EVALUATION OF EGG PRODUCTION CURVES OF SHIKABROWN® PARENTS USING MATHEMATICAL MODELS

BY

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DEPARTMENT OF ANIMAL SCIENCE

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OCTOBER, 2016

DECLARATION

I hereby declare that this dissertation has been written by me and that it is a record of my own research work. It has not been presented in any previous application for higher degree. All quotations are indicated and the sources of information are specifically acknowledged by means of references.

______________________ __________________ _______________

Name of Student	Signature	Date

CERTIFICATION

This dissertation entitled "EVALUATION OF EGG PRODUCTION CURVES OF SHIKABROWN® PARENTS USING MATHEMATICAL MODELS" by Afiniki AHMADU meets the regulations governing the award of the degree of Master of Science of the Ahmadu Bello University, Zaria and is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

I dedicate my second degree to my sister, Rauta Ahmadu.

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ABSTRACT

This study was conducted to evaluate egg production curves of Shikabrown® parents, using mathematical models. A total of 200 birds: 100from each of the two strains of Shikabrown® parents (sire and dam) lines at the Breeding Unit of Poultry Research Programme, National Animal Production Research Institute (NAPRI) were used for the study. The birds were obtained from the selected lines (sire and dam) and were denoted as strain A and strain B, respectively. Body weight (BWT), age at sexual maturity (ASM), egg number (EGGNO), and egg weight (EWT) were examined. Four non-linear models (Logistic, Richard, Gompertz, and Exponential) and a linear model were used to predict the efficiency of weekly bodyweight and egg production traits. Genetic parameters (heritability, genotypic and phenotypic) correlations were estimated for egg production. Genetic parameters were estimated using VARCOMP procedure of SAS. The adequacies of the models were fitted using R Package, version 3.0.3.High coefficients of determination for BWT (R^2 = 0.84 - 0.93) were recorded in the models for both strains. Strain A had higher R^2 (0.93) for BWT in Richard, Gompertz and Exponential models while strain B recorded (R^2 = 0.89) in Logistic, Richard and Gomprtz models. High coefficient of determination was obtained in a reproductive trait; egg number; in which almost all the models gave (R^2 = 0.70). Exponential model recorded a higher R^2 (0.93) for EGGNO in strain A. This suggests that the strains had similar age at sexual maturity and it implies that the birds' genetic potential can be further exploited for more genetic improvement. EWT in strain A recorded higher R^2 (0.96) coefficient of determination across the four nonlinear models except linear model with (R^2 = 0.95) for egg weight. Significant ($P<0.05$) differences were recorded within models for the egg production traits studied. Significant differences ($P<0.05$) were observed in the birds' performance for BWT and EWT, with strain B having a higher BWT (1.59±0.01) and strain A having a higher EWT (48.75±0.17). Similarly, age of birds in lay had a concomitant significant differences ($P<0.05$) in their BWT as well as their EWT. The birds performed better for BWT and EWT in week 26 and 27 for both strains. Strain B had higher heritability estimates (h^2=0.45) while the least estimates (h^2=0.10) was recorded in strain A for EGGNO. ASM recorded the highest estimates (h^2=0.48) in strain A while least value (h^2=0.18)was observed in strain B. BWT had high genotypic correlations with EWT (r_g= 0.88) and ASM (r_g= 0.48) in strain A. EGGNO had low genotypic correlation with BWT (r_g= 0.01). EWT had negative and low genotypic correlation with EGGNO (r_g= -0.05).ASM was negatively correlated with EGGNO (r_g= -0.93) and EWT (r_g= -0.05). It was concluded that strain significantly ($P<0.05$) had effect on BWT and EWT of Shikabrown® parent with stain B performing better than strain A in BWT and strain A better than strain B in EWT. Coefficient of determination (R^2) obtained from Richard; MLR and Gompertz models can be used to estimate egg number, body and egg weights. R^2 identified differences between strains in predicting egg production traits. Strain B was adjudged good and profitable because the strain had the highest mean values in body weight and egg number and it is being recommended as one of the lines for future improvement of Shikabrown®. Egg weights of Shikabrown® should be improved based on the recorded genetic variability in the parents.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

The domestication of livestock species some ten thousand years ago was a vital step in the development of human civilization. Over the centuries, domestication evolved into breeding and the genetic improvement of livestock such as laying birds and broilers (Tercic and Holcman, 2008). Egg production is the single most important phenotype for evaluating the productivity of laying birds. It helps in evaluating the efficiency of management and optimum managerial practices that will sustain gain at optimum level (Aboul-Seoud, 2008).

Egg production is known to be a complex quantitative trait; it depicts a considerable variation over time within the production cycle of a hen. Several methods of expressing egg production and its component characters have been studied (Schreiweis *et al*., 2006; Dogan *et al.,* 2010). Despite the application of different forms of analysis of variance, however, it remained difficult to give a clear explanation of the variation in egg production over time (Dogan *et al.,* 2010). However, studies by Oni (1997) have shown that when egg production in chickens is summarized on a weekly, biweekly or monthly basis, it gradually increases, attained peak and persist and then gradually decline. In egg production peak is usually attained a month after first egg is laid (Savegnago *et al*., 2012). Although variations to this exist among breeds, strains and lines. This regularity, though not a steady process over time, is generally denoted as egg production curve in poultry. Egg production curves are useful tools representing the evolution of egg production changes and are of particular importance in both breeding and management. Values such as point of inflection, effects of different management systems, feeding requirements and the results of breeding applications can be evaluated using egg production curves (Narinc *et al*., 2010). Fairfull and Gowe (1990) reported that mathematical models can be used to forecast income and flock performance to evaluate theoretical expectations or to predict whole record performance based on part record of egg production. A mathematical model describing such a curve could enable poultry breeders and commercial egg producers to analyze egg production process as well as to predict annual production from part records (Oni, 1997; Fairfull, Gowe, 1990).

Models used to define growth process in animal science include Gompertz Koivula *et al*. (2007) in Finnish Yorkshire boars, gilts and barrows. Richard and Logistic (Osei-Amponsah *et al*., 2014; Grossman and Bohren (1985) in local chickens. Bertalanffy (1938), Barbato (1991) in chickens. Hyperbolastic models which were proposed by Tabatabai *et al*. (2005)have also been used in recent years, while McNally (1971), Gavora *et al.* (1982) and McMillan *et al*. (1986) studied egg production curves extensively, expressing it as a function of calendar time periods.

Evaluation of egg quality is important for both egg laying and breeder flocks. Egg weight, yolk color and shell thickness are the most important quality traits of consumed egg (Stadelman, 1995). Shell thickness, breaking strength, specific gravity, albumen height, yolk height and some other quality traits are also important for hatching and consumed egg (Wolanski *et al*., 2007). Classification of these traits into components could be very helpful in constructing a robust selection index for poultry birds. Principal components analysis (PCA) is a mathematical procedure that uses an orthogonal transformation to reduce a set of correlated variables into a set of uncorrelated variables called principal components. It is a means of identifying patterns in the data by their similarities and differences and a method to compress the data information without much loss of information (Hair *et al*., 2009).

1.2 Statement of the Problem

The Shikabrown® commercial layers were developed as a result of many years of breeding and selection work at the National Animal Production Research Institute (NAPRI), Zaria. The birds were obtained from sets of crosses between two specialized lines of the foundation stock and were tested and proven for good performance in all the six geo-political zones of Nigeria (Kallah, 1999). A complete description of the foundation stock and breeding activities on the egg-type chickens in the Institute (NAPRI) was given by (Adeyinka 1998 and Ikani *et al*., 2014). A total of 1,411 day old grandparent-stock belonging to two strains of egg-type chickens, made up of male (sire), line bred for high body weight: and female (dam), line bred for high egg number were imported between February and April 1985. The sire line has a golden or brown color while the dam line has white or silvery plumage (Kabir and Muhammad, 2012). The chicken is resilient to all known diseases and is suitable for research purposes as it can lay eggs for consecutive two years (Gefu, 2014).

The egg production curve of Shikabrown® was studied about two decades ago by Oni (1997). A lot of changes might have occurred in egg production trends in response to selection over these years. This may be due to the fact that those models lacked optimization capability in the model parameters. Most recently developed models are constructed with optimization qualities and fast response in time needed for convergence. Therefore, there is a need to re-evaluate the egg production curve of Shikabrown® using these mathematical models (Gompertz, Logistic, Richard, Exponential, and multiple linear regression). Mathematical models provide one means of predictions, but they are sometimes inadequate due to poor extrapolative properties or abnormal deviations from expectations (Adams-Bell, 1980). The accuracy of predicting full record from part record production has become highly important in assessing the relative merits of models describing poultry egg production records. Haruna *et al.* (2007) reported that prediction of the whole egg production from part-period production can be maximized by a careful analysis of appropriate data.

1.3 Justification of the Study

Shikabrown® chickens had been tested and certified as a good stock of chicken in the six geo-political zones of Nigeria. However, the institutional evaluation of the production pattern of the chicken was last done in 1997. Change of climatic elements and its effect on livestock had been documented to fit broadly into one of two categories: loss of productivity and increasing cost of production (Adesiji *et al.*, 2013; The Poultry Site, 2009). Evaluation of egg production patterns of Shikabrown® parents after the last one that was done about 20 years ago is necessary.

1.4 Aim

The aim of this study is to evaluate the egg production trends of Shikabrown® parents using mathematical models. This was also carried out to compare and evaluate the egg production curves of Shikabrown® parent using mathematical models in Zaria – Nigeria.

1.5 Objectives:

The specific objectives of this study were to:

i. Evaluate the performance of egg production traits in two genetic lines of Shikabrown® parents
ii. Determine the adequacy of five (5) mathematical models in describing egg production curve in Shikabrown® parents
iii. Evaluate egg quality traits in the two genetic lines of Shikabrown® parents.
iv. Estimate genetic parameters (heritability, genotypic and phenotypic correlations) for egg production traits of Shikabrown® parents.

1.6 **Hypotheses:**

H_o: There is no difference in egg production curves and egg quality traits of Shikabrown® parents obtained through different mathematical models.

H_A: There is difference in egg production curves and egg quality traits of Shikabrown® parents obtained through different mathematical models.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Historical Development of Egg Type Chickens in Nigeria

Concerted efforts at genetic improvement of the Nigerian livestock and birds had started some decades ago (Mbap, 1985), while livestock production began in the early twenties, poultry breeding started in 1985 in Nigeria at the National Animal Production Research Institute, Zaria (Adebambo, 1999). Although research on the local chicken started earlier with comprehensive information about the local fowl. Nigerian indigenous poultry varied due to the different ecological zones and possesses diverse genetic resources of the local breed, (Ajayi, 2010). The local breeds have genes and alleles pertinent to their adaptation to a particular environment and local breeding goals (Romanov *et al*., 1996). The chickens are known to have small body size and grow slowly; it has been found that they reach point of inflection earlier than the exotic (Nwosu *et al*., 1980).

2.2 Importance of Poultry Production in Nigeria

According to Ayoola (2013), Poultry farmers provide 25% of Nigeria's Agricultural GDP. Poultry production has assumed greater importance in improving the employment opportunity and animal food production in Nigeria. Nigerian indigenous poultry varied due to the different ecological zones and possesses diverse genetic resources of the local breed. The local breeds have genes and alleles pertinent to their adaptation to a particular environment and local breeding goals (Romanov *et al*., 1996). They chickens are known to have small body size and grow slowly; it has been found that they reach point of inflection earlier than the exotic (Nwosu *et al*., 1980)

2.3 Factors Affecting Egg Production in Nigeria

In the past years, commercial poultry farmers have been forced out of business due to various problems ranging from shortage and high cost of feed and drugs, inadequate and unavailability of veterinary services and, poor quality of equipment to other input (Adebayo and Adeola, 2005). According to Kekeocha (1984) and Dafwang (1987) age and disease among others, are factors that affect the productivity of laying hens. More so, Mashishi (2007) found that feed-related problems and bad management practices in intensive layer houses can cause decreased number of eggs, abnormal colour, shape and sizes of eggs. Decreased egg production results in a smaller profit to farmers and less money in their pockets. A study by Adebayo and Adeola (2005) revealed that, educational level of farmers had positive and significant relationship with average production, while age has negative and non-significant relationship with the average production of poultry farmers. The amount of egg laid by hens is influenced by many factors, such as breed or strain, age of birds, photo refractoriness, broodiness, molting, nutrition, and other environmental factors, (Anang and Indrijani, 2006).

Egg production is a dependent variable and in Nigeria it is influenced by several factors and to provide maximum output and profitability the cycle must be managed effectively and efficiently through controlling most of these factors. Hunton (1995) and Kekeocha (1984) stated the following factors to be considered;

2.3.1 Breed of bird

The breed of a laying bird influences egg production. Birds with poor genetic traits may not be too efficient in egg production due to their inherent traits. When such breeds of birds are used the egg production capability of such farms will be undermined (Zaman *et al*., 2004). The differences in attaining sexual maturity are attributed to the genetic differences amongst others. Cross-breeding results in early sexual maturity compared with pure-bred hens Wodzinowski (1945). In a study, Fairfull (1990) found that F_2 crosses often had a 5% earlier start of lay than the average of the parent breeds. Sexual maturity tends to be attained at later ages for heavier breeds. This character is also influenced by many environmental factors, such as temperature, nutrition and day length.

2.3.2 Mortality rate

Mortality may arise due to disease conditions, predation or high temperature. The average mortality rate of the flock ranges from 20 to 25 % per year. Shikabrown® has minimal mortality rate up to the time of lay, it was reported to be less than 5 % (Gefu, 2014).

2.3.3 Age at sexual maturity (Age of birds at lay)

Sexual maturity is specific for each breed, strain or population, Anang and Indrijani (2006). The birds with late sexual maturity have generally low egg production (Pingel, *et al*., 1987). Birds typically begin producing eggs in their twentieth or twenty-first weeks and continue for slightly over a year. This is the best laying period and eggs tend to increase in size until the end of the egg production cycle. Age influences within the laying periods, with the increase in yield from first laying to a peak, and then egg production decreases gradually to the end of the first cycle, Gowe and Fairfull, (1982). Therefore, it is possible to breed the birds in the second cycle, but the yield is usually lower than the first cycle, Reiter and Bessei (1988) Anang and Indrijani, (2006).With Shikabrown®, a farmer would get the desirable eggs and body weight within the period of 21 weeks and low feed. At this period, the bird can weigh up to 2 kg. (Gefu, 2014).

A high valuable egg laying strain is very often characterized by early sexual maturity (Kolstad, 1980). Heritability of age at sexual maturity has been reported to be moderate to high. Nema and Johari (1990) reported 0.31 in selected line and 0.37 in control line of White Leghorns, while Chen and Tixier-Boichard (2003) reported a range of 0.53 to 0.56 in Dwarf Brown – Egg layers. Ferdoci *et al.* (1992) reported a value of 0.37±0.153 also in White Leghorn Since age at sexual maturity has moderately high heritability estimates, it has been shown that it could be easily decreased by direct selection and also by selection for increased egg number (Kolstad, 1980; Sorensen *et al*., 1980). An overall decline of 2.87 days in age at sexual maturity per generation in a White Leghorn population was reported by Sharma and Krishna (1998). Age at sexual maturity has also been reported to be affected by sex linked genes (Jerome *et al.,* 1956; Saadeh *et al.,* 1968; Nema and Johari, 1990).

2.3.4 Body weight of birds at lay

Optimum body weight during the laying period should be around 1.5 kg, although this varies according to breed. Underweight as well as overweight birds lay eggs at a lower rate. Hens that mature with higher body weight lay heavier eggs at the onset of lay and at 17th week of production (Tongsiri*et al.,* 2014). Also Álvarez and Hocking (2007) noted body weight as a factor that influences egg production. Body weight at sexual maturity is an important trait which affects egg size due to positive correlation between the two traits. Ayorinde *et al.* (1988) reported that body weight ranging from 1728-1814 g is required for satisfactory performance in layers.

Generally, heritability estimates for body weight is high when measured at any given age. Body weights have been shown to be influenced by maternal effect of dominance or both up to maturity as indicated by consistently higher heritability estimates from dam variance components as opposed to those from sire components. Heritability estimates of body weight vary from one study to another (Kinney,1969).In the report of Sukhbir *et al.* (2001), heritability estimate of body weight at 20 weeks of age from full sib component of variance was 0.20±0.07 and 0.39±0.07 in first and second generations respectively. The heritability estimates for 20 and 40 week body weights from sire component of variance reported by Nema and Johari (1990) were 0.09 and 0.52 in selected line and 0.35 and 0.55 in control line respectively, while Kolstad (1980) reported heritability estimates of 0.68.

El-Salamony *et al.* (2002), reported that selection and line crossing is considered an effective method to increase body weight in chickens. However light body weights of layers are preferable to decrease maintenance requirements and to save final cost where ration is the most expensive item in raising layers (Orunmuyi, 2007).

2.3.5 Site and construction of laying house

The laying house should be built according to local climatic conditions and the farmer's finances. A good house protects laying birds from theft, predation, direct sunlight, rain, excessive wind, heat and cold, as well as sudden changes in temperature and excessive dust (FAO, 2003). If the climate is hot and humid, for example, the use of an open house construction will improve ventilation. The inside of the house should be arranged so that it requires minimum labour and time to care for the birds (FAO, 2003).

2.3.6 Lighting schedules in layer house

Egg production is stimulated by daylight; therefore, as the days grow longer, production increases. In an open housing, commonly found in the tropics, artificial lighting may be used to increase the laying period (FAO, 2003). While during nights, artificial lighting can be introduced for two to three hours to increase egg production by 20 to 30 percent. In closed houses, where layers are not exposed to natural light, the length of the artificial day should be increased either in one step or in a number of steps until the artificial day reaches 16-17 hours, this will ensure constant and maximized egg production. Effective day length should never decrease during the laying period (FAO, 2003).

2.3.7 Types of feed and feed utilization ability of birds

Feed quality is very important in the performance of poultry birds. However not all commercially formulated feeds in the market have adequate nutrients for the optimum performance of chicks and layers (Abeke *et al*., 2008). Free-range hens will produce more meat and eggs with supplemental feed, but only if they are improved breeds or crossbreeds. The selection of local hens is done on the basis of resistance and other criteria rather than feed utilization for production. Body weight of laying hens plays a significant role in feed intake. The heavy body weight requires more feed for maintenance whereas small bodied layers are known to be efficient utilizers of feed stuffs. Therefore, light body weights of pullets are preferable (Orunmuyi, 2007).

2.3.8 Culling of unproductive birds

Culling is the removal of undesirable (sick and/or unproductive) birds, from the flock. There are two methods of culling: mass culling, when the entire flock is removed and replaced at the end of the laying cycle; and selective culling, when the farmer removes individual unproductive or sick birds. Culling enables a high level of egg production to be maintained, prevents feed waste on unproductive birds and may avert the spreading of diseases (FAO, 2007).

2.3.9 Effect of climate

The optimal laying temperature is between 11° and 26° C. A humidity level above 75 percent will cause a reduction in egg laying. Emery *et al*. (1984) reported that laying performance parameters and egg quality were affected by the housing conditions, particularly the ambient temperature. The effect of the environmental conditions of the open house was also reflected on the feed intake of both hybrid strains which was lower than that of their corresponding standard values(Emery *et al*., 1984).Environmental conditions such as temperature and humidity Abiodun and Adedapo (20060; Hester, (2005) especially thermoneutral or comfort zone for chickens affects egg production (Rozenboim *et al*., 2007; Mashaly *et al*., 2008).

2.3.10 Management practices

Effective and efficient management practices are necessary to increase the productivity of the birds and consequently increase income (FAO, 2003). This entails not only proper housing and feeding, but also careful rearing and good treatment of the birds and ensuring good hygiene in poultry houses as well as adequate biosecurity measures (FAO, 2003).

2.3.11 Vaccination and disease control

Diseases and parasites can result in appreciable decrease in egg production. Some of the diseases that can lead to decrease egg production include bacterial such as tuberculosis, fowl typhoid e.t.c (Peebles *et al*., 2006), Viral which include Newcastle disease, Infectious Bursal Disease Virus, fowl pox and Bird Flu (Sun *et al*., 2009). Fungal (Aspergillosis), Protozoan (Coccidiosis) and Nutritional (Rickets, Perosis), Respiratory or intestinal problems (Yegani and Korver, 2008), and nutritional imbalances (Safaa *et al*., 2008; Jewers, 1990; Steinfeld *et al*., 2006). Also important parasites that are agents and can cause disease themselves include external Parasites fleas (lice, mites) and internal parasites (roundworms, tapeworms).

2.3.12 Collection of eggs

Frequent egg collection will prevent hens from brooding eggs or trying to eat them and will also prevent the eggs from becoming damaged or dirty. Shikabrown® lays for one and half times more than imported birds, that means farmers can continue picking eggs and having steady source of income for one and half year(Gefu, 2014).

2.4 Modeling of Production Pattern in Livestock

Mathematical modeling was defined by Dumas and Hardjosubroto, (2008) as "the use of equations to describe or simulate processes in a system which inherently applies knowledge and is indispensable for science and societies, especially agriculture". Mathematical modeling plays an integral role in the development of agricultural systems and they represent key functions of a system. For example, when modeling animal systems the quantitative values of: age, weight, scanning of fat measurements, estimating dry matter intake, and carcass evaluations are extremely important for developing body composition models (McPhee, 2009). According to Akpa (1999), models should not be complex in computation and should be easy for any scientist with basic knowledge of regression to use. The numerical calculations and analysis in some models ranges from simple to complex (McPhee, 2009).

Modeling is a research tool that is applied to livestock production systems in order to use research information more effectively. While only a limited number of production systems or alternatives can be examined experimentally, modeling offers the possibility of examining large numbers of alternatives under different conditions (Gous, 2009). Prerequisites to the use of this research tool are the existence of appropriate models and sufficient quantitative information to produce valid results (Gous, 2009).

The use of mathematical modeling in animal production has allowed farmers and researchers to describe and understand biological processes and prioritize the aims of production research from identifying the study's components to evaluating the response variable's effects (Galeano-Vasco *et al*., 2014).

