08, 33.91±0.21, 15.65±0.12 and 6.46±0.04. There was direct (positive) association amongst the six variables studied, albeit at varying degrees and the correlation coefficient ranged from 0.21 to 0.82. The overall mean egg compositions are 60.53%, 27.94% and 11.53% respectively for albumen, yolk and shell. Only age group and egg weight exerted significant ($p<0.001$) influence on egg components, the other two factors investigated (egg length and egg width) were not significant ($p>0.05$) on egg components. The proportion of total variance due to age group was 30.82%, 12.82% and 15.02% for yolk weight, albumen weight and shell weight, while egg weight accounted for 14.46%, 56.09% and 29.77% respectively. There was positive allometry ($b = 1.009$) for albumen weight for most of the age groups and negative allometry for yolk ($b = 0.907$) and shell weight ($b = 0.742$). Albumen weight is more of a function of hen's age.

Key words: Egg components, egg size, allometry

Introduction

Egg is a biological structure intended by nature for reproduction. It protects and provides complete diets for the developing embryo and serves as the principal source of food for the first few days of the chick's life. Eggs are special cells found in female animals and nearly all animals produce them, some animals including birds lay their eggs external to their body and it is unquestionably one of the most nutritionally balanced foods for man.

Egg, a major poultry product is chiefly composed of albumen, yolk and the egg shell, accounting for about 58%, 31% and 11% of the egg mass. The albumen contains more than half the egg protein, while the yolk contains all the fat and most of the vitamins in the egg. The significance of table eggs as a cheap and readily available sources of protein in the developing countries of the world cannot be overemphasized and the contribution of the major constituents of egg i.e. albumen and yolk in the dietary intakes of humans have been well documented (Khurshid, 2005; Orji *et al.*, 1998).

Intraspecific variation in egg composition and its allometric relationship with egg weight as a result of differences in sizes of eggs has been well documented (Dzialowski and Sotherland, 2004; Hill, 1995; Arnold *et al.*, 1991; Hill, 1988; Alisauskas, 1986; Ricklefs, 1984; Birkhead and Nettleship, 1984). Intraspecific variation in eggs has been attributed to several factors such as heritability, size and nutritional status of hen, feed availability, laying sequence and some combination of these factors (Alisauskas, 1986; Quinney, 1983; Van Noordwijka *et al.*, 198l; Otto, 1979; Schreiber and Lawrence, 1976). Allometric relationship between egg components and egg mass had earlier being studied along the altricial-precocial birds divide.

The intent of this present study therefore is to investigate the allometric relationships between egg components and egg sizes at different stages of lay of the domestic chicken (*Gallus gallus*) and also determine the quintessential factors affecting proportion of the various egg components.

Materials and Methods

This research was conducted at the Department of Zoology, Faculty of Science, Lagos State University, Ojo-Lagos, Nigeria. Eggs for the study were obtained from a privately owned commercial poultry farm in the South Western humid tropics of Nigeria. The eggs were freshly laid and collected from farm around 5.00pm local time each day and the exploratory measurements were taken the next morning at the laboratory.

Experimental animals and management: The Harco Black strains of commercial layers were used in this study and details of management practices employed on the farm is described by Abanikannda *et al.* (2007).

Experimental design: Ten trays comprising thirty eggs each, spread across five distinct age groups (A [22-32];

Table 1: Mean±Standard Error of means for egg size and egg components

Age Groups (weeks)	N	Egg Weight (g)	Egg Length (mm)	Egg Width (mm)	Albumen Weight (g)	Yolk Weight (g)	Shell Weight (g)
A (22 – 32)	60	51.06±0.51^{c}	54.03±0.25^{c}	41.31±0.19^{b}	31.43±0.41^{b}	13.71±0.15^{c}	6.04±0.07^{c}
B (33-43)	60	55.85±0.47^{b}	55.55±0.21^{b}	42.61±0.13^{a}	34.21±0.42^{a}	15.52±0.20^{b}	6.58±0.08^{ab}
C (44-54)	60	56.05±0.55^{ab}	56.49±0.31^{ab}	42.55±0.19^{a}	34.06±0.43^{a}	16.15±0.21^{b}	6.55±0.09^{ab}
D (55-65)	59	58.15±0.61^{a}	56.96±0.38^{a}	42.95±0.17^{a}	34.58±0.51^{a}	17.25±0.30^{a}	6.32±0.08^{bc}
E (66-76)	60	57.15±0.56^{ab}	57.45±0.29^{a}	42.56±0.15^{a}	35.26±0.45^{a}	15.67±0.24^{b}	6.82±0.09^{a}
Combined	299	55.64±0.28	56.09±0.15	42.40±0.08	33.91±0.21	15.65±0.12	6.46±0.04

Means with different superscript within the same column are significantly ($p<0.05$) different

B [33-43]; C [44-54]; D [55-65] and E [66-76] weeks) were sampled. However, one egg from the age group D was broken during transportation and was excluded from the study, thus a total of 299 eggs were used in the analyses.