Poultry enterprises may vary from basic backyard poultry keeping to mechanized and automated production plants (Ebraheem *et al*., 2012). The importance of the poultry industry is that it concentrates in providing employment not only to those engaged in production directly, but also for the hatchery operations, feed dealers, manufacturers of incubators, building materials, processors of egg and poultry products and all dealers engaged in the marketing of eggs and poultry from the time they leave the producer until they are in thehands of consumers (Morly, 1982).

Many researchers investigated factors that affect the performance of laying hens, and hence, their profitability. Ghasemi *et al*. (2010) investigated whether the supplementation of a diet with a mixture powder of garlic and thyme may assist in improving performance of laying hens and egg quality traits, however, in their report, they concluded that dietary inclusion of garlic and thyme can have beneficial effects on performance of laying hens in terms of improving egg weight and yolk color. Effects of dietary inclusion of feed additives in laying hens were also investigated (Zarei *et al.*, 2011).

2.5 Effects of Model Parameters on Egg Traits and Growth Curves

Selection based on partial or whole record ignores the possibility that different periods within the record may have dissimilar genetic parameters (Oni *et al*., 2007). Atta *et al*. (2010) found that Wood's formula could precisely fit the data of egg production; it could also be used for prediction and evaluation of the total production depending on a part of production records. Wolc *et al*. (2007) examined the goodness of fit of eight models describing production curves and the production model described by Wood (1967) had a high goodness of fit (R^2 ranged between 0.65 and 0.87). They also reported that Wood's model was one of the most adequate prediction of total production based on part record. They added that this model represented an additional phase called persistency which is defined as the number of weeks during which peak production was maintained (Atta *et al*., 2010). It is also worthy to note that Wood's equation can be used with satisfactory precision to predict the laying performance for whole production period based on part records of the production cycle (Atta *et al*., 2010).

Growth, which is under the control of genetics and environment, can be described by the changes throughout the life accompanied by the utilisation of materials, and leading to an increase in volume, size, or shape of an organism. These changes can be followed by measurements of body weight in regular intervals and summarized by mathematical equations fitted to growth curves (Sezer and Tarhan, 2005). Biologically, interpretable growth parameters can smooth the variation caused by the environment and random events (Aggrey, 2002; 2003). Biological meanings of the model parameters provide an opportunity to develop breeding strategies by modifying either management practices or genetic makeup of the shape of growth curves. Additionally, these functions allow for the study of differences between the lines that have diverse genetic background (Sezer and Tarhan, 2005).

2.6 Different Mathematical Models Used in Laying Birds

One of the major considerations in choosing a mathematical model of egg production is the ability to predict whole record production from part record (Oni *et al*., 2007).Timmerans (1973) observed that the parameters in the compartmental model described by Gavora *et al.* (1971) changed substantially with two genetically different strains. Gompertz's model has three model parameters; they include initial weight, mature weight and rate of maturing (Gavora *et al*. 1982). Goliomytis *et al*. (2003) explained that Richard’s model has four parameters which include weight of body as a component of age, upper asymptotic weight as age approaches infinity, rate of maturing and the shape parameter determining the position of inflection point. Three models viz Gompertz, Richards and Logistic were used by Sam (2006), to find the effect of rearing methods on body weight and major components parts in broiler chickens raised to maturity. All the three models gave a good coefficient of determination values (R^2) of 93-98%. It was found that Gompertz gave the best estimation for body weight and major component parts, while Richards's model gave the estimation for maturation rate. It also suggests that no single model can wholly describe growth parameters in chickens.

Gavora *et al.* (1982) synchronized egg production records to age at first egg; it was found that when all data were used in the fitting, the linear model gave the lowest R^2 of the three curves (Compartmental, Wood and Regression models). A comparison between the models, on the basis of R^2 for the two exponential models shows that the compartmental model has a higher R^2 for all strains in both the hen-housed and survivor data (Mcmillan *et al*., 1986). They noted that linear regression is more reliable and its parameters are also the simplest to be estimated. However, in practice it would not be difficult to record egg production over the first few weeks of lay, and then fit a linear regression to data collected over a specified period of production, rather than use a nonlinear curve-fitting computer routine to fit the production beginning at the first week of lay (Mcmillan *et al*., 1986). Mcmillan *et al*. (1986) observed that compartmental model performed quite well in its predictive capacity compared to the linear model, while the Wood's model did not. Gavora *et al.* (1982) showed that on an R^2 basis, the compartmental model came out slightly ahead of the Wood's model and further ahead of the linear regression model when the initial weeks of lay were not excluded from the fit.

Thus, it is inappropriate to use the early nonlinear part of the egg production curve when using a linear model, even with data synchronized on age at first egg. When the application includes goals other than simply predicting full record egg production from a part record, it would be more appropriate to use the compartmental model than the linear or Wood's models (Mcmillan *et al*., 1986).

In the past, the rapid development of regression methodology is observed. It provides a tool to analyse longitudinal records in animal breeding that reveal specific patterns of change over a trajectory (Wolc *et al*., 2007). Regression models have already been implemented in dairy cattle breeding programs (Schaeffer *et al*., 2000; Amin 2001), but their possible advantages. These advantages include higher accuracy of selection, the use of information on course of traits, and the possibility to change course of trait through selection have been also suggested for other farm animals like pigs Huisman, (2002) and sheep (Horstick *et al*. 2002). It is well known, that although it is not steady process over time, egg production in poultry shows a regularity, which is generally denoted as the egg production curve, especially when summarised on a weekly or monthly basis in a group of hens (Yang *et. al*., 1989). To describe trajectory of production curves over time many regression models have been suggested (Schaeffer *et al*, 2000). An average egg production curve can be included as the fixed or random part of the model. In second case, the individual genetic curve is estimated for each bird. Using such approach the birds with most desired laying trace can be selected. The biologically meaningful curve parameters like persistency or decreasing slope can be directly selected for(Wolc *et al*., 2007).If the characteristics of sexual maturity are taken into account, the model from Yang is more favourable than other mathematical models(Anang and Indrijani, 2006).

2.7 Derived Models for Egg Production Curve from Lactation Curve

There are mathematical models of egg production that have been published. The models are presented below:

2.7.1 Gamma function

Gamma function (Wood, 1967)

$$y_t = at^b e^{(-ct)}$$

Where *yt*= average of daily yield

t = time (week)

a,*b*,*c* = constant

This model was performed for milk production in dairy cattle, but it can be used also to describe the egg production.

2.7.2 Modification of Wood model, applied to poultry

(McNally, 1971)

$$y_t = at^b e^{[-ct+dt^{(0.5)}]}$$

Where *yt*= egg production during t

t = time

a,*b*,*c*,*d* = constant

2.7.3 McMillan function

(McMillan, *et al*., 1970a and 1970b)

$$y_t = M\left(1 - e^{-\zeta(t-t_0}\right)e^{-\alpha t}$$

Where y_t= egg production during t

M = the potential maximum daily egg production

t = time

t_0 = the initial day of egg laying

ζ= the rate of increase in egg laying

α= the rate of decrease in egg laying

This model was performed to predict egg production in Drosophila. McMillan function was developed by McMillan *et al*. (1970a), where is the initial day of egg laying; M is the potential maximum daily output of eggs, is the rate of increase in egg laying and is the rate of decay of egg production (Narinc *et al*., 2014).

2.7.4 Algebraic function

(Adam-Bell, 1980)

$$y_t = \frac{1}{0.01 + ar^{(t-b)}} - C\,(t-d)$$

Where *yt*= percent of hen day production during*t*

t= time (week)

a,b,c,r,d= constant

The Adams-Bell model is mostly used to predict total production from early records (Cason and Britton, 1988).

2.7.5 Compartmental model

(McMillan, 1981)

$$y_t = A(e^{-k_2 t} - e^{-k_1 t})$$

Where *yt*= average of egg production during *t*

t = time

k_1,k_2= instaneous rate of increase and decrease in egg production

A = maximum potential of egg production

In compartmental function transformed into egg production model by McMillan (1981), it is assumed that the hens begin production at a maximum laying rate and the starting times are exponentially distributed within a hen group. In this function, k_1 represents instantaneous rates of increase and k_2 instantaneous rates of decrease in egg production and A is the maximum potential of egg production (Narinc *et al*., 2014).

2.7.6 Post-peak of linear regression

(Gavora, *et al*., 1982)

$y_t = m - kt$

Where yt= average of egg production during t

t = time (28 day period)

m,k = instaneous rate of increase and decrease in egg production

2.7.7 Logistic model

(Cason and Britton, 1988)

$$y_t = a(e^{-bt})\left[\frac{1}{(1+c^{c+dt})}\right]$$

Where y t= egg production during t

t = age of flock (week)

a,b,c,d = constant

2.7.8 Modification of Compartmental Model

(Yang *et al*., 1989)

$$y_t = \frac{ae^{-bt}}{[1+ e^{-c(t-d)}]}$$

Where yt= percent of hen day production during t

t = time (week)

a = a scale of parameter

b = the rate of decrease in laying ability

c = the reciprocal indicator of the variation in sexual maturity

d = the mean age of sexual maturity

The modified compartmental model was developed by Yang *et al*. (1989), where is the scale parameter, is the rate of decrease of egg laying, is an indicator of variation in sexual maturity, and is the mean number of weeks in test until sexual maturity (Narinc *et al.*, 2014).

2.7.9 Gloor function

(Gloor, 1997)

$$y_t = LL\left(1 - e^{-at^b}\right)(e^{ct^d})$$

Where *yt*= egg production during *t*

LL= asymptote

t = time (week)

a = the rate of linear increase in egg laying

b = the rate of increase in egg laying

c,*d* = the rate of decrease in laying ability

In Gloor function, the asymptote of egg production is the rate of linear increase in egg laying, is the rate of increase in egg laying, and are the rate of decrease in laying ability (Gloor, 1997).

2.7.10 McNally model

(McNally, 1971)

$$y_t = at^b\, e^{[-ct+dt^{(0.5)}]}$$

Where y_t = egg production rate at *t* weeks of laying;

a= asymptotic value of egg production at the peak of egg –laying;

b,*c*, and *d* = constants.

The McNally model is a modified version of the Gamma model developed by McNally (1971) with the addition of an extra parameter, d, which is proportional to the square root of time Narinc *et al*. (2014).

2.7.11 Segmented polynomial model

(Fialho and Ledur, 1997)

$$y_t = 0 \text{ for } t < t_p - t_{ip}$$

$$y_t = Peak - 3.Peak.\left[\frac{t_p - t}{t_{ip}}\right] + 2.\text{ Peak}.\left[\frac{t_p - t}{t_{ip}}\right]^3$$

$$y_t = P - s\,(t - t_p) \text{ for } t_p \leq t$$

Where y_t = egg production rate at *t* weeks of laying;

Peak = peak production level (% egg/hen-day)

s = rate of production decrease after the peak (eggs/hen-day decrease per week);

tip= time interval between start and peak of production.

Segmented Polynomial model is the production curve having three segments (Fialho *et al*., 2011). In the first segment, the egg production is considered to be zero. Between the first laying and the peak production, the curve is represented by an ascending cubic function (Segment 2). Finally, following the peak, production is modeled with a linear decreasing function (Narinc *et al*., 2014).

2.7.12 Persistency model

(Grossman *et al*., 2000)

$$y_t = \left[\frac{Peak}{t_p}\right].t - 0.3.\left[\frac{Peak}{t_p}\right].Ln.\left[\frac{e^{t_p/0.3} + e^{t_p/0.3}}{1 + e^{t_p/0.3}}\right] + 0.3\text{ .s. Ln.}\left[\frac{e^{l/0.3} + e^{(t_p + P)}}{1 + e^{(t_p + P)}/0.3}\right]$$

Where y_t = egg production rate at *t* weeks of laying;

Peak = peak production level (% egg/hen-day);

tp= age of hen, in weeks, at the peak;

s= rate of production decrease after the peak (eggs/hen-day decrease per week);

p= number of weeks during which a constant egg production level is maintained after the peak.

Persistency model was developed by Grossman *et al*. (2000) to describe the egg production curve with a new measure for persistency, based on the proposed definition, utilising it as a selection criterion to improve the total egg production (Narinc *et al*., 2014).

2.8 Egg Production Curve

Appropriate mathematical functions precisely represent the entire production phase of the chicken and provide suitable means for biological comparisons and interpretations. Egg production curves help in predicting egg production, determining the optimum culling age of breeders and help making economical decisions. Several models have been proposed by different workers for the analysis of egg production curves in poultry (Anang and Indrijani, 2006).

Egg production is a result of many genes through biochemical, anatomical, and physiological processes (Anang and Indrijani, 2006).Egg production in poultry is a complex quantitative trait and shows considerable individual variation over the laying period. Statistical models used to describe poultry egg production curves are useful for many management decisions to be taken to increase egg production (Wolc *et al*., 2011). Prediction of total egg production as early as possible during the laying cycle using part records facilitates a poultry breeder to select breeding birds early thereby helping in reducing the cost of egg production/day-old chicks (Ganesan *et al.*, 2011).

The purpose of modeling the production curve in poultry eggs is to achieve a more detailed analysis of the egg production cycle and describe the curve phases and duration

(Fialho *et al.*, 2011). The curve also facilitates the production prediction, the long-term projection of eggs yield, and economic planning of production and decision-making, among others (Yang *et al.*, 1989; Groen *et al.*, 1998; Gavora *et al.*, 1982).

Egg production curve describes the relation between number of eggs and time of the laying period. The most important use of egg production models in poultry is to estimate the economic and genetic worth by predicting the total egg production from part records (Ganesan *et al.*, 2011). One of the main concerns for the poultry breeder is how to best define egg production as a trait for selection. The rate of egg production changes over time, and can be represented in terms of a "production curve". The shape of the curve is defined by the following stages (Wolc *et al*., 2011).

i. Sexual maturity (which marks the onset of production), followed by a stage of increasing production to a maximum

ii. Production peak, followed by a steady decline in egg production

iii. Persistency of production.

In modern layers, the production rate almost reaches its maximal biological potential (one egg per hen per day) during peak production. Therefore, there is hardly any variation among birds at this stage. What differs among birds is how long they can maintain a high rate of lay and at what rate production decreases after the peak. Statistical models, called random regression models can be used to describe changes of breeding values over time. For birds with desired high persistency, their advantage over their contemporaries increases with age (Wolc *et al*., 2011).

The egg production curve has been modeled using weekly production data (Miyoshi *et al*., 1996) and logistic functions (Adams-Bell, 1980; Cason and Britton, 1988), polynomial functions Adams-Bell, (1980), exponential functions (Foster *et al*., 1987), segmented polynomials (Lokhorst, 1996; Narushin and Takama, 2003), and nonlinear models (Savegnago *et al*., 2011).

2.8.1 Classification of models

Thornley and France (1984) described a scheme for classifying models that is widely recognized as a standard and used extensively by scientists modeling Ecological, Agricultural, Hydrological, and Environmental systems. They are dynamic or static, deterministic or stochastic, mechanistic or empirical. In brief, Baldwin (1995) described the classification as follows:

i. *Dynamic* - models based upon differential equations;
ii. *Static* - models usually algebraic in form and solved for a specific set of conditions, which exist at a set point in time;
iii. *Deterministic* - implies that all solutions of an equation or set of equations are exact;
iv. *Stochastic* - refers to models defined by probability functions, which inherently seek to take account of the variance that is not fully understood;
v. *Mechanistic* - refers to equations derived from some theory or hypothesis about the fundamental nature of the system. A mechanistic model assumes that full knowledge of casual relationships within the system is implied and computed results should relate to a broad range of realities. Riggs (1963) originally used the term 'theoretical' and Thornley and France (1984) suggested the term 'mechanistic'; and
vi. *Empirical* - refers to models that use existing data to describe the relationship of observations between one or two variables (Riggs, 1963). Empirical models are widely used in Animal science and care must be applied when extrapolating beyond the limitations of the data.

The above definitions are of value but ambiguities do exist (Baldwin, 1995).

2.9 Egg Production Traits

The evaluation of external and internal quality of the egg is essential for consumers' preference. Many factors are known to influence egg quality traits. These include; breeds/strain/, temperature, relative humidity, rearing practices and season (Washburn, 1990). The uniformity of the external and internal egg quality has become one of the major traits in selection (Thierry, 2012). The Haugh unit is considered to be related to freshness of the egg and has a big importance in some specific markets. It characterizes the albumen height for a constant egg weight and is measured during the whole production cycle with fresh eggs, but also after a longer period of storage. After cracking the egg, the albumen height is measured at a constant distance (0.5-1.0cm) from the yolk (Thierry, 2012).With longer cycles of production, egg quality measurements are becoming traits of huge importance in breeding programs. More than the quality itself, the uniformity of egg quality traits can be seen as the main requirement (Thierry, 2012).

2.10 Genetic Parameter (Phenotypic and Genotypic Correlations) Estimates For Egg Production Traits

Egg production is a trait that is expressed over a long trajectory of time and as such undergoes both genetic and environmental effects (Wolc *et al*., 2007). Knowledge about the patterns of egg-laying might contribute to more accurate prediction of genetic effects. There are several studies on monthly egg production reporting genetic parameters (Zieba, 1990; Preisinger and Savas, 1997; Savas *et al*., 1998; Anang *et al*., 2000; Nurgiartiningsih *et al*., 2005).

Negative genetic and phenotypic correlations exist between egg number and egg weight, sometimes, the total weight of eggs produced in a defined interval (egg mass) is used to access the egg production. Generally, there is a positive correlation between body weight, feed consumption, sexual maturity and egg weight. Also, negative genetic correlation exists between body weight and egg production (Okwonkwo, 2014). Genetic improvement is important to increase productivity through increasing gene frequency of reproduction. Growth traits enclosed with suitable environment according to Duma *et al*. (1989) can achieve maximal performance.

A phenotypic correlation is said to be the correlation between records of two traits on the same animal and is usually estimated by the product moment correlation statistic (Searle, 1961). While genetic correlation, on the other hand, is the correlation between an animal's genetic value for one trait and the same animal's genetic value for the other trait, estimators for which have been proposed by Hazel (1943). Usually estimate of a phenotypic correlation is reported smaller in magnitude than that of the corresponding genetic correlation (e.g. with certain poultry records) (Lerner and Cruden, 1948), sheep records (Morley, 1951) and with certain dairy records (VanVleck 1960; Searle, 1961).

The genetic correlation coefficients between egg quality traits like egg weight (EW), shell thickness (ST), Haugh Unit (HU), Yolk Index (YI) and Shape Index (SI) are independent of the laying age, and for faster genetic response in egg quality traits, and independent culling method(Wolc *et al.,* 2007). Genes governing the expression of egg quality traits appear to be independent of each other, it is possible to localize, isolate and intersperse the genes simultaneously in foundational poultry lines using biotechnological tools for faster genetic gain (Okwonkwo, 2014). Genetic improvement is important to increase productivity through increasing gene frequency of reproduction. Growth traits enclosed with suitable environment can achieve maximal performance (Duma *et al*., 1989). The ratio of genetic variance to phenotypic variance as reported by Wolc *et al.* (2007), was relatively high (above 35% in all lines) in the first month of lay and substantially decreased in further periods. Genetic correlations between the first two periods and the other months were low and even negative between the first month and more distant periods. For other periods the correlations decreased as the interval between periods increased (Wolc *et al.*, 2007).

Correlations permit prediction of direction and magnitude of change in the dependent trait as a correlated response to direct selection of the principal trait (Laxmi *et al*., 2002). Thus, correlations are of great interest to the breeder. The extent and direction of correlated selection response are determined by the genetic correlation or covariance between the concerned traits (Verma *et al*., 1983). Therefore, for improving the total economic value of an animal, it is important to know both the effect of the trait actually being selected and its effect on the other traits. This information becomes more relevant especially in flocks that undergo selection, in view of the fact that continued selection tends to bring about change in the genetic correlations among traits.

2.10.1 Heritability of egg production traits

Knowledge of genetic parameters for economically important traits is a prerequisite for effective genetic improvement programs of layer breeds (Tongsiri*et al*., 2014). Several authors have reported on heritability estimates for economically important traits for layer chicken (Lerner and Cruden, 1948; McClung *et al*., 1976; Wei and Van der Werf, 1995; Dana *et al*., 2011). However, almost these entire studies involved layer chickens managed under controlled environments in the temperate climates. Genetic parameters specific to the selection environment is essential to optimize genetic gain through selection, (McClung *et al*., 1976).

Several factors related to egg quality such as egg size, shell thickness, Haugh unit, shape index as well as egg number and number of blood spots are known to have heritable basis, and medium to high repeatability (Ibe and Okonkwo, 1994).

Heritabilities of albumen height (AH), albumen weight (AW), eggshell color (ESC), eggshell index (ESI), eggshell strength (ESS), eggshell thickness (EST), eggshell weight (ESW), egg weight (EW), Haugh units (HU), and yolk weight (YW), were measured to be (0.51, 0.59, 0.46, 0.40, 0.24, 0.34, 0.64, 0.63, 0.41, and 0.45), respectively (Zhang *et al*., 2005). The genetic correlations between EW and AW, YW, and ESW were high ranging from (0.67 to 0.97), whereas those for (ESC) with external and internal egg quality traits were low ranging from (−0.23 to 0.13). Thus, although heritability for these traits were moderate to high, genetic correlations with ESC were low, suggesting a minor relationship between shell color and physical attributes of the shell as well as internal egg quality in brown-egg dwarf layers (Zhang *et al*., 2005). Wolc *et al*. (2007), found a low heritability of cumulative records of laying hens ranging from (0.08 to 0.1), from the peak production until the end of recording and the consecutive periods were highly correlated.

In their report, Anang *et al*. (2001) reported heritability and repeatability under a comparable model to be equal to 0.06 and 0.07, respectively. Low values of heritability make further searching for new models and new definitions of egg production traits necessary. Anang *et al*. (2000b) further argued that genetic evaluation based on the average monthly production could be better than the use of cumulative production.