Data collection and statistical analyses: Each egg was properly and appropriately labeled. Measurements of weight and length of the eggs were done with digital scales and electronic Vernier caliper respectively.

After taking the external measurements (egg weight, egg length and egg width) of the egg sizes, measurements of the internal components were obtained by carefully making an opening around the sharp end of the egg, large enough to allow passage of both the albumen and the yolk through it without mixing their contents together. The yolk is then carefully separated from the albumen and placed in a Petri dish for weighing. Simultaneously, the associated albumen is placed on another Petri dish and weighed. Both Petri dishes used in weighing the egg contents had initially being weighed and the difference in the weights of the Petri dish after and before the egg component is taken as the weight of the egg components. After each weighing, the Petri dishes are washed in clean water and wiped dry before next weighing. The shell weight was obtained by carefully placing the opened part in the shell and weighing on the electronic scale. It should be noted that the shell membrane was not separated from the egg shell, thus egg shell weight is inclusive of the membrane weight. All measurements in this study are wet measurements.

Some data transformation and manipulation was done before basic descriptive measures about the variables were taken. Allometry entails the study of the relative growth of a part of an organism in relation to the growth of the whole. This involves estimating the regression of the dependent variable (egg component) on the independent variable (egg weight) and it is described as the line of best fit;

$$Y = a + bX \quad \text{.............................} \quad (1)$$

However, since the relationship between egg component and egg size is not strictly a linear one, there is need for logarithmic transformation of the raw data to obtain the allometric equation;

$$\log(Y) = \log(a) + b[\log(X)] \quad \text{.............................} \quad (2)$$

The general form of the allometric equation is;

$$Y = aX^{b} \quad \text{..} \quad (3)$$

where, Y = egg component, X = egg size, b = the allometric exponent (slope of the relationship between egg component and egg size) and a = a constant (the allometric coefficient).

All statistical analyses were done using the appropriate sub-routines in the S-Plus (2001) statistical software.

Basic measures of relationship amongst the parameters under study were estimated using the correlation procedures and log-log regression of the different components (yolk weight, albumen weight and shell weight) on egg weight was done using logarithmic transformation on the raw data.

Factors affecting egg components (albumen weight, yolk weight and shell weight) is as described by the statistical model of the analysis of variance;

Y_{ijklm} = $\mu + A_i + W_j + L_k + D_l + e_{ijklm}$

Where Y_{ijklm} = the observed egg component (albumen, yolk and shell)

μ = population mean

A_i = i^{th} fixed effect of age group (i = 1-5)

W_j = j^{th} covariate of egg weight

L_k = k^{th} covariate of egg length

D_l = l^{th} covariate of egg width

e_{ijklm} = residual random error.

Results

Egg size: The overall mean egg weight was 55.64g (Table 1), with a 95% confidence interval of 55.09-56.19g. The minimum egg weight in this study was 42.50g, while 67.80g was the highest egg weight recorded. The respective lower 95% confidence limits for egg weight across the age groups A-E was 50.04, 54.91, 56.94 and 56.02, while the upper 95% confidence limits was 52.08, 56.78, 57.15, 59.36 and 58.20g respectively. Mean egg length for the combined ages in the study was 56.09±0.15mm (Table 1), with lower and upper 95% confidence intervals of 55.80 and 56.38mm respectively. The 95% confidence limit for mean egg length across

Table 2: Correlation matrix of egg sizes and egg components

	Egg Weight	Egg Length	Egg Width	Yolk Weight	Albumen Weight	Shell Weight
Egg Weight	1.0000	0.7276	0.8047	0.5910	0.8187	0.6042
Egg Length		1.0000	0.4027	0.4440	0.6284	0.4879
Egg Width			1.0000	0.4763	0.6744	0.5055
Yolk Weight				1.0000	0.2075	0.3455
Albumen Weight					1.0000	0.4107
Shell Weight						1.0000

Table 3: Analysis of variance of factors affecting egg components

Source	df	Albumen Weight MS	Yolk Weight MS	Shell Weight MS
Age Group	4	127.80***	98.41***	5.19***
Egg Weight	1	2236.17***	184.70***	41.13***
Egg Length	1	8.67	0.14	0.27
Egg Width	1	11.20	0.04	0.54
Residuals	291	4.19	2.40	0.26

^{ns} = (p>0.05); * = (p<0.05); ** = (p<0.01); *** = (p<0.001)

age groups A-E was 53.52, 55.14, 55.86, 56.19 and 56.87mm, while the respective 95% upper confidence limits was 54.54, 55.96, 57.11, 57.72 and 58.03mm.

The mean egg width in this study was 42.40±0.08mm (Table 1), with 95% confidence intervals of 42.23 and 42.56mm respectively. Mean egg width for the age groups is presented in Table 1. The respective 95% lower confidence limits for the age groups are 40.93, 42.36, 42.16, 42.61 and 42.25mm, while the upper confidence limits are 41.69, 42.87, 42.94, 43.29 and 42.87 respectively for age groups A-E.

Egg components: Eggs used in this study is composed of about 60.53%, 27.94% and 11.53% respectively of albumen, yolk and shell. The minimum albumen weight recorded was 24.30g, while the maximum albumen weight was 46.90g. For the combined group, mean albumen weight was 33.91±0.21g (Table 1), while the 95% confidence interval was 33.49 and 34.33g. The respective 95% lower confidence limit for age groups A-E are 30.61, 33.37, 33.20, 33.56 and 34.37g, while 32.26, 35.04, 34.91, 35.61 and 36.16 was the respective upper limits.

The mean yolk weight for the combined group was 15.65±0.12g (Table 1), with 95% confidence intervals of 15.42 and 15.89g. The least yolk weight was 11.20g while the highest yolk weight was 28.20g. Confidence limits of yolk weight across age groups A-E are respectively 13.41, 15.12, 15.73, 16.65 and 15.19g for the lower, while the upper limits are 14.01, 15.91, 15.73, 16.65 and 16.14 respectively.

Minimum egg shell weight was 4.80g while 9.20g was the maximum recorded shell weight in this study. Mean shell weight was 6.46±0.04g (Table 1) with confidence intervals of 6.39 and 6.54g. The 95% lower confidence limits of shell weight for age groups A-E was respectively 5.90, 6.42, 6.37, 6.17 and 6.65g, while the upper limits are 6.19, 6.74, 6.72, 6.48 and 7.00g respectively.

Linear relationship amongst egg composition and egg size variables: The correlation matrix of egg sizes and egg components are presented in Table 2. There was a direct (positive) relationship between all the variables investigated albeit at varying degrees. The weakest relationship (0.21) recorded is between yolk weight and albumen weight, while the strongest association is between egg weight and albumen weight (0.82). There was no inverse relationship amongst the variables investigated.

Factors affecting egg composition: Aside from age group which was highly significant (p<0.001) on all three egg components (Table 3), it is only egg weight of the three egg size variables (egg weight, egg length and egg width) studied that exerted significant (p<0.001) influence on the weight of egg components.

Allometric measures of egg component and egg weight: Since it is only egg weight that exerted significant (p<0.001) effect on egg components (Table 3), it is only the allometric relationship between egg component weight and egg weight that was investigated and presented in Table 4. Out of the three egg components studied, it is only albumen weight that recorded positive allometry (allometric exponent>1.00), which implies that albumen weight increases disproportionately with egg weight, meaning that large eggs will contain relatively more albumen than smaller eggs. Conversely, there was negative allometry (allometric exponent<1.00) for both yolk and shell weight. It is also noteworthy that all allometric exponents of the different egg components at different age groups were significant (p<0.05).