Heritability of egg production is generally low, this is an indication that variability due to additive gene action is probably small and that non-additive gene, actions such as over dominance, dominance and epitasis may be important (Orunmuyi, 2007). Heritability estimate of egg number determined from dam component of variance is generally higher than that determined from sire component. In the report of Nema and Johari (1990), the heritability estimate of egg production was low in selected line (0.13) and medium in magnitude in control line (0.28) from sire component of variance. The dam component for selected and control lines were higher indicating involvement of maternal effects in the inheritance of egg production. Singh *et al.* (1986) also support this view. They further reported that the heritability estimates for part period egg production was higher than annual and residual egg production which suggests that selection should be based on early production to improve annual egg production. Balvir *et al.* (2000) also reported heritability estimate for egg production to 280 days of are in a population of White Leghorn to be 0.164±0.064 while Oni *et al.* (2007) reported that the heritability estimates pooled over five generations from sire, dam and sire plus dam components of variance were 0.13±0.05, 0.16±0.07 and 0.15±0.03 respectively for egg production to 280 days of age in strain A of Rhode Island Chickens. Orunmuyi (2007) also reported corresponding estimates for strain B of the same Rhode Island chickens to be (0.23±0.04, 0.18±0.08 and 0.16±0.03).

2.10.2 Egg quality traits

Egg quality traits had received considerable attention by breeders because of their economic importance in the poultry industry, Orunmuyi (2007).The quality of egg-related traits is important from the viewpoints of conservation and industrial use. Modern consumers are concerned with freshness, but they also demand quality and this extends to appearance, colour and freedom from extraneous material of any kind, (Orunmuyi, 2007). Fulton (2004) and Roberts (2004) defined some egg-related traits such as age at the first egg, egg weight, eggshell thickness, albumen size, and yolk color, as egg production and quality traits. The principal component analysis using egg traits can generate more intensive data from multivariate. Characteristics of eggs will be understood more by analyzing the relationship among egg quality traits with principal components (Fulton, 2004 and Roberts, 2004).

One of the most important egg quality traits to be considered in a poultry breeding program is shell strength (Ledur *et al*., 2002). According to Grunder *et al*. (1991), specific gravity (SG) is eggshell strength as it relates to resistance to breakage and is relatively simple to measure (Gowe and Fairfull, 1995). Albumen height (AH) and Haugh units (HU) are traits used to evaluate albumen quality, which also deteriorates with age (Liljedahl *et al.*, 1999). One of the mechanisms to counteract the decline of fitness traits with age is heterosis (Liljedahl *et al*., 1999), and it is very pronounced for egg production. However, most egg quality traits have little or no heterosis (Fairfull and Gowe, 1986; Fairfull *et al*., 1987), and in most crosses, the reciprocal effects of these traits are as large as or larger than the heterotic effects (Fairfull, 1990).

The stabilization of eggshell quality will lead to high hatching rate from the early egg laying stage and to the production of more healthy offspring throughout their life spans (Liao *et al*., 2013). Since the egg-related traits are called reproductive traits, it will therefore be essential for the conservation of the Shikabrown® to know fundamental reproductive traits including age at the first egg that indicates the timing of sexual maturity. These basic data will help to conserve any breed of interest into the future.

Twenty two egg quality traits measured by Tatsuhiko *et al. (*2015) using principal component analysis and eigenvectors were calculated. Prior to the principal component analysis, Tatsuhiko *et al. (*2015) performed standardization for all trait data. Principal component analysis with egg quality traits revealed five principal components (PC1, PC2, PC3, PC4, and PC5) were estimated (8.31, 4.21, 2.27, 1.72, and 1.03) respectively, for eigenvalue and (24.87, 16.86, 15.47, 14.13, and 8.37) respectively, for variance %. These five principal components explained 79.70% of the total phenotypic variance (Tatsuhiko *et al.,* 2015).

Egg quality traits are significantly correlated with hatchability which is one of the most important reproductive traits (Wolc *et al*., 2011). In addition egg quality traits could provide some indication on hatchability under the situation in which individual recording of hatchability is not available. Apuno *et al*. (2011) worked with local chicken and found that egg weight was significantly correlated with egg width, egg length and shell weight. It suggests that egg weight in local chickens could be predicted using these factors.

2.10.3 Egg number

Egg production in domestic fowl can be described using various production periods. These periods include part year (280 days), Annual (480-500 days) and residual (above one year). The most widely used criterion in most poultry selection experiment is the part year egg production, which has the characteristic of reducing the generation interval by half consequent upon which the rate of genetic gain is increase (Orunmuyi, 2007).

Reports have shown that there is positive correlation between part year and annual egg and among part, annual and residual production. Sharma and Krishna (1998) reported positive genetic correlation between part and residual period percentages of production. John *et al.* (2000) reported an average of 0.45 as genetic correlation between partial and residual egg number from light Sussex and Brown Leghorn population. Sukhbir *et al.* (2001) also reported that the genetic correlations between part and annual egg production, and among part, annual and residual production were positive and high in magnitude. Bohren (1970) therefore concluded that the selection based on partial egg records to improve the annual egg record would be valid for some population when selection is only on egg number in the part period, but response may be erratic when selection of other traits is included (Orunmuyi, 2007).

2.10.4 Egg weight

Variation exists in the size of hen's egg. The weight of the egg is equal to the sum of the weights of its parts. The small size of the eggs laid by pullets at the beginning of the laying period is due in part to the smaller size of yolk in such eggs, as well as the lesser amount of albumen (Orunmuyi, 2007). Egg weight is a very important correlated trait in any population of chickens selected for egg production. Small eggs are known to receive fewer prices in the market while too big egg will require excess feed to produce them for which the egg producer will not be compensated (Orunmuyi, 2007). Moderate egg weights are preferable in egg layers (Kolstad, 1980). There is a linear increase of 1g per week in the weight of egg from the time the hen starts laying up to 6–7 months when the size levels off. The mature egg weight is between 50– 60g on the average.

Egg weight seems to have fairly high heritability. This shows that certain genes rather than environmental factors affect this trait Orunmuyi (2007). There have been variations in the heritability estimates for egg weight reported in literature. Nema and Johari (1990) reported that the heritability estimates for egg weight at 32 and 40 weeks of age were high, the values being (0.81 and 0.72) in selected line and (0.62 and 0.49) in the control line respectively. They further explained that sex-linked effects in the inheritance of egg weight were evident from their study. Balvir *et al.* (2000) reported heritability estimates for 32 weeks egg weight to be (0.579±0.121) in White Leghorn. Oni *et al.* (2007) reported that the heritability estimates for egg weight average pooled over generations from Sire, Dam and Sire + Dam were (0.24±0.06, 0.2±0.07) and (0.24±0.04) respectively for strain I and (0.34±0.05, 025±0.06 and 0.29±0.04) respectively for strain II both of Rhode Island chickens while Ferdoci *et al. (*1992) reported a high value of (0.7747 ± 0.2171) in White Leghorn.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location of the Study Area

The research was conducted at the Poultry Unit of the National Animal Production Research Institute (NAPRI) Shika, Zaria. The Institute is located in Northern Guinea Savannah zone of Nigeria on latitude $11^{o}12'16.78''$N and longitude $7^{o}33'39.18''$E with an elevation of 691 metres above sea level (Ovimaps, 2015). Being in the semi-arid region, it receives a mean precipitation of 1,107mm per annum, stretching over 120-170 days from late April to early October. Seasonal distribution of rainfall is approximately 0.1% in late dry (January-March), 25.8% in early wet (April-June), 69.6% in the late wet (July-September) and 4.5% in the early dry (October-December). Average maximum temperature is 38.89^{o}C, while the average minimum ambient temperature is 8.89^{o}C and the yearly average for the past 7 years is 25.55^{o}C. The mean relative humidity during dry and wet seasons is 21% and 72%, respectively (Ovimaps, 2015).

3.2 Experimental Birds

A population of 100 birds each of two strains of Shikabrown® Parents (sire and dam) housed at the Breeding Unit of Poultry Research Programme of National Animal Production Research Institute (NAPRI) were used for the study. The birds were obtained from the selected lines (sire and dam lines) and were denoted as strain A and strain B, respectively. Strain A was identified with a gold plumage while strain B with a silver plumage.

3.3 Management Practices

3.3.1 Egg collection and hatching

Pen mating was carried out by trap-nesting using a mating ratio of 1 male: 9 females. Fertile eggs were marked with sire and dam identification numbers and were collected over a seven-day period. The eggs were fumigated using Diskol® and stored in a Dublino® 3TN Tropic cabinet egg cooler at room temperature of 25^0C. On the 8^{th} day (following 7-days of collection) the eggs were set in the incubator. Candling was done on the 18^{th} day of incubation and all infertile eggs were removed. On the day of hatching, all chicks were wing-banded and pedigreed by sire and dam families. The chicks were vaccinated against Newcastle Disease Vaccine (NDV) using intraocular route of administration.

3.3.2 Management of birds

Chicks were brooded and reared on the deep litter in the restricted breeding section of the Poultry Unit. Electric bulbs and charcoals were used as sources of heat. Feed was placed in flat feeders and water in plastic drinkers commonly used for chicks. The birds were brooded from day old to 6 weeks after which they were transferred to the rearing house. Cockerels were separated from hens at about 8-12 weeks. Brown colour was used for auto sexing of cockerels and white colour for hens from pullet chicks. At 18 weeks, birds were moved to cage house where the females were housed in single hen cage ($900cm^2$/bird). The birds were vaccinated against known and common poultry diseases such as Marek's Disease (MD), Newcastle Disease Virus (NDV), Infectious Bursal Disease Virus (IBDV) (Gumboro) and Fowl-pox. Furthermore, other routine medication and management operations carried out included anti-coccidial administration, deworming and delousing.

3.3.3 Nutrition

Birds selected for the study were fed grower ration which contained 16.5 % Crude Protein (CP) and 2737 Kcal ME/Kg from 8 weeks to point of lay at 20 weeks of age. At point of lay, breeder mash containing 18% Crude Protein (CP) with 2724kcal ME/Kg was offered to the birds. Feed and water were given *ad libitum* while fresh feed was offered every day.

3.4 Production Traits Measured

i. Body weight (BWT) (Kg): Was measured on weekly basis using Camry® Commercial Mechanical Weighing Scale.

ii. Age at Sexual Maturity (ASM): Was obtained on the day each pullet laid the first egg, recorded in days.

iii. Egg number (EGGNO): Counted as the number of eggs laid by a hen in a week from point of lay to 12th week.

iv. Egg weight (EWT) (g): Measured using sensitive electronic balance scale on weekly basis from point of lay to 12th week.

3.5 Egg Quality Traits Estimations

Ten (10) eggs from each of the two strains were used to measure the internal and external egg quality traits. Eggs used for this study were sampled on the day each egg was laid. Measurements were taken from them on the same day. The weights were taken to the nearest 0.05g with sensitive electronic scale (Electronic compact scale, KERRO BL20001).

3.5.1 External egg quality traits measured

i. Egg length (ELT) and Egg width (EWD) were measured in centimeter by measuring the longest length and width of the egg using vernier caliper at sensitivity of and 0.01mm.

ii. Eggshell thickness (SHT): Was measured in millimeter together with shell membranes at the equatorial parts of the egg using a micrometer screw gauge.

iii. Egg shell weight (SHWT) (g): The shell was carefully dried with tissue paper to remove the remains of albumen white membrane. It was measured using sensitive electronic scale with sensitivity of 0.05g (Electronic compact scale, KERRO BL20001: made in Taiwan).

3.5.2 Internal egg quality traits measured

i. Yolk height (YHT) and Albumen height (AHT): Were measured when the eggs were broken and the content gently poured out into clean petri dishes. The measurements were taken using vernier caliper in centimeter.

ii. Yolk width (YWD) and Albumen width (AWD): Were measured when the eggs were broken and the content gently poured out into clean petri dishes. The measurements were taken using vernier caliper in millimeter.

iii. Yolk weight (YWT) and Albumen weight (AWT): The egg contents were gently poured, separated and scooped with tablespoon and poured in clean petri dishes and measured using sensitive electronic scale.

iv. Yolk index (YIDX) (%)**:**Was calculated according to the formula described by Olawumi and Ogunlade (2009):

$$Yolk\ index = \frac{Yolk\ height\ (mm) x\ 100\ \%}{Yolk\ width\ (mm)}$$

v. Haugh unit was calculated using the values obtained for the egg weight and albumen height using the formula given below:

Haugh unit (HU) = 100 log (H+7.5-1.7W$^{0.37}$)

Where:

H: albumen height in mm.

W: egg weight in gram.

3.6 Data Collection

At 20 weeks of age, 100 birds from each of the two strains were randomly picked and transferred to individual battery cage in order to monitor egg production. Eggs collected were recorded in daily egg record book and summarized at the end of every month. Records of body weight at 20 to 32 weeks of age were taken on weekly basis. For each bird, egg production was standardized into 28 days period,(Gavora, *et al*., 1982; Oni, 1997; Orunmuyi, 2007), starting from the day the pullet laid the first egg which was recorded up to 92nd day of egg production.

3.7 Data Analysis

3.7.1 Analysis of variance

Data obtained on egg production traits (BWT, ASM, EGGNO and EWT) were analyzed using General Linear Model and Pearson Correlation Procedure of SAS (SAS, 2004). Data obtained for egg quality traits were analyzed using General Linear Model and Pearson Correlation Procedure of SAS (SAS, 2004). Similarly, the prediction equation for egg weight using external egg quality traits was generated using Procedure of SAS (SAS, 2004).

3.7.2 Correlation procedure

The phenotypic correlation values related to both external and internal egg quality traits were estimated using Pearson's Correlation method of SPSS (2004) procedure.

3.7.3 Regression analysis for external egg quality traits

Regression procedure of SAS (SAS, 2004) was used to generate the prediction equation for egg weight using egg length and width.

Regression Equation: $y = a + b_1 x_1 + b_2 x_2$

Where:

y = egg weight

a = intercept

x_1 = egg length

b_1 = regression coefficient for egg length

x_2= egg width

b_2 = regression coefficient for egg width

3.7.4 Principal component analysis for egg quality traits

The suitability of the egg quality traits data generated in this study for principal component analysis was tested with Barlett's Test of sphericity. The Chi square values obtained for strain A (Chi square = 985.542; P < 0.001) g- Grams, cm-centimeter. (*P< = 0.05, **P< = 0.001) and strain B (Chi square = 764.562; P < 0.001)g- Grams, cm-centimeter. (*P< = 0.05, **P< = 0.001) indicated the validity of the data for principal component analysis.

3.7.5 Estimation of variance components, heritability and correlations

VARCOMP procedure of SAS (SAS, 2004) was used to generate variance components which were used to estimate heritability and genetic correlation. The model used was as follows:

$$Y_{ijk} = \mu + S_i + D_j + e_{ijk}$$

Where:

Y_{ijk} = Observation of the k^{th} hen in the j^{th} dam group and i^{th} sire group.

μ =Overall population mean

S_i = effect of the i^{th} sire

D_j= effect of the j^{th} dam mated to the i^{th} sire

e_{ijk}= error term associated with individual observation.

Heritability was estimated using the formula:

$$h^2{}_S = \frac{4\,\delta^2{}_S}{\delta^2{}_T}, \text{ where } T^2 = S^2 + E^2$$

T = Total phenotypic variance, S = Sire variance, E = Environment

While the correlation coefficient (r) is a measure of the variation in trait Y attributable to the linear relationship with trait X (Snedecor and Cochran, 1989).

$$r = Cov\,(X,Y) = \frac{\delta xy}{\sqrt{Var\,(X)Var\,(Y)}}$$

3.8 Models Fitted

Each mathematical model was fitted independently to data collected on each strain of breeder hens. Denoting egg production in the 28-day period starting from the day of 1st egg by Y., the following models were studied:

1. Logistic

$$y_t = \frac{C}{[1 + Exp[-a*(weeks - b)]]}$$

Where:

a = growth rate

b = inflection point

c= asymptote

2. Richard

$$y_t = \frac{[d-c]}{c + [1 + Exp[-a * [weeks - b]]]^f}$$

Where:

a= growth rate

b = inflection point

c = asymptote 1

d= asymptote 2

f= power

3. Gompertz

$$y_t = a * Exp[-Exp[-b * [weeks - c]]]$$

Where:

a = asymptote

b = growth rate

c = inflection Point

4. Linear

$$y_t = a + b * weeks$$

Where:

a = intercept

b = slope

5. Exponential

$$y_t = a + b * Exp\,[c * weeks]$$

Where:

a=asymptote

b= scale

c= growth rate

In all the models fitted, y represents the body weight in grams, egg number or egg weight in grams respectively; t = is the age of hen or its productive cycle, in weeks or months. Similarly, the constants, a, b, c, d, and f represent the model parameters as defined by the above equations and have their specific significance in each model. Also the authors referred to the parameters in the model as constants to be evaluated and did not attribute any biological meaning to them, Narinc *et al*. (2014).

Model equation used for the trial was nested classification based on sires within lines as shown below:

$Y_{ijk} = \mu + L_i + S_j + D_k + e_{ijk}$

Where:

Y_{ijk} = the record of the k^{th} line of j^{th} sire mated to k^{th} dam

μ = overall mean

L_i = effect of the i^{th} line

S_j = effect common to all animals of the j^{th} sire within the i^{th}line

D_k = effect common to all animals of the k^{th} grouped dam mated to the j^{th} sire within the i^{th} line

e_{ijk} is the random effect/error associated with the record of the i^{th} animal.

It is assumed that e_{ijk} is independently, identically and normally distributed with zero means and variance. Quantitative data obtained in this study were analyzed using

General Linear Model procedure of SAS 9.2 (SAS, 2004). Significant differences in means were separated using Duncan Multiple Range test (Duncan, 1955).

3.9 Statistical Criteria to Evaluate the Fitted Curves

The adequacy of fit of each model was evaluated by Akaike's Information Criterion (AIC), Root Mean Square Error (RMSE), Coefficient of determination (R^2), and graphical analysis.

3.9.1 Akaike's Information Criterion (AIC)

Akaike's information criterion (Akaike, 1974), that can be approximated to the least mean square method (Motulsky and Christopoulos, 2003), was calculated as follows:

AIC = n. In $\left[\frac{SS_{Error}}{n}\right]$ + 2.k,

Where:

n is the number of data points, *k* is the number of parameters in the model, and SS_{Error} is the sum of the squared error.

3.9.2 Mean square error (MSE)

The Mean Square Error was calculated as follows:

$$MSE = \frac{\sum_{i=1}^{n}\sum_{i=1}^{m}(y_{it}-\hat{y}_{it})^2}{nm-p}$$

Where:

y_{it} *and* $\hat{y}_{it}$ Are the observed and predicted weeklyegg production rates, respectively, of hen *i* at week *t* of laying,

n is the total number of hens, *m* is the total number of weeks of egg laying evaluated,

nm is the total number of observed values in the data set, and

p is the number of model parameters.

3.9.3 Coefficient of determination (R^2)

The R^2 was calculated as follows:

$$R^2 = \left[\frac{SS_{model}}{SS_{total}}\right]$$

Where:

SS_{model} = is the sum of the squares of the model

SS_{total}= is the total sum of the squares.

3.9.4 Model error

The fitted curve may present a good fit, as indicated by statistical measurements; that is, small values of MSE and high values of R^2. However, these indicators by themselves do not indicate the trend of the fitted curve. The model error (ME) at *t* week of egg laying is defined as:

$$MER_t = \frac{\hat{y}_t - \bar{y}_t}{\bar{y}_t}$$

Where:

MER is the model error

$\hat{y}_t$ is the average predicted egg production rate atweek *t* of laying and

$\bar{y}_t$is the average observe egg production rate at week *t* of laying.

The MER is expressed as the deviation between the averages predicted egg production rate minus the average observed egg production rate on the basis of the average observed egg production rate. When $\hat{y}_t$ (predicted) and $\bar{y}_t$ (observed) are equal, the deviation of theadjusted egg production rate at week *t* is zero. When $\hat{y}_t$ (predicted) is higher than $\bar{y}_t$(observed), the predictionof egg production at *t* is overestimated (positive model error). When $\hat{y}_t$ (predicted) is smaller than $\bar{y}$ (observed), the prediction of egg production at *t* is under-estimated (negative model error). The model error (ME) is obtained as the mean of all the model errors (MER).

3.9.5 Graphical evaluation of curve fitting

Data used for the fitted curve was evaluated using R Statistical Software, version 3.0.3 (2013).

CHAPTER FOUR

4.0 RESULTS

4.1 Effects of Strain and Age on Egg Production Traits of Shikabrown® Parent

Table 4.1 shows the descriptive statistics for egg production characteristics as affected by Strain. In Table 4.1, there was significant (P<0.05) difference existed for BWT and EWT except for ASM and EGGNO. Coefficient of variation ranged from low (9.13%) for EWT to high for EGGNO (28.46 %). BWT was better (P<0.05) in strain B with a higher value of (1.59±0.01) compared to (1.55±0.10) for strain A. EWT in strain A had higher value (P<0.05) (48.75±0.17) than its counterpart (47.92±0.17). EGGNO and ASM were not affected by strain. EWT was significantly (P<0.05) affected by strain at 24, 26, 27 and 28 weeks of production. BWT attained higher growth (P<0.05) at 27 and 28 weeks of production. Decline in BWT especially for strain A and EWT in strain B were recorded at week 28 and week 29, respectively.

4.2 Effects of Strain on Body Weight of Shikabrown® Parent

Figure 4.1 shows the effect of age on body weight of Shikabrown® parent. The curve showed that strain B attained a mature bodyweight earlier, but showed little increase in body weight over the duration of the study. Strain A on the other hand, attained mature bodyweight late, but showed relatively steady increase in bodyweight over the duration of the study. At 32 weeks, Strain A was significantly (P<0.05) higher in bodyweight than Strain B. As the birds advanced in age, their body weights also increased unlike Strain B where there were periods of rising and falling in bodyweights of birds irrespective of age. See Appendix I on the effect of age on body weight and egg weight of Strain A and Strain B.

Table 4.1: Effect of Strain on Egg Production Traits

	Strain A	**`Strain B**	
Traits	Mean±SE	Mean±SE	CV (%)
BWT (Kg)	1.55±0.10[b]	1.59±0.01[a]	18.26
ASM (days)	158.30±1.50	154.24±1.50	16.67
EGGNO(g)	14.33±0.24	14.48±0.24	28.46
EWT(g)	48.75±0.17[a]	47.92±0.17[b]	9.13

Traits: BWT: Body weight, ASM: Age at Sexual Maturity, EGGNO: Egg number, EWT: Egg weight
[ab] Means with different superscripts on the same row are significantly different (P<0.05)

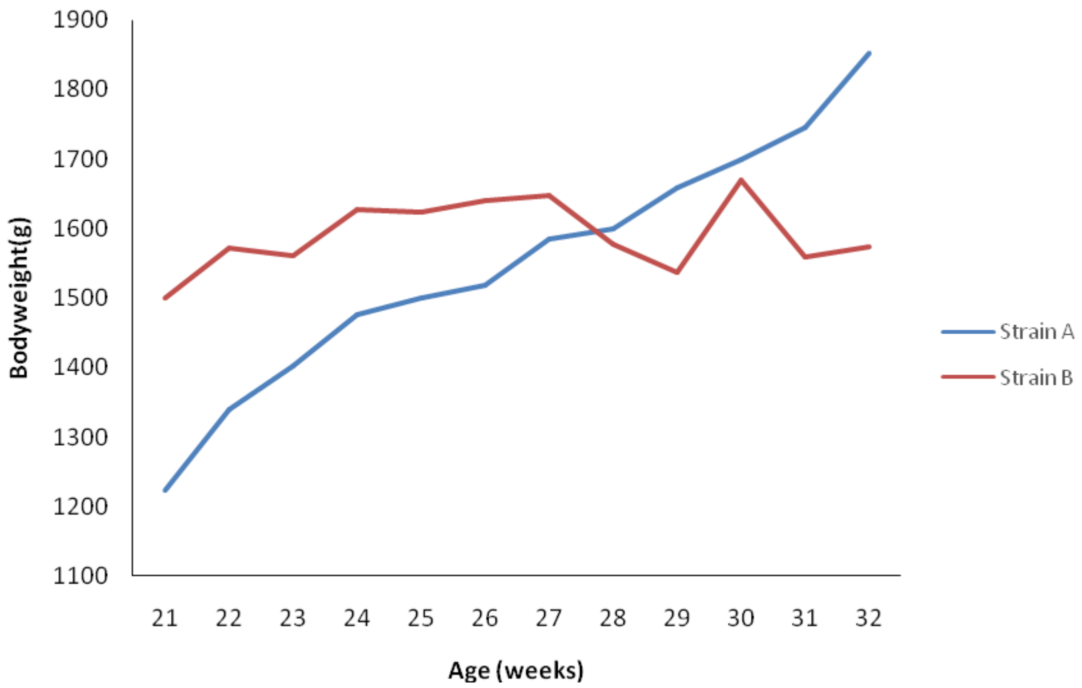

Figure. 4.1: Effect of Strain on Body Weight of Shikabrown® Parent

4.3 Effect of Age on Egg weight

Figure 4.2 shows the effect of age on egg weight of Shikabrown® parent. Similar trend was also observed in both strains for egg weight as did for body weight. Strain A showed a rapid rise in egg weight within 21stand 22nd weeks of age. The rate of increase in egg weight in the subsequent 22nd and 31st weeks of age although significant (P>0.05) and steady, it was less rapid than between 21st and 22nd weeks and between the 31st and 32nd week. Strain B showed an increased egg weight at an earlier age than strain A, but increase significantly over time (21st to 27th week). The egg weight declined subsequently from 28th to 31st weeks of age. The egg weight of strain A was less than the egg weight of strain B in the first five weeks of the study, however it was less than the egg weight of strain A in the subsequent seventh weeks, with the egg weight of strain A being significantly (P<0.05) bigger at the 12th week of the study. Strain B roughly showed a pleateau trend, meaning there was no significant (P>0.05) increase in egg weight over time.

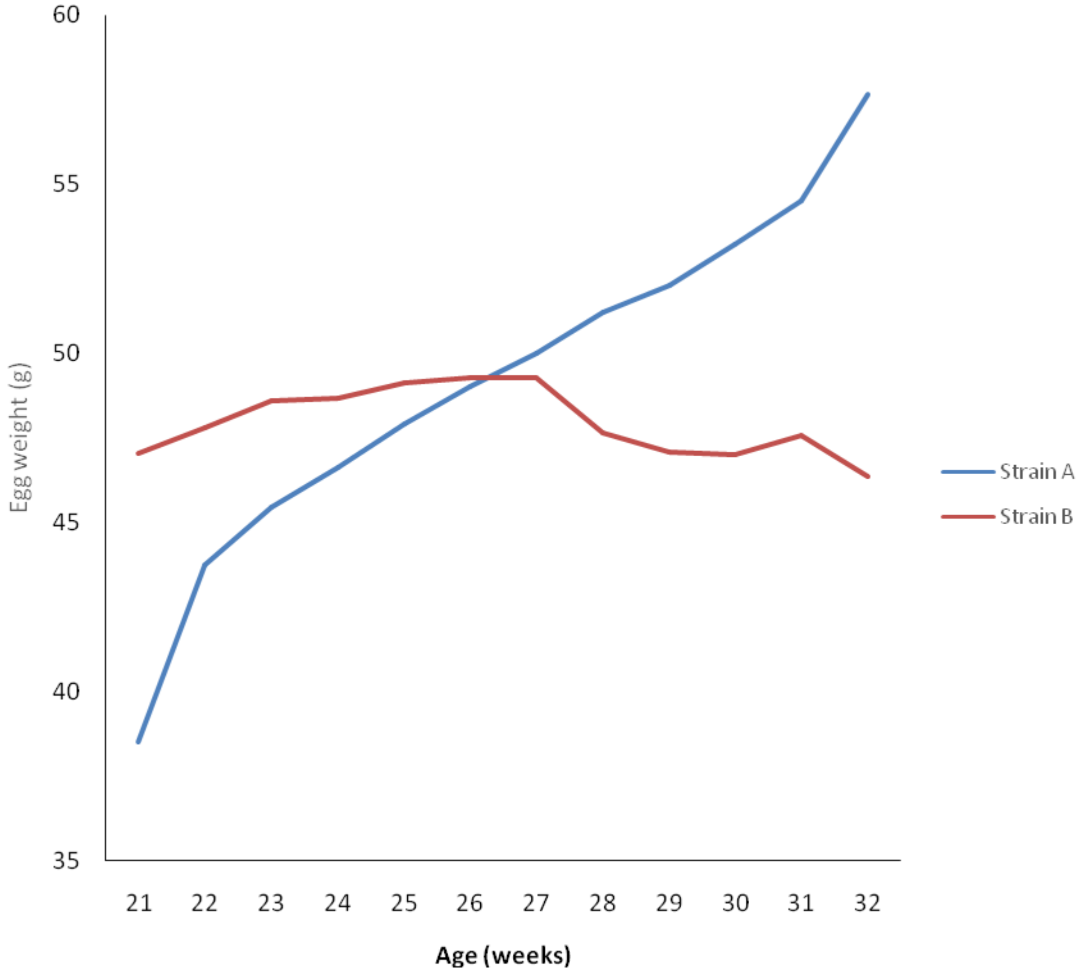

Figure. 4.2: Effect of Age on Egg Weight of Shikabrown® Parent

4.4 Variation in Egg Number of Shikabrown® Parent over Time

Figure 4.3 shows the variation in egg number over the duration of study (March, April and May). In March, strain B laid higher number of eggs than strain A. Both strains laid appreciably higher number of eggs in the month of April with strain B having an edge over strain A. In May, there was a significant ($P<0.05$) distinction between the performance of strain A, and strain B, in egg number. Strain A performed appreciably better than strain B with a decisively higher record of eggs laid in May. Generally, there was a steady increase in number of eggs laid by strain A over the duration of the study, with the highest number of eggs laid in May. On the other hand, the number of eggs laid by strain B increased from March to April, when it peaked, but declined in May.

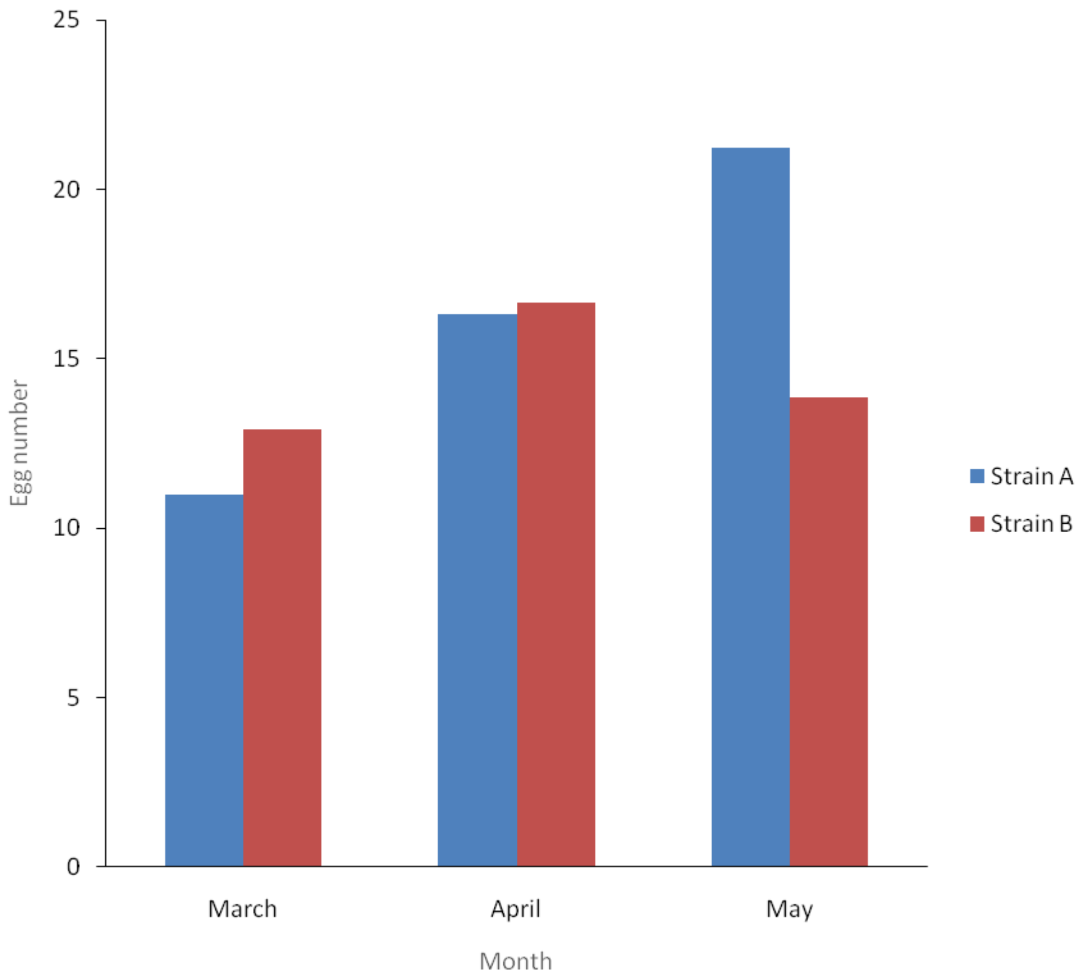

Figure. 4.3: Variation in Egg Number of Shikabrown® over Time

4.5 Models Comparism of Strain A and Strain B for Body weight

Tables 4.2 and 4.3 showed the model comparism of Strain A and Strain B for body weight. For the body weight model selection criteria, the R^2 values for the Logistic, Richards, Gompertz, Linear and Exponential models in Strain A were 0.92, 0.93, 0.93, 0.92, and 0.93 respectively. Richards, Gompertz and Exponential models were similar and had the highest coefficient of determination (R^2) values of (R^2= 0.93), while Logistic and Linear models recorded the least (R^2= 0.92). Consequently, the Logistic and the linear models had the highest RMSE (Root Mean Square Error) and AIC (Akaike Information Criterion) values. The RMSE and AIC values for the Gompertz, Richard and Exponential models were 47.86 and 12408.80, 47.60 and12395.58 12395.58 and47.59, respectively. Similarly, in Strain B, the highest coefficient of determination was estimated by Logistic, Richard and Gompertz models, with similar value of 89% each for the prediction accuracy. Least prediction value was estimated by Exponential model with R^2 value of 0.84.

The Richard models in both strains had the highest number of model parameters (5) while the linear model recorded the least number of parameters. Richard model had the best prediction accuracy (93 and 89%) in strain A and B which was validated by the least values recorded for the AIC (12397.81 and 2774.05) estimates and RMSE (47.60 and 63.15).

An inverse relationship was seen between the parameter estimates of ‘a’ (growth rate) and ‘c’ (asymptote). Increase in growth rate for a model translates to a decrease in asymptotic value. In strain A for body weight, Exponential model recorded ‘a’ value of 3062.09 and an inverse ‘c’ value of -0.03. Logistic model on the other hand, recorded a ‘c’ value of 2424.97 and an ‘a’ value of 0.09. This inverse relationship between growth rate ‘a’ and asymptotic ‘c’ was constant in egg number and egg weight of the birds studied. Actual and modeled fits for body weights of strain A and B are shown in Figures 4.4 and 4.5.

Table 4.2: Model Comparism of Strain A for Body weight

Model	Parameters	Parametric Estimates					Goodness of Fit		Validation	
Strain A		a	b	c	d	f	RMSE	R^2	AIC	AIC Wt
Logistic	3	0.09	19.86	2424.97			48.11	0.92	12421.03	1.47
Richard	5	0.02	-2.16.33	4384.30	3341.06	-67.66	47.60	0.93	12397.81	0.75
Gompertz	3	2621.33	0.10	15.64			47.86	0.93	12408.80	0.00
Linear	2	592.19	48.72				48.15	0.92	12421.88	1.47
Exponential	3	3062.09	-3534.24	-0.03			47.59	0.93	12395.58	0.75

RMSE = Root Mean Square Error, R^2 = Coefficient of determination, AIC (Model efficiency) = Akaike Information Criterion, AIC Wt (Model ranking) = Akaike Information Criterion, a= Growth rate, b = Inflection point, c = Asymptote 1, d = Asymptote 2, f = Power

Table 4.3: Model Comparism of Strain B for Body weight

Model	Parameters	Parametric Estimates					Goodness of Fit		Validation	
Strain B		a	b	c	d	F	RMSE	R^2	AIC	AIC Wt
Logistic	3	0.13	18.09	2072.48			64.17	0.89	2782.43	0.00
Richard	5	0.02	-74.92	2505.54	2462.66	-21.73	63.15	0.89	2774.05	0.16
Gompertz	3	2132.02	0.10	15.05			63.70	0.89	2776.80	0.04
Linear	2	187.60	51.21				65.63	0.88	2807.04	1.07
Exponential	3	2227.35	-4922.58	-0.00			1.99	0.84	2770.79	0.80

RMSE = Root Mean Square Error, R^2 = Coefficient of determination,AIC (Model efficiency) = Akaike Information Criterion, AIC Wt (Model ranking) = Akaike Information Criterion, a= Growth rate, b = Inflection point, c = Asymptote 1, d = Asymptote 2, f = Power

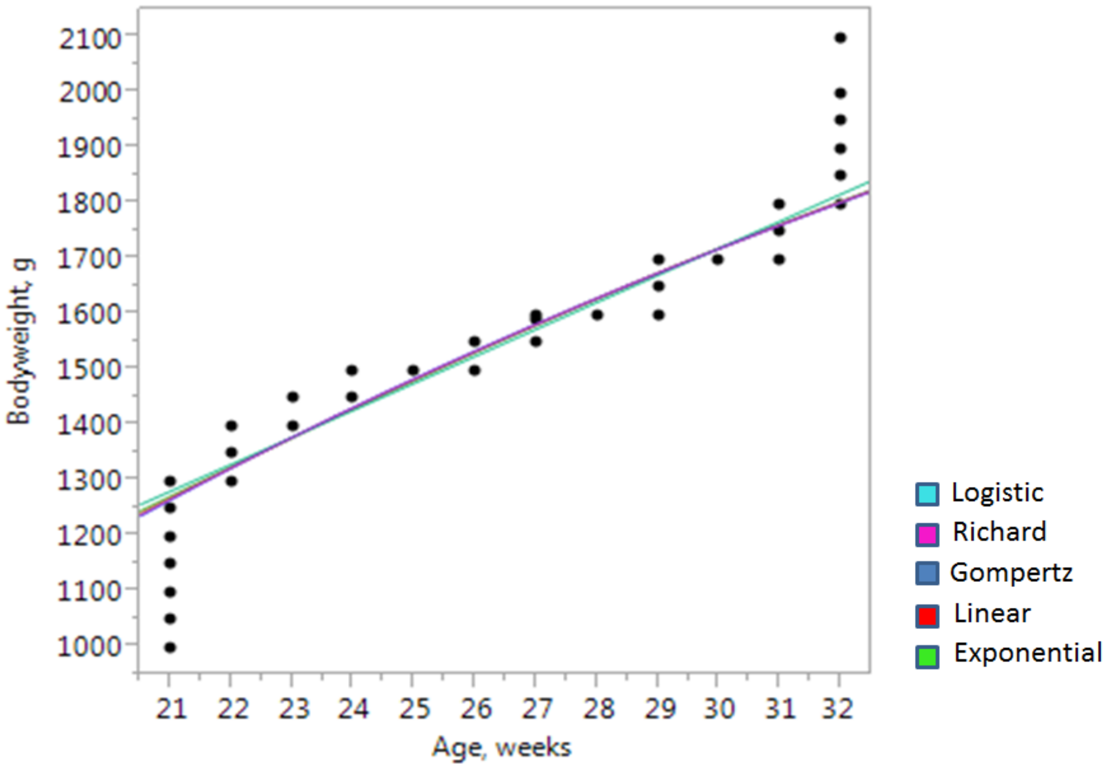

Figure 4.4: Growth curves of strain A birds, estimated by Logistic, Richard, Gompertz, Linear and Exponential models for Shikabrown®Parent.

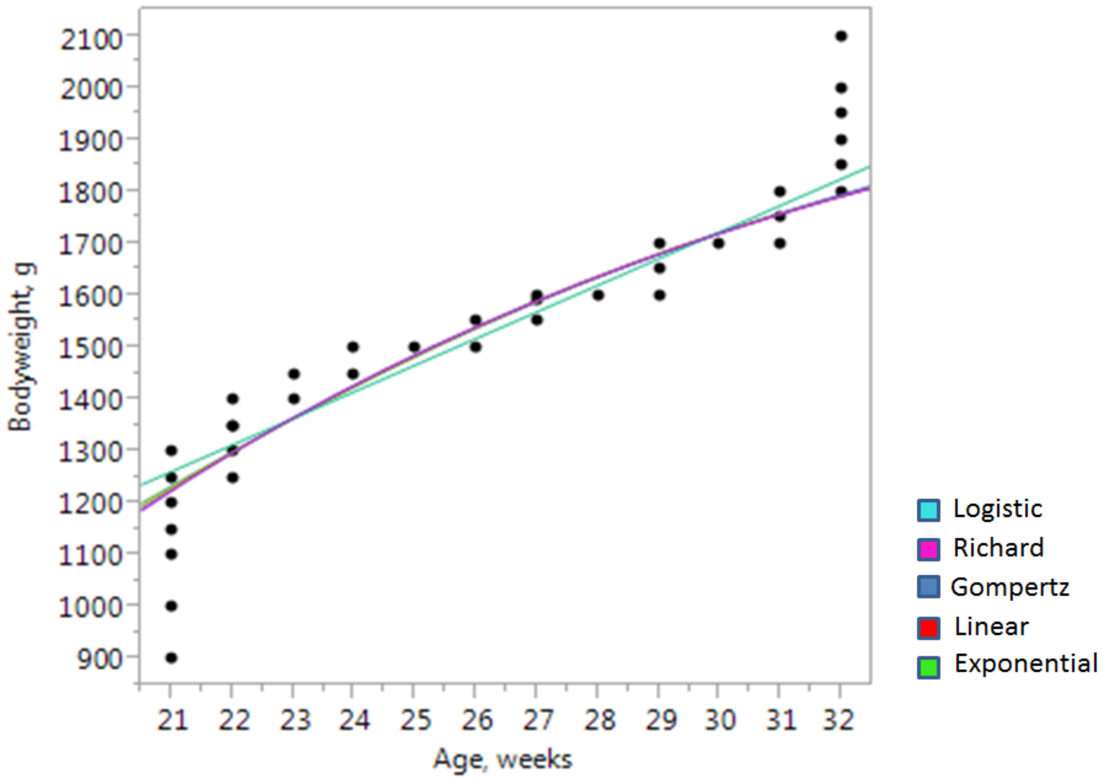

Figure 4.5: Growth curves of strain B birds, estimated by Logistic, Richard, Gompertz, Linear and Exponential models for Shikabrown®Parent.

4.6 Model Comparison for Egg number in Strain A and B

Model parameter estimates and goodness-of-fit criteria for egg number in Strain A and B are shown in Tables 4.4 and 4.5. All the models provided acceptable fit to the data. However, based on calculated values for coefficient of determination, R^2 and RMSE, Exponential model (R^2= 0.93, RMSE = 47.59) provided the best fit in strain A. The order of performance of Logistic, Gompertz, and Linear models were similar (R^2= 0.70, RMSE = 2.30) as for RMSE and AIC, in the other models with the exception of Richard (RMSE = 2.32) model in both strains.

Parameter estimate of 'a' for egg number showed that Gompertz and Exponential model gave growth rate value of (35.33; 73.70) and (39.61; 152.37) in strain A and B, respectively. Asymptotic value 'c' for Gompertz and Exponential were (3.37; -0.01) and (3.64; -0.04) in strain A and B, respectively. Graphical representation of actual egg number and fitted models are shown in Figures 4.6 and 4.7.