Discussion

Egg size: The least mean egg weight was recorded in age group A, which progressively increases with increasing hen age up to a maximum in age group D before a slight decline afterwards. Aside from age group A which was statistically different (p<0.05) from the other four age groups, there was no statistical difference in the mean values of age groups B, C and E on one hand and the difference in age groups C, D and E on the other hand was not statistically significant (p>0.05). The pattern of distribution of the mean values for egg weight, egg length and egg width across the various age groups is presented in Fig. 1. The initial 9.38 percent increase

Table 4: Allometric coefficient (a), allometric exponent (b) and coefficient of determination (r^2) of egg components on egg sizes at various age groups

		Albumen Weight			Yolk Weight			Shell Weight		
Age Groups (weeks)	N	a	b	r^2	a	b	r^2	a	b	r^2
A (22-32)	60	-1.214***	1.185***	0.821	0.922^{ns}	0.431**	0.149	-1.860***	0.930***	0.609
B (33-43)	60	-1.185**	1.172***	0.674	0.648^{ns}	0.520**	0.118	-1.683**	0.886***	0.375
C (44-54)	60	-0.456^{ns}	0.989***	0.611	-1.068*	0.956***	0.497	-1.577**	0.858***	0.388
D (55-65)	59	-1.428***	1.223***	0.744	-0.117^{ns}	0.728***	0.233	-0.487^{ns}	0.573***	0.233
E (66-76)	60	0.314^{ns}	0.803***	0.397	-0.079^{ns}	0.699***	0.209	-0.921^{ns}	0.702***	0.297
Combined	299	-0.533***	1.009***	0.672	-0.899***	0.907***	0.379	-1.118***	0.742***	0.382

^{ns} = (p>0.05); * = (p<0.05); ** = (p<0.01); *** = (p<0.001)

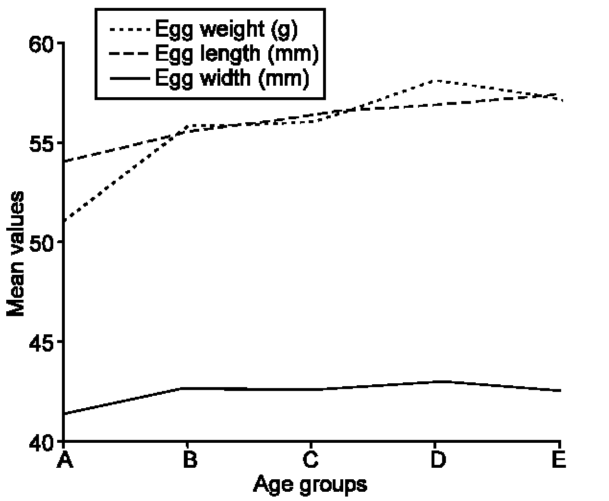

Fig. 1: Mean values of egg sizes (weight, length and width) across various age groups

in mean egg weight of age group B over age group A is consistent with those already reported in literature and this significant difference is attributable to the fact that at age group A, the birds just started laying and much change in the bird's physiology and anatomy takes place immediately after this stage. Differences in the nutritional status, anatomical and physiological state of the birds with advancing age have been adduced for the observed intraspecific differences in egg weight (Abanikannda *et al.*, 2007; Bunchasak *et al.*, 2005; Monira *et al.*, 2003). The observed differences in the mean egg weight values reported by these researchers as a result of differences in the breeds studied and sample size notwithstanding, the pattern of intraspecific variation in egg weight is consistent with those obtained in this present study.

The consistent increase in egg length across the age groups is presented in Fig. 1. Apart from the mean egg length of age group A which was statistically (p<0.05) different from the mean egg length of the other four age groups, there was no statistical difference (p>0.05) in the mean egg length of age groups B and C and age groups C, D and E (Table 1). This observation agrees with reports of Anderson *et al.* (2004), Gunlu *et al.* (2003) and Monira *et al.* (2003) who all reported consistent increase in mean egg length with increasing age of laying hens. The variation in the mean egg length values reported by these researchers could be due to the differences in the breeds investigated and the prevailing environmental conditions under which the study was carried out.

There was inconsistent pattern in the mean egg width across the age groups (Fig. 1), but the difference was not noticeable except in the age group A which was statistically (p<0.05) different from the four other age groups, though there was decline in mean egg width at age groups C and E. This observation however contradicts earlier reports (Abanikannda *et al.*, 2007; Gunlu *et al.*, 2003) who all observed consistent increase in egg width with increasing hen age. This disparity may be due to the relatively smaller sample size (n = 299) in this study, which tends to amplify population variability unlike when sample size is larger.