Table 4.4: Model Comparism of Strain A for Egg Number

Model	Parameters	Parametric Estimates					Goodness of Fit		Validation	
Strain A		A	b	c	d	f	RMSE	R^2	AIC	AIC Wt
Logistic	3	0.75	3.66	29.04			2.30	0.70	1037.90	0.19
Richard	5	1.12	3.82	5.51	25.51	1.03	2.32	0.70	1042.10	0.02
Gompertz	3	35.33	0.41	3.37			2.30	0.70	1037.90	0.19
Linear	2	-4.45	5.17				2.30	0.70	1036.90	0.42
Exponential	3	73.70	-81.85	-0.01			47.59	0.93	1240.58	0.75

RMSE = Root Mean Square Error, R^2 = Coefficient of determination, AIC (Model efficiency) = Akaike Information Criterion, AIC Wt (Model ranking) = Akaike Information Criterion, a= Growth rate, b = Inflection point, c = Asymptote 1, d = Asymptote 2, f = Power

Table 4.5: Model Comparism of Strain B for Egg Number

Model	Parameters	Parametric Estimates					Goodness of Fit		Validation	
Strain B		a	b	c	d	f	RMSE	R^2	AIC	AIC Wt
Logistic	3	0.65	3.83	30.91			2.30	0.70	1037.90	0.19
Richard	5	1.70	3.94	9.28	23.11	1.04	2.32	0.70	1042.10	0.02
Gompertz	3	39.61	0.34	3.64			2.30	0.70	1037.90	0.19
Linear	2	-3.12	4.85				2.30	0.70	1036.30	0.42
Exponential	3	152.37	-156.77	-0.04			2.30	0.70	1037.90	0.42

RMSE = Root Mean Square Error, R^2 = Coefficient of determination, AIC (Model efficiency) = Akaike Information Criterion, AIC Wt (Model ranking) = Akaike Information Criterion, a= Growth rate, b = Inflection point, c = Asymptote 1, d = Asymptote 2, f = Power

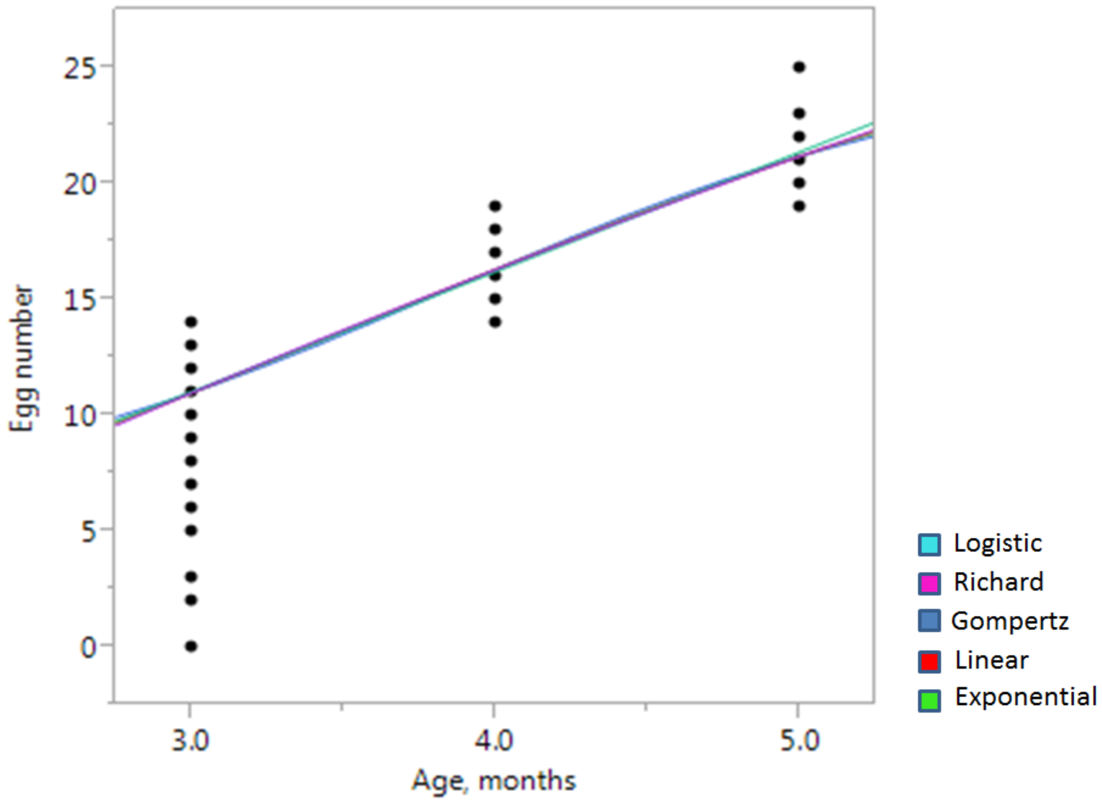

Figure 4.6: Fitted curves of Strain A birds for egg number, estimated by Logistic, Richard, Gompertz, Linear and Exponential models for Shikabrown®Parent.

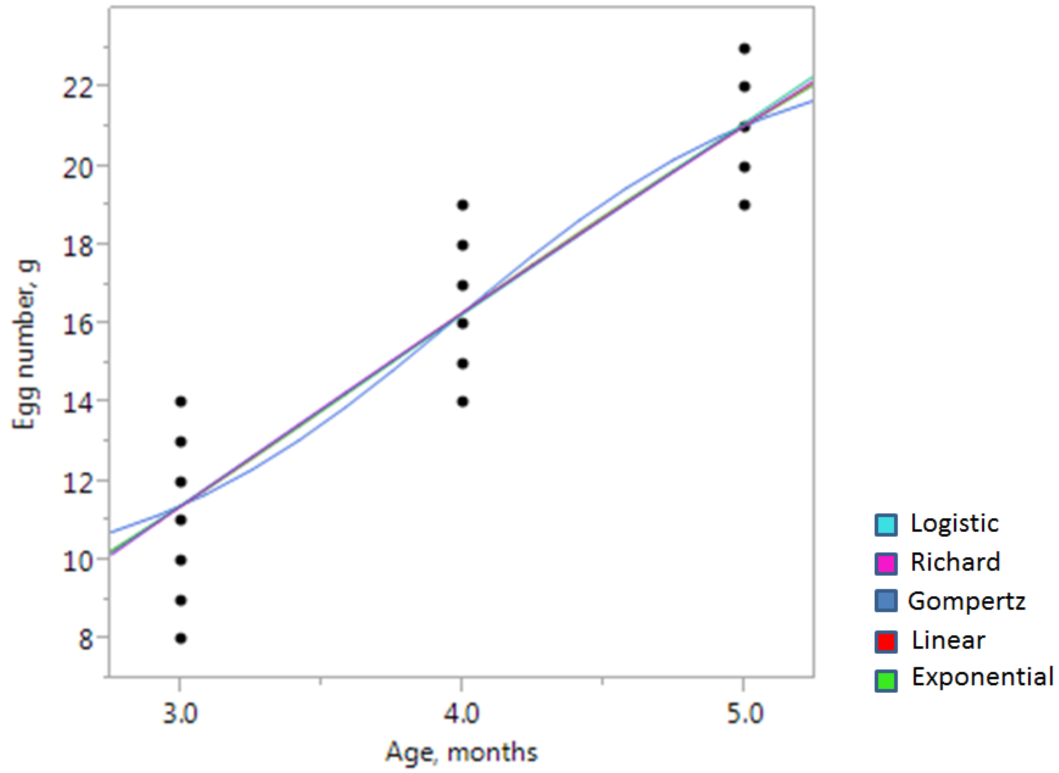

Figure 4.7: Fitted curves of Strain B birds for egg number, estimated by Logistic, Richard, Gompertz, Linear and Exponential models for Shikabrown®Parent.

4.7 Model Comparison for Egg weight in Strain A and Strain B

The parameter estimates and goodness-of-fit criteria derived for egg weight are summarized in Tables 4.6 and 4.7 for Strain A and B. Based on the results obtained; all models fitted the egg weight data satisfactorily. Calculated values for RMSE, R^2, and AIC indicated that Gompertz, Richard, Exponential and Logistic models provided the best (R^2 = 0.96) fits in Strain A. The Linear model gave a lesser (R^2 = 0.95) fit for strain A. Growth rate 'a' for egg weight in Strain A was higher in Exponential model (66.52), followed by Gompertz (64.57). Asymptotic 'c' value of (-0.10; 13.86) was recorded for Exponential and Gompertz models in Strain A. Similar pattern was observed also in Strain B, with Gompertz, Richard, Exponential and Logistic models having the same coefficient of determination (R^2 = 0.84) and Linear model with a lesser fit (R^2 = 0.83). Also Exponential and Gompertz models recorded an 'a' value of (66.59; 64.62). Asymptotic value of (-0.08; 13.62) were recorded for Exponential and Gompertz models in Strain B. Figures 4.8 and 4.9 showed actual and modeled curves for egg weight in Strain A and B.

Table 4.6: Model Comparism of Strain A for Egg weight

Model	Parameters	Parametric Estimates					Goodness of Fit		Validation	
Strain A		A	b	c	d	F	RMSE	R^2	AIC	AIC Wt
Logistic	3	0.13	16.57	63.25			1.21	0.96	48.89	0.13
Richard	5	0.04	-140.64	81.03	69.31	-1599.26	1.30	0.96	62.77	0.00
Gompertz	3	64.57	0.11	13.86			1.19	0.96	48.45	0.16
Linear	2	12.08	1.40				1.24	0.95	46.09	0.51
Exponential	3	66.52	-145.43	-0.10			1.16	0.96	47.96	0.20

RMSE = Root Mean Square Error, R^2 = Coefficient of determination, AIC (Model efficiency) = Akaike Information Criterion, AIC Wt (Model ranking) = Akaike Information Criterion, a= Growth rate, b = Inflection point, c = Asymptote 1, d = Asymptote 2, f = Power

Table 4.7: Model Comparism of Strain B for Egg weight

Model	Parameters	Parametric Estimates					Goodness of Fit		Validation	
Strain B		A	b	c	d	F	RMSE	R^2	AIC	AIC Wt
Logistic	3	0.13	16.38	63.29			2.02	0.84	2782.43	0.00
Richard	5	0.01	34.31	67.62	67.62	-10.95	2.00	0.84	2774.05	0.16
Gompertz	3	64.62	0.10	13.62			2.00	0.84	2776.79	0.04
Linear	2	12.68	1.38				2.06	0.83	2807.04	1.07
Exponential	3	66.59	-139.47	-0.08			1.99	0.84	2770.79	0.80

RMSE = Root Mean Square Error, R^2 = Coefficient of determination, AIC (Model efficiency) = Akaike Information Criterion, AIC Wt (Model ranking) = Akaike Information Criterion, a= Growth rate, b = Inflection point, c = Asymptote 1, d = Asymptote 2, f = Power

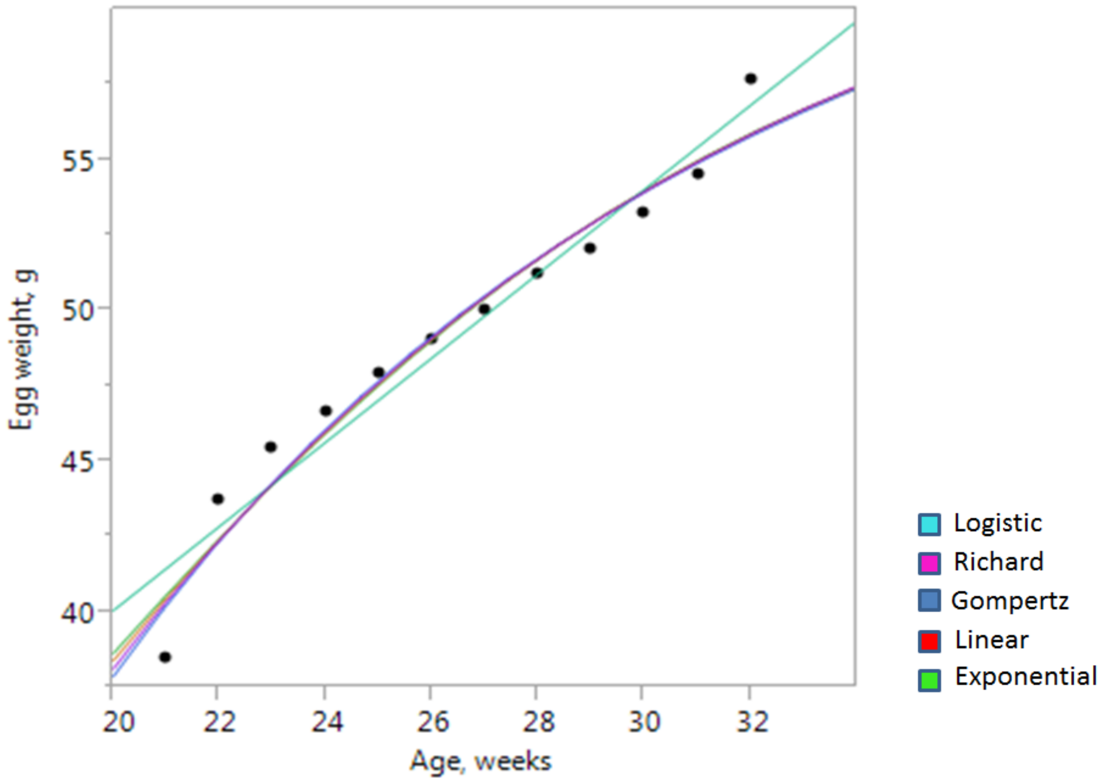

Figure 4.8: Fitted curves of Strain A birds for egg weight, estimated by Logistic, Richard, Gompertz, Linear and Exponential models for Shikabrown®Parent.

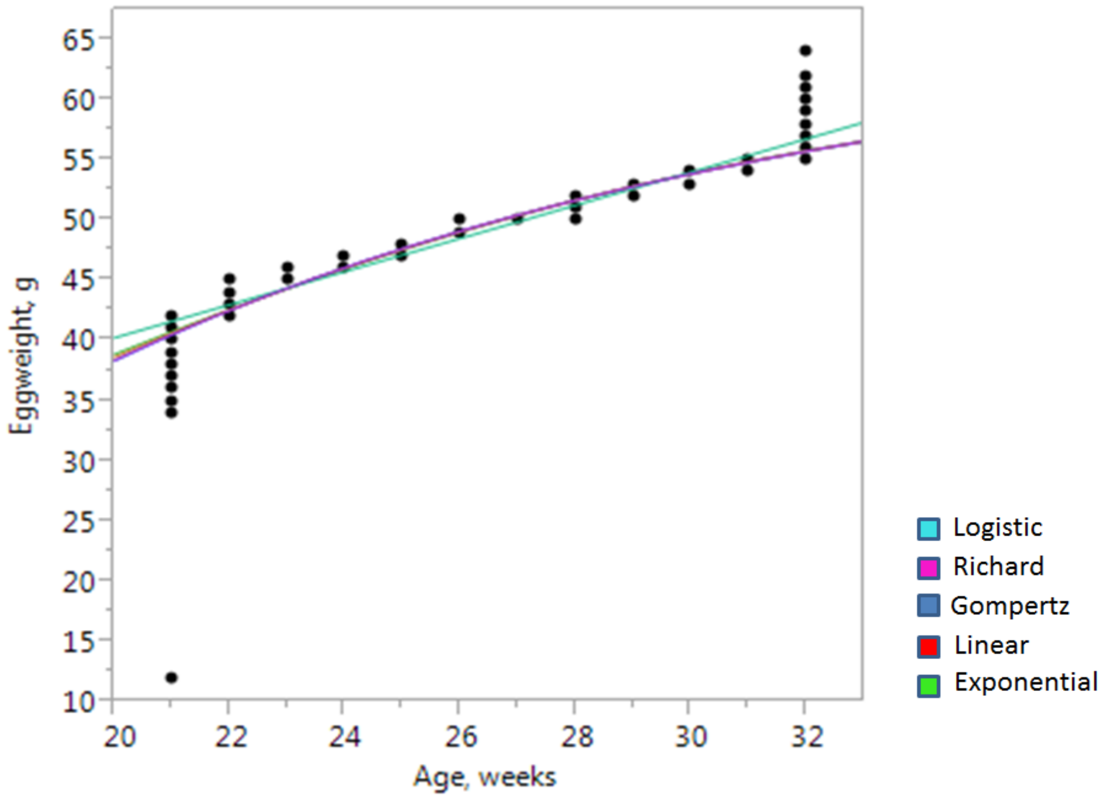

Figure 4.9: Fitted curves of Strain B birds for egg weight, estimated by Logistic, Richard, Gompertz, Linear and Exponential models for Shikabrown®Parent.

4.8 Egg Production Traits Comparison for Strain A and B

Tables 4.8 and 4.9 showed the values estimated for egg production traits in Strain A and B. It shows the relationship between model parameters and egg production traits. In both strains, Exponential and Gompertz models recorded higher weight changes (a) for body weight. Exponential model had higher value in Strain A as compared to B (3062.09 and 2227.35) while Gompertz model also recorded similar pattern (2621.33 and 2132.02). Significant differences are recorded within models for the egg production traits studied. Egg weight in Strain A recorded the best prediction accuracy (R^2 = 0.96) across the four nonlinear models with the exception of linear model with (R^2 = 0.95) for egg weight. This is followed by body weight with the range of 0.92-0.93 for the prediction accuracy recorded in the models. Coefficient of determination of (R^2 = 0.70) was obtained in a reproductive trait; egg number, in which similar value was recorded for Richard, Gompertz, Logistic and linear models. Exponential model recorded a higher R^2 of (0.93) for egg number in strain A. Also within egg production traits of interest in strain B, body weight also recorded a higher R^2 value of 0.89 each in strain A for Logistic, Richard and Gompertz models, followed by R^2 value of (R^2 = 0.70) in linear model, the least R^2 was (R^2 = 0.84) recorded for body weight in Exponential model. In Strain B also, similar value of (R^2 = 0.70) was recorded for egg number as was the case in strain A. Egg weight was (R^2 = 0.83) for linear models in strain B.

Table 4.8: Traits Comparism within Models for Strain A

Model	Trait	Parametric Estimates					Goodness of Fit		Validation	
		a	b	c	d	f	RMSE	R^2	AIC	AIC Wt
Logistic	BWT	0.09	19.86	2624.96			48.11	0.92	12421.03	1.47
	EGGNO	0.75	3.66	29.04			2.30	0.70	10.37.90	0.19
	EWT	0.13	16.57	63.25			1.21	0.96	48.89	0.13
Richard	BWT	0.02	-2.16.33	4384.30	3341.06	-67.66	47.60	0.93	12395.60	0.75
	EGGNO	1.12	3.82	5.51	25.51	1.03	2.32	0.70	1042.10	0.02
	EWT	0.04	-140.64	81.03	69.31	-1599.26	1.30	0.96	62.77	0.00
Gompertz	BWT	2621.33	0.10	15.64			47.86	0.93	12421.03	0.00
	EGGNO	35.33	0.41	3.37			2.30	0.70	1037.90	0.19
	EWT	64.57	0.11	13.86			1.19	0.96	48.45	0.16
Linear	BWT	592.19	48.72				48.15	0.92	1242.88	1.47
	EGGNO	-4.45	5.17				2.30	0.70	1036.90	0.42
	EWT	12.08	1.40				1.24	0.95	46.09	0.51
Exponential	BWT	3062.09	-3534.24	-0.03			47.59	0.93	12395.58	0.75
	EGGNO	73.70	-81.85	-0.01			47.59	0.93	12395.58	0.75
	EWT	66.52	-145.43	-0.10			1.16	0.96	47.96	0.20

BWT: Body weight, EGGNO: Egg Number, EWT: Egg Weight, RMSE = Root Mean Square Error, R^2 = Coefficient of determination, AIC (Model efficiency) = Akaike Information Criterion, AIC Wt (Model ranking) = Akaike Information Criterion, a= Growth rate, b = Inflection point, c = Asymptote 1, d = Asymptote 2, f = Power

Table 4.9: Traits Comparism within Models for Strain B

Model	Trait	Parametric Estimates					Goodness of Fit		Validation	
		a	b	c	d	f	RMSE	R^2	AIC	AIC Wt
Logistic	BWT	0.13	18.09	2072.48			64.17	0.89	13096.78	8.94
	EGGNO	0.65	3.83	30.91			2.30	0.70	1037.90	0.19
	EWT	0.13	16.38	63.29			2.02	0.84	2782.43	0.00
Richard	BWT	0.02	-74.92	2505.54	2462.66	-21.73	63.15	0.89	13079.45	5.05
	EGGNO	1.70	3.94	9.28	23.11	1.04	2.32	0.70	1037.90	0.19
	EWT	0.01	34.31	67.62	67.62	-10.95	2.00	0.84	2774.05	0.16
Gompertz	BWT	2132.02	0.10	15.05			63.70	0.89	13079.45	5.05
	EGGNO	39.61	0.34	3.64			2.30	0.70	1036.30	0.42
	EWT	64.62	0.10	13.62			2.00	0.84	1776.79	0.04
Linear	BWT	-4.45	5.17				2.30	0.70	1036.90	0.42
	EGGNO	-3.12	4.85				2.30	0.70	1036.30	0.42
	EWT	12.68	1.38				2.06	0.83	2807.04	1.07
Exponential	BWT	2227.35	-4922.58	-0.00			1.99	0.84	2770.79	0.80
	EGGNO	152.37	-156.77	-0.04			2.30	0.70	1037.90	0.42
	EWT	66.59	-139.47	-0.08			1.99	0.84	2770.79	0.80

BWT: Body weight, EGGNO: Egg Number, EWT: Egg Weight, RMSE = Root Mean Square Error, R^2 = Coefficient of determination, AIC (Model efficiency) = Akaike Information Criterion, AIC Wt (Model ranking) = Akaike Information Criterion, a= Growth rate, b = Inflection point, c = Asymptote 1, d = Asymptote 2, f = Power

4.9 Error of Prediction for Linear Regression Model in Strain A and B

Table 4.10 summarizes prediction model for linear model for Strain A and B. The errors of determination for nonlinear models (Richard, Gompertz, Logistic and Exponential) were not determined due to the rigorous computation of higher number of parameters in the models. Error of determination for Strain A had less prediction error ($-8.02x10^{-5}$) compared to Strain B (1.11×10^{-2}) for body weight. This is further depicted in (Figure 4.13) by the good fitting between the body weight and the predicted body weight. Strain B recorded less prediction error ($-5.05x10^{-6}$) for egg number than Strain A ($4.06x10^{-6}$). Similarly, Strain B recorded lesser prediction error ($5.25x10^{-1}$) for egg weight than strain A, which had a larger prediction error (3.56×10^{1}) for egg weight.Figures 4.10, 4.11, 4.12, 4.13, 4.14 and 14.15 gives the graphical representations of the error of prediction for linear model for BWT, EGGNO and EWT in each strain.