Egg components: Age group A recorded the least *wet albumen* weight (Table 1), there was a slight but progressive increase in albumen weight across the age group except for drop at age group C (Fig. 2). It was only at age group A that albumen weight was significantly different (p<0.05) from other age groups and this implies that despite the numerical differences in albumen weight at other age groups, the difference is not large enough to be statistically significant. It is also only age group A that has a mean albumen weight below the combined average and there is 8.85% percent increase in albumen weight at the next age group. This observation may be as a result of the very high correlation (0.82) between egg weight and albumen weight, suggesting that difference in albumen weight is more a function of egg weight than age of hen. Since this is an intraspecific study, it is not surprising that the variability in albumen weight is not as pronounced as when comparison is made across breeds or species. Genetic basis for variation in albumen weight of eggs have been reported by many workers (Hill *et al.*, 1995; Hill, 1995; Alisauskas, 1986; Hochachka, 1986).

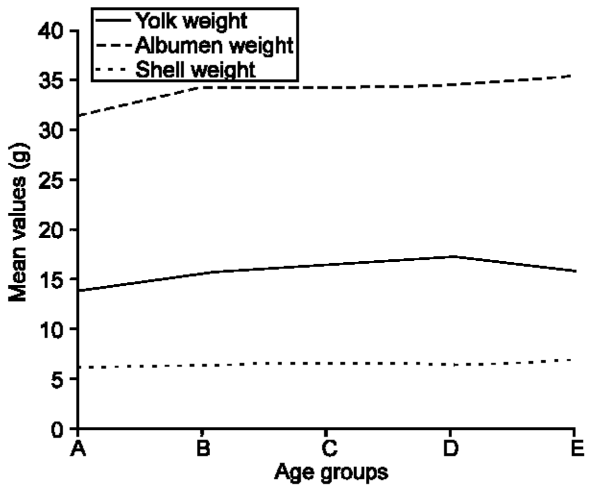

Fig. 2: Mean weight (g) of egg components (yolk, albumen and shell) across various age groups

Yolk weight progressively increases from age group A through D before a slight decline at age group E (Table 1). The least yolk weight was recorded at age group A and the largest was at age group D (Fig. 2). Despite the similarity in the distribution pattern of yolk weight and egg weight, it has been reported that yolk weight is affected more by hen age along with genetic factors rather than egg size and this probably explains why the difference in yolk weight is very pronounced as the age of hen increases. This observation is in agreement with reports of Hill (1995), Arnold *et al.* (1991) and Alisauskas (1986).

After an initial increase in shell weight from age group A to B, there was a steady decline in the mean shell weight until an increase in age group E (Fig. 2). The least yolk weight was recorded in age group A and the highest was obtained in age group E (Table 1). This trend could be explained by the fact that egg size increases with hen age and more shell will be required to accommodate the egg's internal components (Hocking *et al.*, 2003). It should be noted that shell weight in this study is the wet weight of the egg shell after its contents had been separated from it and it also includes the weight of the shell membrane.

Relationship amongst egg size and egg component variables: Apart from the moderate association between egg weight and shell weight and yolk weight, the relationship between egg weight and the other four variables studied were very high (Table 2). Based on the strength of this measure of association between the variables studied, an ANOVA was performed to determine the extent of influence of each of the size variable on the egg components studied. Similar reports on the relationship between egg's size parameters have been reported by other researchers (Abanikannda *et al.*, 2007; Gunlu *et al.*, 2003; Farooq *et al.*, 2001).

Factors affecting egg components: The analysis of variance (ANOVA) in this study included age group as a fixed source of variation and egg weight, egg length and egg width as covariates on egg components weight. Table 3 presents the ANOVA for the three egg components.

Age group was highly significant ($p<0.001$) on all three components (albumen, yolk and shell) weights. The largest source of variation in yolk weight is due to age group, accounting for almost 31 percent ($\eta^2 = 30.82\%$) of the total variation, but accounted for about 13 percent and 15 percent respectively for variation in albumen and shell weight. This implies that age group was the greatest source of the variation observed in yolk weight which actually corroborated the initial result obtained in the computation of the mean yolk weight across the age groups. Significant effect of hen age on egg components has been reported by several researchers (Gerber, 2006; Hocking *et al.*, 2003; Flint and Grand, 1996; Alisauskas, 1986; Hochachka, 1986).