Table 4.10: Error of Prediction for Linear Regression model in strain A and B

Traits	Prediction Equation	R^2	RMSE	Error of Prediction
Strain A				
BWT	BWT = 259.198 + 48.717 Week	0.92	47.59	-8.02×10^{-5}
EGGNO	EGGNO = -4.454 + 5.169 Week	0.72	47.59	4.06×10^{-6}
EGGWT	EGGWT = 12. 681 + 1.380	0.83	1.16	3.56×10^{1}
Strain B				
BWT	BWT = 1509.177 + 3.08 Week	0.88	1.99	1.11×10^{-2}
EGGNO	EGGNO = 12.531 + 0.490 Week	0.70	2.30	-5.05×10^{-6}
EGGWT	EGGWT = 51.023 – 0.133 week	0.83	1.99	5.25×10^{-1}

BWT: Body weight, EGGNO: Egg Number, EWT: Egg Weight, RMSE = Root Mean Square Error, R^2 = Coefficient of determination.

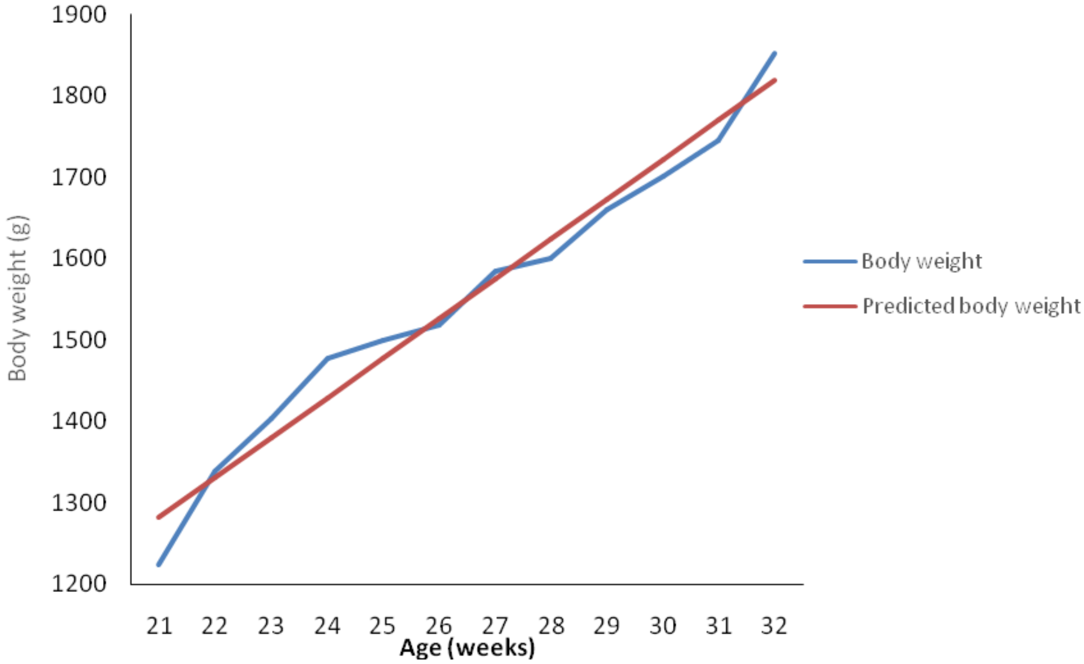

Figure 4.10. Body weight and predicted body weight of Strain A for Linear model

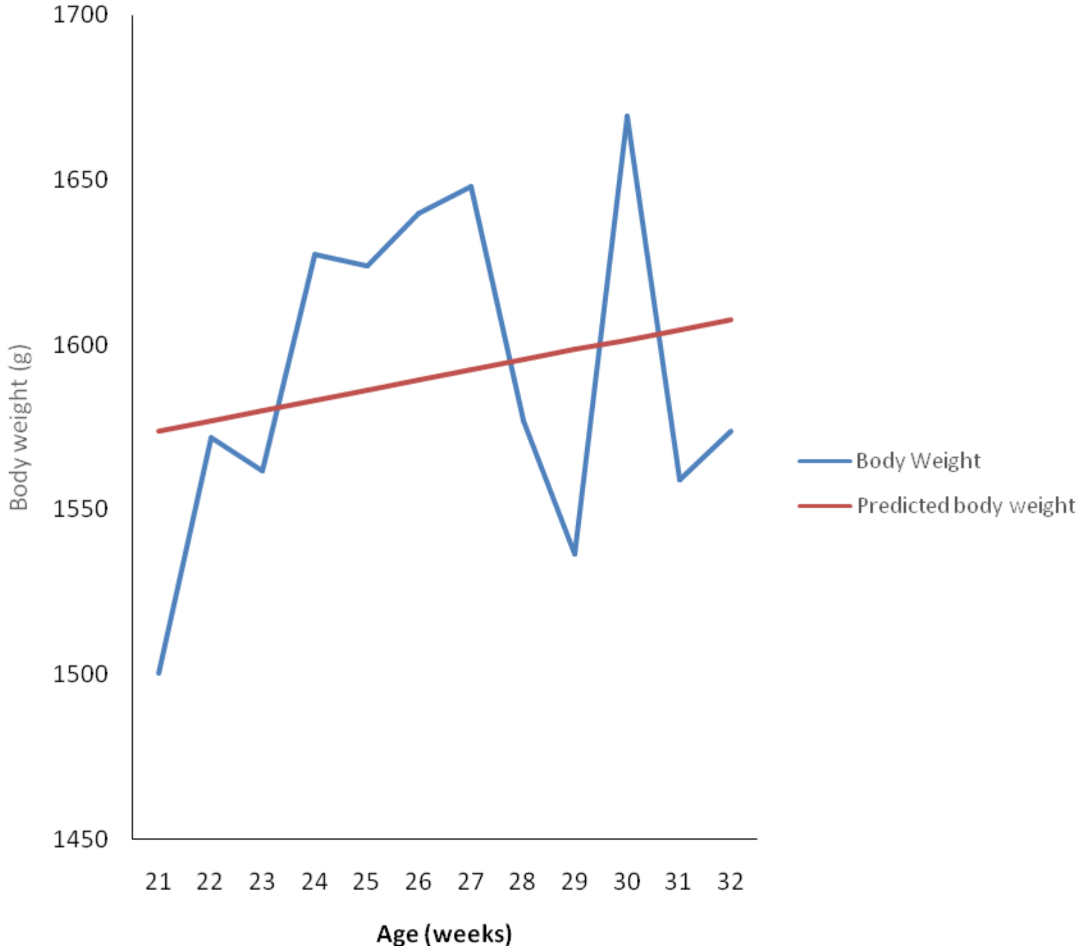

Figure 4.11. Body weight and predicted body weight of Strain B for Linear model

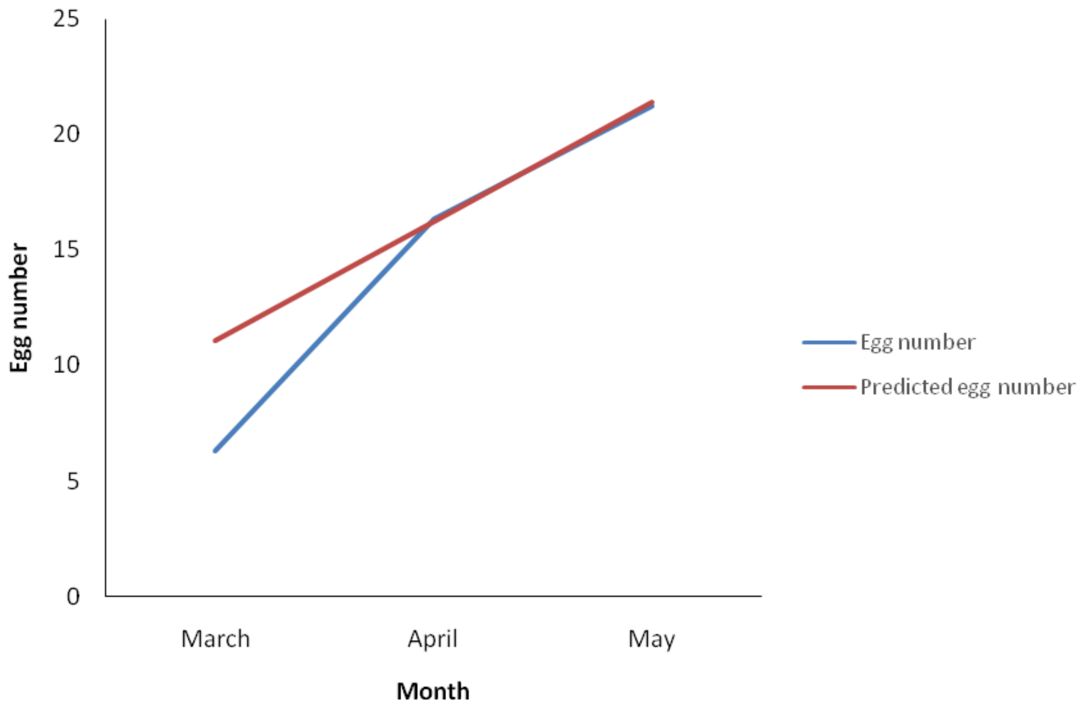

Figure 4.12. Egg Number and predicted egg number of Strain A for Linear model

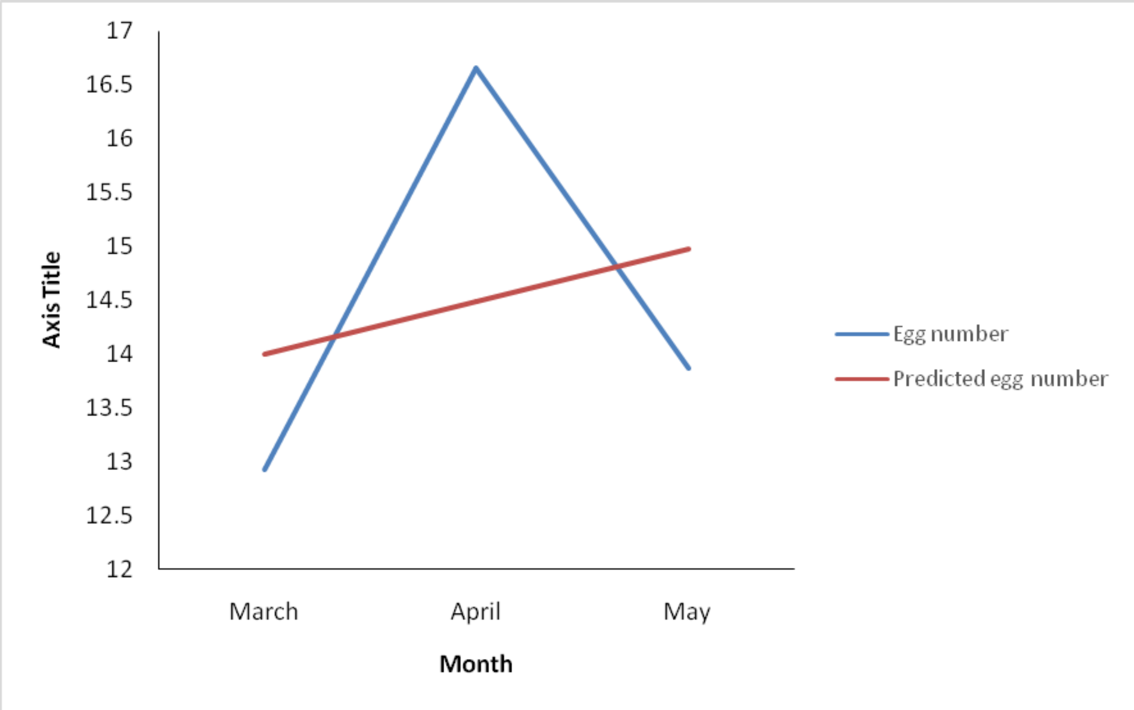

Figure 4.13. Egg Number and predicted egg number of Strain A for Linear model

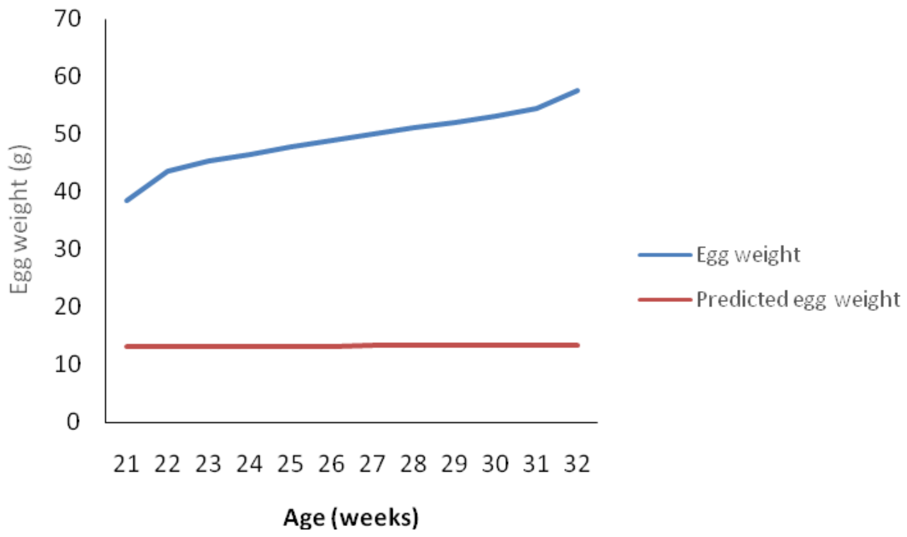

Figure 4.14. Egg weight and predicted Egg weight of Strain A for Linear model

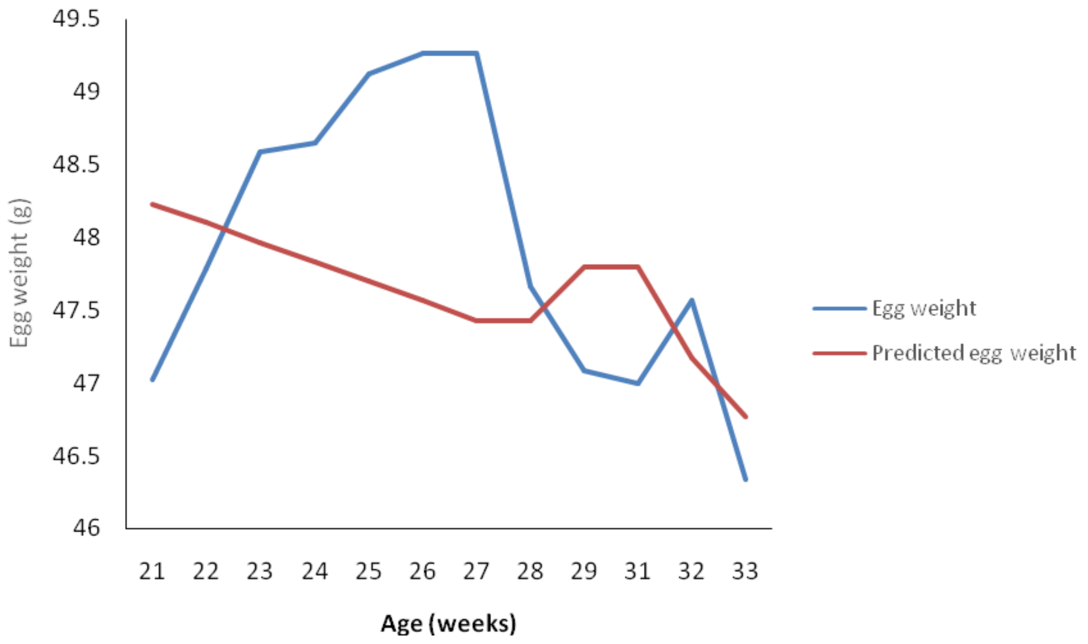

Figure 4.15: Egg weight and predicted egg weight using linear for Strain B

4.10 Performance of Strains for Egg Quality Traits

Table 4.11 shows the least squares means (± standard error) and coefficients of variation for egg quality traits in the two strains of Shikabrown® parent. Among the egg quality traits studied, non-significant differences (P>0.05) were recorded for most of the egg quality parameters (Egg weight, egg width, albumen weight, albumen width, albumen height, yolk weight, yolk height, yolk width, shell thickness, haugh unit, yolk index, and shell weight) respectively in both strains. Variation for egg length was observed among the two strains. Strain B had significantly (P<0.05) longer egg length (5.61±0.06) than strain A (5.44±0.04).

Strain B had higher values compared to Strain A for egg weight (50.00g), egg length (5.61cm), egg width (0.04cm), albumen width (2.22cm), albumen height (0.86cm), haugh unit (120.48) and yolk index (44.71%) respectively, while Strain A recorded higher values in yolk weight (14.80g), yolk width (4.08cm), shell thickness (0.37mm) and shell weight (4.30g), respectively. The two Strains recorded similar values of (29.60) in albumen weight.

Table 4.11: Least Squares Means (±standard error) and Coefficient of Variation for Egg Quality Traits for Strain A and Strain B

	Strain A		Strain B	
Traits	LSM±SE	C.V %	LSM±SE	C.V %
EEQT				
EWT (g)	48.60±0.93	6.10	50.00±1.14	7.18
ELT (mm)	5.44±0.04[b]	2.40	5.61±0.06[a]	3.39
EWD (mm)	3.98±0.03	2.51	4.04±0.03	2.48
SHT (mm)	0.37±0.10	48.65	0.29±0.02	34.48
SHWT (g)	4.30±0.33	24.65	4.10±0.20	5.01
IEQT				
AWT (g)	29.60±1.7	18.38	29.60±0.73	7.84
AWD (mm)	1.84±0.10	12.50	2.22±0.28	39.19
AHT (cm)	0.73±0.03	12.33	0.86±0.11	40.70
YWT (g)	14.80±0.55	11.82	13.80±0.42	9.57
YHT (cm)	1.53±0.11	23.53	1.57±0.03	6.37
YWD (mm)	4.08±0.55	42.89	3.52±0.11	7.95
YIDX (%)	42.76±6.48	47.92	44.71±0.03	0.83
H-U (%)	118.13±4.26	11.39	120.48±0.77	21.46

Traits: EEQT= External Egg Quality Traits: EWT = Egg Weight: ELT = Egg Length: EWD = Egg Width: IEQT = Internal Egg Quality Traits: AWT = Albumen Weight: AWD = Albumen Width: AHT = Albumen Height: YWT = Yolk Weight: YHT= Yolk Height: YWD= Yolk Width: SHT = Shell Thickness: H-U = H-unit: YIDX = Yolk Index: SHWT = Shell Weight. C.V= Coefficient of Variation. LSM- Least Squares Mean, SE–Standard Error Means with different superscripts on the same row are significantly different ($P<0.05$).

4.11 Principal Component Analysis for Egg quality Traits in Strain A

The principal component analysis for egg quality traits in Strain A are shown in Table 4.12. PC1 loaded for SHWT (0.61), AHT (0.75), YHT (0.93), YIDX (0.82) and H-U (0.88). PC1 had more loadings for internal egg quality traits and the values are significantly higher than the only external egg quality trait (SHWT) recorded. PC1 is termed as internal egg quality trait component. PC2 had significant loadings on four variables: EWT (0.81), ELT (0.72), EWD (0.51) and SHT (0.63). PC2 is termed as External egg quality trait component. PC3 loaded for YWT (0.65) and YWD (0.70) respectively. It is termed as Yolk component. PC4 loaded for AWD (0.49) and is termed as Albumin component. The percentage variance generated for strain A was 83.10 %.

Table 4.12: Eigenvalues and Share of Total Variance Along with Factor Loadings and Communalities of Egg quality Traits of strain A

Trait	PC1	PC2	PC3	PC4	Communality
EWT (g)	0.41	**0.81**	-0.11	-0.18	0.74
ELT (mm)	-0.07	**0.72**	0.07	-0.48	0.81
EWD (mm)	0.55	**0.57**	-0.00	0.09	0.90
SHT(mm)	0.21	**0.63**	-0.01	0.54	0.68
SHWT (g)	**0.61**	-0.42	-0.51	-0.16	0.86
AWT (g)	0.24	0.21	0.35	-0.71	0.79
AWD (mm)	-0.32	0.47	-0.32	**0.49**	0.75
AHT (cm)	**0.75**	-0.04	-0.04	-0.18	0.64
YWT (g)	0.47	-0.47	**0.65**	0.22	0.83
YHT (cm)	**0.93**	0.04	0.26	0.17	0.81
YWD (mm)	-0.39	0.26	**0.70**	0.15	0.75
YIDX (%)	**0.82**	-0.05	-0.47	0.06	0.74
H-U	**0.88**	-0.12	0.36	0.21	0.72
Eigenvalue	4.32	2.64	0.84	0.51	
%Variance	43.2	26.4	8.4	5.1	

Trait: EWT: Egg weight, ELT: Egg length, EWD: Egg width, AWT: Albumen weight, AWD: Albumen width, AHT: Albumen height, YHT: Yolk height, YWD: Yolk width, SHT: Shell thickness, H-U: Haugh unit, YIDX, Yolk index, SHWT: Shell weight.

4.12 Principal Component Analysis for Egg Quality Traits in Strain B

Principal component analysis for Strain B is shown in Table 4.13. Four components were mathematically generated, out of which PC1 (54.50%), PC2 (28.00%), PC3 (1.14 %) and PC4 (0.9%). The percentage variance generated in Strain B was 84.54 %. In Strain B, PC1 is seen as the mass and length component. PC1 contained external and internal egg quality traits. It loaded for EWT (0.96), ELT (0.69), EWD (0.79), AWT (0.81), YWT (0.85 and YWD (0.82). PC2 had loadings for SHT (0.57), AWD (0.68), YHT (0.66), YINDX (0.66) and H-U (0.71). PC2 loaded significantly more for internal egg quality traits than the only external egg quality trait generated, SHT (0.57). PC3 loaded for AHT (0.63) only and can be termed as Albumin component. PC4 only loaded for SHWT (0.71). Communality ranged from 0.64-0.86 for all the measured traits.