The effect of egg weight on all egg components studied was highly significant ($p<0.001$) and the extent of explanation of the total variance as a result of egg weight varies considerably among the egg components (Table 3). Whilst egg weight accounted for about 57 percent of total variation in albumen weight, it merely accounted for about 15 percent and 30 percent of the variation observed in yolk weight and shell weight respectively. The implication of this is that, more than half the source of variation in albumen weight is due to egg weight and this explains why there was less difference in albumen weight due to age group (Table 1). It is not surprising that egg weight exerted such influence on egg components weight, since the sum of the egg components weight is the egg weight, this association is reflected both by the very strong correlation coefficient between egg weight and egg component weight (Table 2) and the relatively higher *eta squared* of egg weight in the ANOVA of egg components. This observation confirms earlier reports of Flint and Grand (1996), Hochachka (1986) and Alisauskas (1986).

The two other covariates (egg length and egg width) were not significant ($p>0.05$) on egg component weights in this study (Table 3), although some researchers reported their significant effect on egg component but the experimental animals were different (Kern and Cowie, 1995; Alisauskas, 1986). This led to the exclusion of egg dimensions in the determination of allometric relationships between egg components and egg sizes.

Allometric measures of egg components and egg weight: Allometric coefficients, exponents and their respective coefficient of determination are presented in Table 4.

There was positive allometry only in the log-log regression of albumen weight on egg weight, though with increasing age of the hen, allometric exponent decreases consistently from age group A, before a rise at age group D. It is only at age groups C and D that negative allometry was observed in albumen weight. This observation is expected considering the very high measure of association between both variables and the very high dependence of albumen weight on egg weight as represented by its *eta* squared in the ANOVA. Apart from age group E, where the coefficient of determination was relatively low (r^2 = 0.397), the log-log regression of albumen weight on egg weight was relatively high and this implies that egg weight is a good estimator of albumen weight. It is also noted that, though not significant, the allometric coefficient was only positive at age group E. The domestic chicken, a typical example of precocial bird exhibited trait characteristics of altricial birds in the positive allometry of albumen weight obtained in this study. This study reveals that in chicken table eggs, larger eggs contain proportionately more albumen than smaller eggs, an observation which contradicts the submissions of Dzialowski and Sotherland (2004), Hill (1995), Alisauskas (1986) and Ricklefs (1984) who all reported positive allometry of albumen weight on egg weight in altricial birds but negative allometry of albumen weight in precocial birds.

Egg yolk exhibited negative allometry in this study, with the allometric exponents increasing from age group A to C before a further consistent decline to age group E. Apart from the allometric coefficient of group C and the combined group, the coefficient was not significant ($p>0.05$) for the other age groups. It should be noted that unlike the albumen, the coefficient of determination in the yolk analysis was relatively low, ranging from r^2 = 0.118 in age group B to r^2 = 0.497 in age group C. This means that although the allometric exponents for yolk was significant ($p<0.01$) at all age groups, the variation observed mostly was not from differences in egg weight but rather hen age. This trend is equally different from the reports of Dzialowski and Sotherland (2004), Hill (1995), Alisauskas (1986) and Ricklefs (1984) who all reported positive allometry of yolk weight in precocial birds. This result further confirms the *eta squared* (η^2 = 0.3082) obtained in the ANOVA of age group on yolk weight and the low coefficient of determination (r^2 = 0.3493) of association between yolk weight and egg weight, suggesting that variation in yolk weight was more of differences in age of birds rather than weight of eggs.

The shell exhibited negative allometric relationship with egg weight, with allometric exponent decreasing across the age groups before picking up again at age group E. The allometric coefficient followed a similar pattern across the group (Table 4). Unlike the yolk weight, shell weight has relatively higher r^2 and the result revealed that about 61 percent of variation in shell weight was due to egg weight at onset of lay.

Conclusion: The following conclusions can be drawn on the allometric relationship between egg components and egg sizes.

(i) There is significant ($p<0.05$) intraspecific variation in the mean values of all variables studied across the various age groups.
(ii) Egg weight is highly positively correlated to all other variables studied, except yolk weight which had very low correlation coefficient.
(iii) Only age group and egg weight exerted significant ($p<0.001$) influence on the egg components studied. The largest source of variation for yolk weight is age group, while egg weight was the greatest source of variation for albumen and shell weight.
(iv) All allometric relationships between egg components and egg weight were highly significant ($p<0.01$) and it is only albumen weight that exhibited positive allometry, while yolk weight and shell weight displayed negative allometry.
(v) Albumen weight was more dependent on egg weight, while yolk weight was dependent on hen age.

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