Table 4.13: Eigenvalues and Share of Total Variance Along with Factor Loadings and Communalities of Egg Quality Traits of Strain B

Trait	PC1	PC2	PC3	PC4	Communality
EWT (g)	**0.96**	-0.04	0.24	-0.01	0.83
ELT (mm)	**0.69**	-0.43	0.14	0.27	0.87
EWD (mm)	**0.79**	0.31	0.31	-0.32	0.89
SHT(mm)	-0.69	**0.57**	0.04	0.12	0.77
SHWT (g)	0.05	0.52	0.27	**0.71**	0.85
AWT (g)	**0.81**	-0.15	0.39	0.23	0.83
AWD (mm)	0.20	**0.68**	0.62	-0.13	0.80
AHT (cm)	0.03	-0.06	**0.63**	-0.63	0.92
YWT (g)	**0.85**	0.22	0.13	0.29	0.85
YHT (cm)	0.55	**0.66**	-0.48	-0.15	0.93
YWD (mm)	**0.82**	0.08	-0.54	-0.10	0.74
YIDX	-0.65	**0.66**	0.32	0.03	0.89
H-U	0.38	**0.71**	-0.56	-0.15	0.82
Eigenvalue	5.45	2.80	2.14	1.29	
%Variance	54.50	28.00	1.14	0.9	

Trait: EWT: Egg weight, ELT: Egg length, EWD: Egg width, AWT: Albumen weight, AWD: Albumen width, AHT: Albumen height, YHT: Yolk height, YWD: Yolk width, SHT: Shell thickness, Hu: Haugh unit, YIDX, Yolk index, SHWT: Shell weight.

4.13 Phenotypic Correlation among External and Internal Egg Quality Traits in Strain A

The phenotypic correlation among quality traits for Strain A is shown in Table 4.14. Most of the external egg quality traits had high and positive phenotypic correlation with egg weight. The correlation coefficients obtained were (r_p =0.60, 0.66 and 0.48; $P<0.05$) for the relationships between egg weight and egg length, egg width and shell thickness, respectively. Similarly, phenotypic correlation obtained between egg weight and yolk weight is moderately low (r_p = -0.30; $P<0.05$), positively low with albumen weight (r_p = 0.23; $P<0.05$).

The phenotypic relationships between albumen weight and all other internal egg quality traits were mostly low. Albumen weight of Strain A was lowly and negatively correlated with yolk weight (r_p =-0.02; $P>0.05$), yolk width (r_p =0.03; $P>0.05$) and haugh unit (r_p =0.23; $P<0.05$). Negative and high phenotypic correlation was obtained in the relationship between albumen weight and albumen width (r_p = -0.42; $P<0.05$). Haugh unit was highly correlated (r_p =0.61; $P<0.05$) with albumen height.

Table 4.14: Phenotypic correlation matrix of egg quality traits for strain A

Traits	EWT	ELT	EWD	SHT	SHWT	AWT	AWD	AHT	YWT	YHT	YWD	YIDX	H-U
EWT (g)													
ELT (cm)	0.60**												
EWD (cm)	0.66**	0.22*											
SHT(mm)	0.48**	0.11	0.52**										
SHWT (g)	0.04	-0.33*	0.26*	-0.32*									
AWT (g)	0.23*	0.36*	0.18	-0.12	-0.11								
AWD (cm)	0.11	0.23*	-0.01	0.28*	-0.33*	-0.42*							
AHT (cm)	0.37*	0.16	0.18	-0.08	0.56**	0.09	-0.16						
YWT (g)	-0.30*	-0.31*	0.01	-0.09	0.13	-0.02	-0.49*	0.36*					
YHT (cm)	0.33*	-0.10	0.50**	0.29*	0.35*	0.26*	-0.22	0.66**	0.60**				
YWD (cm)	0.01	0.17	0.03	-0.06	-0.58*	0.03	0.24*	-0.24*	0.15	-0.14			
YIDX	0.27*	-0.16	0.37*	0.14	0.68**	0.09	0.01	0.56**	0.07	0.70**	-0.66**		
H-U	0.25*	-0.14	0.41*	0.26*	0.27*	0.23*	-0.24*	0.61*	0.68**	1.00**	-0.08	0.63**	

*Traits: EWT: Egg weight, ELT: Egg length, EWD: Egg width, AWT: Albumen height, YWT: Yolk weight, YHT: Yolk width, SHT: Shell thickness, H-U: Haugh unit, YIDX: Yolk index, SHWT: Shell weight. (*P< = 0.05, **P< = 0.01)

4.14 Phenotypic Correlation among External and Internal Egg Quality traits in Strain B

Table 4.15 shows the phenotypic (r_p) correlation among quality traits for internal and external egg quality trait of strain B. High coefficient of correlations were recorded for most external egg quality traits. Egg weight is highly (P<0.05) correlated with egg length (r_p = 0.69; P<0.05) and egg width (r_p = 0.80; P<0.05). Conversely, high and negative phenotypic correlation is obtained between egg weight and shell thickness (r_p = -0.71; P<0.05). A lowly correlation coefficient is obtained between egg weight and shell weight. Similarly, egg weight with other internal egg qualities (r_p = 0.82, 0.87 and 0.66; P<0.05) were obtained for the relationships with yolk weight, albumen weight and yolk width, respectively.

Phenotypic correlation obtained between albumen weight is significantly (P<0.05) correlated (r_p = 0.77; 0.41; P<0.05) with yolk weight and yolk width. High and negative relationship between albumen weight and shell thickness and yolk index as (r_p =-0.62; -0.49; P<0.05) respectively. A low and negative correlation (r_p = -0.09; P>0.05) existed between albumen weight and haugh unit. Low and positive correlations were obtained between albumen weight and (r_p = 0.01; 0.09, 0.13; P<0.05), respectively.

Table 4.15: Phenotypic correlation matrix of egg quality traits for strain B

Traits	EWT	ELT	EWD	SHT	SHWT	AWT	AWD	AHT	YWT	YHT	YWD	YIDX	H-U
EWT (g)													
ELT (cm)	0.69**												
EWD (cm)	0.80**	0.33*											
SHT(mm)	0.87**	0.62**	0.68**										
SHWT (g)	0.30*	-0.14	0.58**	0.34*									
AWT (g)	0.23*	0.12	0.32*	0.01	0.38*								
AWD (cm)	0.82**	0.52**	0.77**	0.77**	0.29*	-0.14							
AHT (cm)	0.39*	0.02	0.51**	0.09	0.28*	-0.18	0.48*						
YWT (g)	0.66**	0.46*	0.51**	0.41**	-0.08	-0.22*	0.56**	0.78*					
YHT (cm)	-0.71*	-0.57*	-0.33*	-0.62*	0.24*	-0.11	-0.40*	-0.06	-0.55*				
YWD (cm)	0.21*	-0.12	0.36*	-0.09	0.23*	-0.24*	0.33*	0.98**	0.70**	0.09			
YIDX	-0.57*	0.72**	-0.21*	-0.49*	0.48*	0.10	-0.31*	-0.09	-0.68*	0.82**	0.03		
H-U	0.11	0.12	-0.05	0.13	0.42*	-0.13	0.31*	0.17	-0.10	0.30*	0.18	0.40*	

Traits: EWT: Egg weight, ELT: Egg length, EWD: Egg width, AWT: Albumen height, YWT: Yolk weight, YHT: Yolk width, SHT: Shell thickness, H-U: Haugh unit, YIDX: Yolk index, SHWT: Shell weight. (*P< = 0.05, **P< = 0.01)

4.15 Estimates of Heritability of Production Traits in Strain A and B

The heritability estimate for production traits in Strain A and B is shown in Table 4.17. The highest (h^2=0.65 ± 0.08) and lowest (h^2=0.10 ± 0.01) estimate of heritability were obtained in Strain A for egg number and body weight respectively. Heritability estimate for ASM was moderately higher (h^2=0.48 ± 0.24) in strain A than Strain B (h^2=0.18 ± 0.03). Similar trend was observed for egg weight in Strain A (h^2=0.34 ± 0.15) and (h^2=0.28 ± 0.34) for strain B respectively.

Table 4.17: Heritability Estimates of production traits in Strain A and B

Traits	Strain A	Strain B
BWT	0.65 ± 0.08	0.44 ± 0.15
ASM	0.48 ± 0.24	0.18 ± 0.03
EGGNO	0.10± 0.01	0.45 ± 0.25
EWT	0.34 ± 0.15	0.28± 0.34

Traits: EGGNO = Egg Number: EWT = Egg Weight: ASM = Age at Sexual Maturity: BWT = Body weight.

4.16 Genotypic (r_g) and Phenotypic (r_p) Correlation Coefficients for Egg Production Traits in Strain A

Table 4.18 shows the genotypic (r_g) and phenotypic (r_p) correlation coefficients for egg production traits in Atrain A. Genotypic correlations in Strain A for ASM was highly positive (r_g= 0.87)and correlated with BWT. However, a high negative genotypic correlations were obtained between ASM and EGGNO (r_g= -0.93), EGGNO and EWT (r_g= -0.85). A lowly but positive genotypic correlations were recorded between BWT and EGGNO (r_g= 0.01) and between EWT and ASM (r_g= 0.23) respectively. Correlation between EWT and BWT was not available.

Significant ($P<0.05$) differences were recorded more in phenotypic correlations of Strain A. High and positive phenotypic (r_p) correlations were obtained (r_p= 0.88; 0.88, 0.43; $P<0.05$) between BWT and EWT, ASM and EGGNO and between BWT and ASM, respectively. Moderate and negative phenotypic correlation (r_g= -0.36; $P<0.05$) was obtained between BWT and EGGNO. Lowly but negative phenotypic correlations (r_p = -0.10; -0.05) were obtained between ASM and EWT and between EGGNO and EWT respectively.

Table 4.18: Genotypic (lower diagonal) and Phenotypic (upper diagonal) Correlation Coefficients of Production Traits in Strain A

Traits	BWT	ASM	EGGNO	EWT
BWT		0.43*	-0.36*	0.88*
ASM	0.87*		0.88*	-0.10
EGGNO	0.01	-0.93*		-0.05
EWT	NE	0.23	-0.85*	

Traits: ASM: Age at Sexual Maturity, BWT: Body weight, EGGNO: Egg number, EWT: Egg weight.NE: Not Estimable,(*P< 0.05).

4.17 Genotypic(r_g) and Phenotypic (r_p) Correlation Coefficients for Egg Production Traits in Strain B

Table 4.19 shows the genotypic (r_g) and phenotypic (r_p) correlation of production traits in strain B. Positive significant ($P<0.05$) difference were recorded between EWT and BWT (r_g=0.88), between EGGNO and ASM (r_g=0.88; $P<0.05$) and between ASM and BWT (r_g=0.43; $P<0.05$). Moderate but negative genotypic correlation was obtained between EGGNO and BWT (r_g=-0.36; $P<0.05$). Lowly and negative genotypic correlations were obtained (r_g=-0.10; -0.05; $P>0.05$) between EWT and ASM and between EWT and EGGNO respectively. No significant phenotypic (r_g) correlations were obtained for strain B. lowly associations were obtained (r_g= 0.02; 0.03; 0.04; 0.03; 0.08; 0.03 $P>0.05$) between BWT and ASM, BWT and EGGNO, BWT and EWT, ASM and EGGNO, ASM and EWT, and between EGGNO and EWT, respectively.

Table 4.19: Genotypic (lower diagonal) and Phenotypic (upper diagonal) Correlation Coefficients of Production traits in Strain B

Traits	BWT	ASM	EGGNO	EWT
BWT		0.02	0.03	0.04
ASM	0.43*		0.03	0.08
EGGNO	-0.36*	0.88*		0.03
EWT	0.88*	-0.10	-0.05	

Traits: ASM: Age at Sexual Maturity, BWT: Body weight, EGGNO: Egg number, EWT: Egg weight, (*P< 0.05).

4.18 Genotypic Correlations (r_g) for Production Traits in both Strains

Data for genotypic correlations between production traits is shown in Table 4.20 for both Strains. A high negative genotypic correlation existed among most of the production traits. The negative associations were obtained (r_g = -0.63; -0.37; -0.27; P<0.05) between EGGNO and ASM, BWT and ASM and between ASM and EWT, respectively. Moderately positive genotypic correlation was obtained between BWT and EWT (r_g = 0.45; P<0.05). A lowly but negative correlation was obtained between BWT and EGGNO (r_g = -0.11; P>0.05).

Table 4.20: Genotypic Correlation Coefficients of Production Traits in strain A and B

Traits	BWT	ASM	EGGNO	EWT
BWT		-0.35*	-0.11	0.45*
ASM			-0.63*	-0.27*
EGGNO				NE
EWT				

Traits: ASM: Age at Sexual Maturity, BWT: Body weight, EGGNO: Egg number, EWT: Egg weight, NE: Not Estimable (*P< 0.05).

4.19 Prediction Equation of Egg Weight using External Egg Quality Traits

The equation below shows prediction equation for weight of Shikabrown® eggs using external egg quality traits. Egg weight was determined with a high precision of 70% accuracy at using easy to measure external egg traits quality; egg length and egg width, without breaking the egg.

Prediction equation: **Egg weight = 68.997 + 7.990 egg length +18.491 egg width. Adjusted R^2 is 0.701.**

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Egg Production Traits of Shikabrown® Layers

Differences in age at sexual maturity are subject to genetic variation (Agaviezor *et al.*, 2011). However it is not clear whether age at sexual maturity is inherited independently of body size (Agaviezor *et al.*, 2011).Variation observed in age at sexual maturity, ASM which is higher in strain A (158 days) as compared to strain B (154 days), could be as a result of different body weight at maturity of the strains considered. Similarly, Sowunmi *et al*. (1998) reported that the body weight at first egg depends to a large extent upon age. Those that mature when relatively young weigh less than those that do not begin laying until they are older.

Heritability estimate of age at sexual maturity was high in Strain A (0.48±0.24) and low in Strain B. This differed with the result reported by Oni *et al*. (2007) on the same Strains. This confirms the line breeding of Strain A which was biased for high body weight. ASM is positively correlated with BWT. Heritability estimates were generally low to moderate. This indicates that intensity of production is low. This also signifies that the higher the ASM, the higher the heritability estimates, as evidenced in Strain A of the present study. This finding agrees with the results of (Wolc *et al*., 2011 and Orunmuyi 2007). The heritability estimates for partial egg production in the present study for both Strains at 22 weeks were similar to those found by Wei and Van der Werf (1995) and Anang *et al*. (2000a), which were between 0.41 to 0.49 (from 18 and 25 wk of age); 0.18 to 0.49 (between 18 and 65 wk of age) respectively. Sabri *et al*. (1999) reported heritability estimates of 0.27 at 26 weeks of age, which were lower than in the present result, probably due to the different methodologies used to estimate the genetic parameters.

Age at sexual maturity was negatively correlated with egg number and egg weight (-0.63) and (-0.27) respectively. The negative correlations between ASM and egg number and egg weight observed in the present study indicates that if selection is used to increase ASM, then there will be negative selection for egg number and egg weight. This was also reported by Hazary *et al.* (1991), that there is a negative genetic change in age at sexual maturity (-2.40 days) after seven generations of selection on egg mass. Johari *et al*. (1988) had also reported negative correlation between egg number and ASM. Low and high estimates of heritabilities for ASM have been reported in literature. Ideta and Siegel (1966) reported a low value (0.19), while Chen and Tixier-Boichard (2003) reported high values of (0.53-0.56) in laying hens. Low to moderate values were reported by Oni *et al*. (2007). Moderate values were also reported by Ferdoci *et al*. (1992) and by Koerhuis and McKay (1996) in juvenile body weight in broiler chickens. Nema and Johari (1990) reported heritability of 0.31 in selected line and 0.37 in control line of White Leghorns while Chen and Tixier-Boichard (2003) reported a range of (0.53 to 0.56) in Dwarf Brown egg layers. Ferdoci *et al.* (1992) reported a value of 0.37±0.153 also in White Leghorn since age at sexual maturity range from moderate to high heritability estimates. In this study, positive and high phenotypic correlation between BWT and ASM was significantly high (r_p=0.43). It is numerically lower to the result obtained by (Agaviezor *et al.*, 2011) who observed a strong, significant and positive phenotypic relationship between body weight at first egg and egg weight in the local hen (r_p = 0.76). These results suggest that selection for increased body weight in the chicken will result in increase in egg size and egg internal quality traits. Genotypic correlations of ASM and EGGNO was high and negative (r_g=-0.63). The result was similar to the findings of Okuda *et al.* (2014). This indicates that the longer it takes the hens to lay, the lower the number of eggs will be laid. Similarly, negative genotypic correlation existed between EWT and EGGNO (r_p=-0.35) and between EWT and ASM (r_p=-0.27). Trend obtained in this study was similar to the pattern obtained by Minvielle, (1998), Mielenz *et al.* (2004) and Abdel-Mounsef (2005) who reported low to high but negative relationship between egg weight, ASM and body weight.

In this present study, individual egg production was expressed in 28-day period from the day the birds laid the first egg because summation of egg production data by Strain was free of the influence of sexual maturity (Oni, 1997). Strain B had the highest body weight (1.59±0.01 Kg) and Strain A had the highest egg weight (48.75±0.17Kg). Generally, body weight increased with age of the birds in both Strain A and Strain B (Crawford, 1990; Hossain and Ahmed, 1993; Ebangi and Ibe, 1994 and Giordani *et al.*, 1992) as they all reported differences in growth rate of chickens as a result of genotype and age. Similarly, increase in body weight of each Strain as they advanced in age, in this study is due to growth and physiological development (Ojedapo *et al*., 2008 and Pingel *et al.,* 1990). Omeje and Nwosu (1986) opined that these relationships could be utilized in the genetic improvement of growth through selection. The trends of egg weight and egg number of the two Strains at different laying weeks as presented in Figures 4.2 and 4.3, respectively. The rise and fall in egg weight followed the trend observed for body weight. Such effects could be attributed to climatic effects, heat stress, as well as, on the health and feed consumption of layers (Hani *et al*., 2011).

Variation exists in the egg number for the months under study (March, April and May). Strain B laid more eggs per bird in the month of March than strain A (Figure 4.3). Both Strains lay almost equally in the month of April. Strain A lay better than Strain B in the month of May. This is consistent with reports of Ojedapo *et al*., 2008 and Bateman *et al.*, 2003. Similarly, egg weight was highest in Strain A (48.75 g), than in Strain B (47.92 g). Also, as observed in this study in Figure 4.2, the trend agreed with the observations of De Ketelaere *et al*. (2002) that egg weight in chicken increases with increase in age of laying birds.

5.2 Egg Production Performance of Shikabrown® Parent Using Models

The growth curves of the Shikabrown® parent as presented by the models for both Strains indicted that goodness of fit criteria was generally high for most of the models (R^2= 0.84 - 0.96) for BWT and EWT. This result is within the range reported by Narinc *et al*. (2010), who reported higher R^2 values of (R^2= 0.98 - 0.99) and also Darmani Kuhi*et al.* (2003), who also reported a range of ($R^{2\,=}$ 98.87 - 99.99%) in chicken. The high R^2 values in the present study indicate that the models adequately described the observed Shikabrown® data on egg production traits. Forni *et al*., (2008) observed that model goodness of fit is generally evaluated by using Root Mean Square Error and Coefficient of Determination.

The effect of Strain on model parameter showed that the constant ‘a’ (growth rate/maximum potential for egg production per strain) for EGGNO was significantly ($P<0.05$) higher (152.37) for Strain B (dam line) in Exponential model than (73.70) for Strain A (sire line). This agrees with the report of (Oni, 1997), who reported maximum egg per period for Strain B as selection to improve number of eggs is concentrated on the female line, while the emphasis on the male line is to improve BWT and EWT. This is further revealed in (Figure 4.10) by body weight and predicted body weight of linear model in Strain A of this present study. Also strain B recorded less prediction error ($-5.05x10^{-6}$) for egg number than Strain A ($4.06x10^{-6}$).

The high coefficient of determination obtained from Richard and Gompertz, agrees with the results of these writers (Aggrey 2002; Anthony *et al*., 1991 and Ricklefs, 1985). The Richard and Gompertz models have been shown to give good descriptions of growth in species such as cattle, chicken, ostrich, turkey, quails and emus (Ersoy *et al*., 2005). The

Gompertz growth model has been cited as the model of choice for chicken data based on its overall fit and biological meaning of model parameters. In addition, it has good fitting for weight information whose inflection points occur, when approximately 35-40% of growth has been achieved (Braccini, 1993). This is in agreement with the findings of Narushin and Takma (2003). They reported Gompertz and Richards models as the best models to predict growth patterns. In this study, the Richards equation provided a better fit than the Gompertz equation. This is in agreement with the report by Faridi *et al*. (2011) and Darmani Kuhi *et al*. (2003), they found Richards equation to be a better model for describing growth data in broilers than the Gompertz equation. This could be due to the higher number of model parameters in Richard model: which has five (5) model parameters than in Gompertz which has three (3) model parameters.

As far as the goodness of fit is concerned, the best value (the lowest) of the AIC gives the closest representation of data (Marc, 2007). However, the suitability of the model for egg production curves depends not only on its general goodness of fits but also on the ability of describing the asymptotic phase of the curve (Macciotta *et al*., 2011). In this study, the asymptotic phases were recorded for Richard, logistic, Gompertz and Exponential models except for linear model. Brown *et al*. (1976) had earlier reported that 'a' parameter values offer the best opportunity to make direct comparisons among models. Comparisons of asymptotic weight obtained with the different models showed as earlier stated that Exponential model had the highest value (3062.09) followed by Gompertz (2621.33), Linear (592.19), Logistic (0.09) and then Richard model (0.02). This is in agreement with the report of Kucuk and Eyduran (2009) that compared Monomolecular, Gompertz and Logistic models and ranked the Monomolecular first and Logistic last in terms of asymptote body weight. However the result contrasted with the results reported by Aggrey (2002), who ranked the Richards ahead of Gompertz and

Logistic. Narinc *et al.* (2010) ranked Gompertz first, Richards next and Logistic last. Similar R^2 value of (0.70) obtained for egg number (Tables 4.6 and 4.7); a reproductive trait, in almost all the models used for the two strains suggests that the Strains had similar age at sexual maturity as buttressed in this study. This also implies that the birds' genetic potential can be further exploited for more genetic gain. The estimation and analysis of the asymptotic weight is essential and project the flock efficiency, as underweight animals have delayed onset of sexual maturity and tend to lay fewer eggs (Kirikci *et al*., 2007).

5.3 Error of Prediction by Linear Regression Model

A two-parameter, linear model represents a simple approach, compared with complex nonlinear models with four to six parameters. The predictive ability of linear model for egg production traits in both Strains were illustrated in Figures (4.10, 4.11, 4.12, 4.13, 4.14, and 4.15). These figures portrayed various characteristics of egg production traits as affected by the errors of prediction. Farooq *et al.* (2002) demonstrated that reliability of prediction equations could be increased and errors of prediction could be reduced through increasing sample size. Haruna *et al.* (2007) reported that prediction of the whole egg production from part of records can be maximized by a careful analysis of appropriate data.

McMillan *et al.* (1986) considered the importance of another criterion, the prediction ability, in judging different models. In the present study, linear model was fitted to BWT, EGGNO and EWT records from 21 to 32 week of age which is the age for early selection in layers (Yang *et al*., 1989). Predicted and observed estimate for egg production traits considered errors of predictions are given in Table 4.12. The results suggest that both the model has fairly good ability to predict. The fitted curve from BWT records showed a good fitting and could also characterize the whole process of body weight in Strain A. This is in line with the earlier report of Oni (1997), who observed that selection in strain A is emphasized on body weight. For EGGNO (12.531; -5.05×10^{-6}) and EWT (51.023; 5.25×10^{-1}) in strain B, the strain had the least errors in prediction, and predicted estimates were smaller than the actual values. This is similar to the results of Oni (1997) and McMillan *et al.* (1986). McMillan *et al.* (1986) fitted data for predicted and error of prediction for egg number from week 21 to 35 and recorded (239.15; -5.37) and from week 21 to 40 and recorded (243.32; -1.20).

5.4 Internal and External Egg Quality Traits in Both Strains

Egg quality traits were similar for most of the internal and external quality parameters and the differences among the Strains were not significant (P>0.05).Values obtained for egg weight in the present study were between (48.60g) for strain A and (50.00g) for strain B. The value is within the range obtained by (Abeke *et al*., 2008) as (51.35g) and Orunmuyi (2007) as (54.39g) from same Shikabrown® layers. The value obtain is numerically lower than 63g, 58.71g, 58.00g and 58.06g reported by (Zhang *et al*., 2005; Nwagu *et al*., 2010; Shafey 2002; and Kabir *et al*., 2014) in Atak, Anak, Hubbard and Ross breeds. Egg weight values is in agreement with the value of 46.6-49 g recorded by Aganga *et al*., (2003) in Tswana laying chickens and Abeke *et al.* (2008) in Rhode Island in NAPRI-X chickens. Egg length in Strain A had higher LSMSE (5.61±0.5 cm) than in strain B (5.44±0.5 cm). Egg length obtained in this study is within the range of value (5.46±0.04 cm) obtained by Nwagu *et al*. (2010) in Hubbard breed. Egg length is a good estimator of Egg weight Obike *et al*. (2012). This indicates that Egg weight in strain A can be improved phenotypically through selection. Coefficient of variation of egg quality traits ranged between 6.1-7.18 %. This was similar to the value reported by (Shafey, 2002) in meat-type breeder flock (Ross) as 2.58-6.96 % and Adelaja (2012) to be 5.0-8.49 % in Japanese quail eggs. This implies that the distribution is homogenous and further shows the phylogenetically relationship of Japanese quail to the chicken (Stock and Bunch, 1982). Egg length ranged between 5.44 – 5.61cm in this study and is higher compared to the findings (4.12- 4.16 cm) of Kabir *et al*. (2014) in Isa Brown and Nera Black respectively. The range agrees with the report of Zhang *et al*. (2005). Egg width ranged between 3.98±0.03-4.04±0.03 cm in the present study. This does not agree with the report of Kabir *et al*., (2014), who reported lower range of (2.92±0.04-2.86±0.04) in Isa Brown and Nera Black respectively. A value of 29.60 g was recorded for Albumen weight in both Strains. This value is however low compared to the values of (36.46 g) reported by Kabir *et al*. (2014), Zhang *et al.* (2005) as (32.02 g) and the range (30.63-40.53 g) by (Shafey, 2002). Albumen width and height were found to be (1.84-2.22) and (0.73-0.86) cm in strain A and B respectively. Yolk weight value is 14.80 g; this value is within the range report of Kabir *et al.* (2014) as 12.26-15.60 g the value 14.77 g reported by Zhang *et al*., (2005) in quails. The yolk weight value contrasted with the range by (Shafey, 2002) to be 15-44-20.76 g and 5.06 g by Punya *et al*. (2008) in quails. Yolk height value of (1.52-1.57) cm recorded it contrasted the value of (1.86-1.62) cm in Isa Brown and Nera Black as reported by Kabir *et al*. (2014). A range of 118-120 was recorded for Haugh unit. This range is obviously higher compared to the range reported by these authors (Punya *et al*., 2008; Kabir *et al*., 2014; Zhang *et al*., 2005). The most widely used methods for internal egg quality measurement are albumen pH and Haugh Units (HU) (Haugh, 1937). Two most valuable external traits in egg are shell thickness and shell weight. In this study, they were found to be 0.37 mm and 4.30 g respectively. These values are however low compared to 0.44 mm, 5.40g reported by (Kabir *et al*., 2014) and 0.21 mm and 1.23 g by Punya *et al*. (2008), 0.34 mm, 7.07g by Zhang *et al*. (2005).

The least-squares means for various internal egg quality traits and indices observed in the present study agreed well with those reported by (Oroian *et al.,* 2002; Kul and Seker, 2004), but were higher than those of Chaudhary *et al*. (1999), Nazligul *et al.* (2001) and Dhaliwal *et al.* (2003), while, Altinel *et al.* (1996) noticed higher means for yolk index and Haugh unit score in similar studies.

5.5 Principal Component Analysis in Both Strains

Result of Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy (0.688) showed the suitability of the data for factor analysis. Also, result from Bartlett's test of Sphericity with Chi-square = 697.893 and 28 degree of freedom confirmed the feasibility of factor analysis application on the data. Pearson correlations among factor score variables; FS1, FS2 and FS3 were zero (r = 0.000) as statistically expected.

Four principal components (PC1, PC2, PC3 and PC4) were extracted for which strain A contributed 83.10 % of the total variance and 84.54% in strain B respectively. Four principal components (PC1-PC4) were seen to explain most of the variation in the data set for the two strains because they attended the Kaiser criterion when eigenvalues were higher than one (Kaiser, 1958). The result obtained is in agreement with the findings of Savegnago *et al*. (2011) who recorded four informative components. In this study, first four principal components explained the additive variance in Strains A and B respectively, which is higher than the value (80.04 %) reported by Savegnago *et al*. (2011), and Oseni, (2014), who reported 78.10 % of total variation in heterogeneous rabbit breeds. Yakubu and Ayoade (2009) reported a higher percentage variance (97 %) in broiler chickens.

Lin *et al.* (2004) performed PCA to give an overview of the multidimensional data in egg weight, shell length and width. They reported that the first two components explained 80% of the total variation. This study is justified as the first two components in Strain B explained 82.59 % variance. PCA applied to this study was to determine the most explanatory variables of total variance recorded in accordance to the variation of the two strains vis-a-vis their concomitant components.

In Strain A, Shell weight, Albumen height, Yolk height, Yolk index, and Haugh unit were associated with the first PC. The first PC was termed internal egg quality trait component because it pulled more internal egg quality traits significantly than the only external egg quality trait. This implies that selection for higher internal egg quality traits in Strain A would be better when PC1 is considered. When external egg quality trait is considered in Strain A, the second PC is the component of choice as it loaded solely for external egg quality trait. PC3 and PC4 are seen as Yolk and Albumin components respectively.

In Strain B, many of the variables were seemingly accounted for in the first PC. It contained the mass and length of egg quality characteristic. So selection for both internal and external egg quality traits is made easier and better in Strain B by PC1. Also the percentage variance is recorded highest in PC1. In the second PC, internal egg quality traits loaded high than shell thickness, and so it was termed as the PC for internal egg quality traits. The third PC in Strain B had significant ($P<0.05$) loadings in albumin height and shell weight. In the fourth PC, Strain B had its highest loadings in shell weight.

Determinants of some egg quality traits are complex and it takes some times to obtain these traits (Sarica *et al*., 2012). This implies that selection can be possible by determining not all but some traits to improve the external and internal traits. Also that the selection of birds for any principal component will not cause a correlated response in terms of other principal components (i.e., they are orthogonal). Thus, the traits of a principal component can be selected without causing genetic changes in the traits of the other principal component because of its orthogonality (Savegnago *et al*., 2011). This study compliments that albumen height and shell thickness has formed a part of the selection programs and is used by the early breeders of Shikabrown® birds.

5.5.1 Principal component analysis for egg quality traits in both strains

The principal component analysis was applied to determine the most explanatory variables of total variance. The general skewness of most traits to PC1during varimax rotation of the inter correlated traits in both Strains agree with reports of several researchers in literature by Yakubu and Ayoade (2009), Akinsola (2012), and (Moses *et al*., 2011) who reported highest loadings on PC1 which they termed as the generalized component. This was supported by Kaiser-Meyer- Olkin measure of sampling adequacy studied from the diagonal of partial correlation, revealing the proportion of the variance in the egg quality traits caused by the underlying factor. This was found to be sufficiently high for all the egg traits in both Strains (0.676for strain A, and 0.598 for Strain B) as shown in (Table 4.13) and (Table 4.14). This is similar but numerically lower compared to the report of 0.951 and 0.950 reported Akinsola (2012). The communalities, which represent the proportion of the variance in the original variables that is accounted for by the factor solution, ranged from (0.64-0.90) for Strain A in (Table 4.13) and (0.74 – 0.93) for Strain B in Table (4.14) respectively. The factor pattern coefficients were used to assess the relative contributions of the various egg traits in determining the numerical value of the corresponding factor (principal component). These coefficients show the relative contribution of each trait to a particular principal component (factor) for the two Strains. The egg quality traits associated with PC1 are by themselves rather good estimator of general egg weight and that the first factor explained the highest percentage of total variance. This result agrees with the report of (Venturini *et al*., 2013), they reported that the first principal component explains the greatest part of the total additive genetic variance. The second principal component explains the second greatest part of the total additive genetic variance and so on, until all of the variance is explained.

In the selection for egg quality traits (external and internal), traits like shell thickness, are used as selection parameters to provide improvement, Sarica *et al*. (2012). Also Albumen height may be used for the selection of internal quality traits. This measure is incorporated into egg grading standards and accepted in markets, Sarica *et al*. (2012), Arthur and Albers (2003). Genetically, shell strength (De Ketelaere *et al.,* 2004) and albumen height (Washburn, 1990) are heritable traits and are concern to commercial breeders.

5.5.2 Phenotypic correlated matrix for egg quality traits in both strains

The positive and high (r_p) between egg weight and most internal and external egg measurements in Shikabrown® indicate that egg weight is directly proportional to the increase of other egg quality traits (egg length, egg width, shell thickness, shell weight, albumen weight, albumen height, albumen width, yolk weight, yolk index). Therefore, any of the components can be used as selection index for the improvement of egg weight. Also positive correlations obtained among the egg quality traits studied indicate that they can be improved phenotypically through selection (Obike and Azu 2012).

The strong and positive (r_p) correlation among egg weight and external egg qualities especially egg length (r_p=0.60; P<0.05), is similar with the result (rp=0.62; P<0.05) reported by (Obike and Azu 2012). This indicates that egg length is a good determinant of egg weight.Malago and Baitilwaken (2009) made similar observation. Egg length had also been reported to significantly (P<0.05) affect egg weight (Momira *et al*., 2003). The association between egg width and egg weight were stronger (r_p=0.66; P<0.05). This may be attributed to the fact that the denser part (yolk) of the egg occupies the width area, thereby translating to heavier weight for eggs. This result corroborated the report of Abanikannda *et al*. (2007). These authors reported a phenotypic correlation of 0.78 and 0.84 between egg weight, egg length and egg width respectively, of Harco heavy breed layers of chicken. Based on the correlations, they concluded that egg length and egg width were good predictors of egg weight. It also agrees with the reports of Nwagu *et al*. (2010) who found highly significant correlations between egg weight, egg length and egg width (r_p = 0.74 and 0.79; $P<0.05$) respectively, of Anak and Hubbard breeder grandparent stock. These positive phenotypic correlations translate into positive genetic correlations, then selection for either egg length or egg width will improve egg width and vice versa as a correlated response. These positive correlations between egg weight, egg length and egg width was buttress by the result of the prediction equation in this present study with an adjusted R^2 of 0.701 %. The prediction equation is thus: Egg weight = 68.997 + egg length + 18.491 egg width

5.6 Heritability Estimates of Egg Production Traits in both Strains

Heritability estimate for egg number was low (0.10±0.01) in Strain A to high (0.45±0.25) in Strain B. This implies that the trait is being governed by additive and non-additive genetic factors. Low but positive values obtained in this study for ASM in Strain B (0.18±0.03) is similar to the estimates obtained by Orunmuyi (2007), who reported the values of (0.15) for ASM in strain B of Rhode Island birds. Low estimate for egg number in strain A, differed from the values estimated by Orunmuyi (2007) and Wei and Van der Werf (1995) who reported a range of heritability estimates in two purebred sire lines to be (0.54 to 0.74) for egg number.

Moderate heritability was recorded for egg weight in both Strains. Strain A had higher values (0.34±0.15), compared to Strain B (0.28±0.34). This inverse relationship between the Strains with regards to their egg number and egg weight might be attributed to the genetic makeup of the two lines. Strain B (female line) was designed to produce more number of eggs (Oni, 1997) than Strain A (male line) and so its egg size tend to be lower than its counterpart. Most heritabilities of egg production reported in literature ranged from low to medium especially when estimated by sire variance (Nema and Johari, 1990; Singh *et al.,* 1986; Sukhbir *et al.,* 2001; Balvir *et al.,* 2000). This is an indication that variability due to additive gene action is probably smaller than the non-additive component. High estimates have been reported when determined through dam component, Nema and Johari (1990).

However, high heritability is recorded in ASM for Strain B (0.48±0.24), body weights in Strains A (0.65±0.08) and strain B (0.44±0.15) respectively. This observation agreed with report of El-Fiky (1994), who had positive and high relationship between body weight and ASM. The positive heritability between the traits indicates that an increase in one trait will lead to an increase in the other traits, since egg weight increases with female body weight and age to a certain extent Minvielle (1998).

5.6.1 Genotypic (r_g) and Phenotypic (r_p) Correlations of Egg production Traits among Strains

Phenotypic (r_p) and genetic (r_g) correlations may be positive or negative and will influence the performance of one trait when the other trait is subjected to selection (Iyiola-Tunji, 2012).They will also influence the rate at which the traits respond to simultaneous selection, such as within an index (Garrick, 2005).In the result obtained, genetic association between egg weight and body weight was not available. This implies that the sample size was small and the iteration was unable to converge. The r_g(where available) were generally high and positive for the association between body weight and other egg production traits. This is an indication that selection for one trait will simultaneously improve the other. Lynch (1999) had reported that genetic correlations are particularly difficult to assess because they require accurate estimates of three parameters: the genetic variances of the two traits, and the genetic covariance between them. Because all three estimates are generally obtained from the phenotypic covariance of relatives, they can take on any value.

ASM had lowly negative and positive values (r_p = -0.10; 0.08 P>0.05) in both Strains A and B respectively. High and negative (r_g = -0.93; = -0.85; = -0.36 P<0.05) correlation obtained between EGGNO and ASM, EWT and EGGNO and between BWT and EGGNO in Strain A, respectively. A high and positive (r_g= 0.87; P<0.05) was obtained between ASM and BWT. Similarly, high and positive (r_p = 0.43; 0.88; 0.88; P<0.05) was recorded between BWT and ASM, ASM and EGGNO and between BWT and EWT respectively. This findings agreed with Hidalgo *et al.* (2011), who reported (-0.01 to -0.77) between ASM and egg weight for some lines and Aboul-Hassan (2001) who also reported negative moderate correlation between ASM and egg number and Adelaja (2012). Results obtained in this study disagreed with Abdel-Mounsef (2005), who reported positive but low correlation between ASM, egg number and egg weight. The high positive r_g correlation (r_p= 0.87P<0.05) between ASM and BWT, indicates that an increase in one will lead to an increase in the other. It agrees with El-Fiky (1994) they had positive and high relationship between body weight and ASM. Egg weight increases with female BWT and age to a certain extent, (Minvielle, 1998).

5.6.2 Prediction equation of egg weight using external egg quality traits

The accuracy of functions used to predict live weight or growth characteristics from live animal using linear body measurements is of immense financial contribution to livestock production enterprises (Afolayan *et al*., 2006).The result (R^2 = 0.70%) obtained in this study is in agreement with the findings (R^2 = 0.690-0.954 %) of Iyiola-Tunji (2012) and Yakubu (2010) in sheep of Northern Nigeria and their crosses.

Baffour-Awuah *et al*. (2000) had suggested that predictors that consider volume of an animal in terms of circumference and body length tend to give better accuracy of prediction of live weight of animals. Semakula *et al*. (2010) affirmed that linear body measurements together with live body weights were influenced significantly ($P<0.05$) by breed, age and sex of the animal.

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

A study was conducted to evaluate egg production curves of Shikabrown® parents, using mathematical models. A total of 200 birds; 100from each of the two Strains of Shikabrown® parents (Sire and Dam) lines at the Breeding Unit of Poultry Research Programme of National Animal Production Research Institute (NAPRI) were used for the study. The birds were obtained from the selected lines (Sire and Dam lines) and were denoted as Strain A and strain B respectively. Strain A was identified with a gold plumage while Strain B with a silver plumage.

At 20 weeks of age, each of the two Strains were randomly picked and transferred to individual battery cage in order to monitor egg production. Eggs collected were recorded in daily egg record book and summarized at the end of every month. Records of body weight at 20 to 32 weeks of age were taken on weekly basis. For each bird, egg production was standardized into 28 days period.

Four non-linear models (Richard, gompertz, exponential and logistic) and a single linear model (Linear regression) were used to predict the efficiency of weekly bodyweight and egg production process. The adequacy of fit of each model was evaluated by Akaike's Information Criterion (AIC), Root Mean Square Error (RMSE), Coefficient of determination (R^2), and graphical analysis.

Ten (10) eggs from each of the two strains were used to measure the internal and external egg quality traits. Eggs used to measure these traits were sampled on their day of lay. Measurements were taken from them on the same day. Simple regression equation was employed to predict egg weight of Shikabrown® eggs using external egg quality traits.

Significant difference existed for BWT and EWT except for ASM and EGGNO. BWT was better in Strain B with a higher value of (1.59±0.01Kg) compared to (1.55±0.10Kg) for Strain A. EWT in strain A had higher value (48.75±0.17g) than its counterpart (47.92±0.17g). EGGNO and ASM were not affected by Strain effect. EWT was significantly ($P<0.05$) affected by Strain at 24, 26, 27 and 28 weeks of production. BWT attained higher growth ($P<0.05$) at 27 and 28 weeks of production. Decline in BWT especially for Strain A and EWT in strain B were recorded at week 28 and week 29, respectively.

High coefficients of determination for body weight (R^2 = 0.84 0.93) recorded in the models for both Strains, with strain A having higher R^2 of (R^2 = 0.93) in Richard, Gompertz and Exponential models. Also a high coefficient of determination (R^2 = 0.70) was obtained in a reproductive trait; egg number, in which similar value was recorded for Richard, Gompertz, Logistic and linear models. Exponential model recorded a higher R^2 of (0.93) for egg number in strain A. This implies that the birds' genetic potential can be further exploited for more genetic gain. Egg weight in Strain A recorded higher (R^2 = 0.96) coefficient of determination across the four nonlinear models except linear model with (R^2 = 0.95) for egg weight. Significant ($P<0.05$) differences were recorded within models for the egg production traits studied. Richard model in both Strains had the highest number of model parameters (5) and the linear model in both Strains had the least (2) number of model parameters. Linear model recorded the least AIC in both Strains amongst the models used. This could be as a result of the minimal model parameters in the model.

Errors of determination for nonlinear models (Richard, Gompertz, Logistic and Exponential) were not determined due to the rigorous computation of higher number of parameters in them. Error of determination for Strain A had less prediction error (-

8.02x10^{-5}) compared to Strain B (1.11 x 10^{-2}) for body weight. Strain B recorded less prediction error (-5.05x10^{-6}) for egg number than strain A (4.06x10^{-6}). Similarly, Strain B recorded lesser prediction error (5.25x10^{-1}) for egg weight than Strain A compared to Strain A, which had a larger prediction error (3.56 x 10^{1}) for egg weight.

Non-significant differences (P>0.05) were recorded for all the egg quality parameters except for egg length (Egg weight, egg width, albumen weight, albumen width, albumen height, yolk weight, yolk height, yolk width, shell thickness, haugh unit, yolk index, and shell weight) in both Strains. Genotypic correlations between traits in Strain A and B ranged from low (-0.27) to high (-0.63). Body weight had high and positive genotypic correlations with EWT (r_g= 0.88) and ASM (r_g= 0.43), respectively. EGGNO had low association with BWT (r_g= 0.11). EWT had negative and moderate genetic correlation with EGGNO (r_g= -0.35). ASM was negatively correlated with EGGNO (r_g= -0.63) and EWT (r_g= -0.27). Strain B had higher heritability estimates (h^2=0.45) while the least estimates (h^2=0.10) was recorded in Strain A for EGGNO. ASM recorded the highest estimates (h^2=0.48) in Strain A while least value (0.18) was observed in Strain B.

Four components were mathematically generated, in which PC1 (54.50%), PC2 (28.00%), PC3 (21.40%) and PC4 (12.90%) had the most informative variables in Strain B while components PC1 (43.2%), PC2 (26.4), PC3 (18.4), and PC4 (15.1) had the highest loading in Strain A. The prediction regression equation obtained was thus:

Egg weight = 68.997 + 7.990 egg length +18.491 egg width. Adjusted R^2 is 0.701.

6.2 Conclusions

The following conclusions are drawn from this study:

1) Body weight of Strain B (1.59±0.01Kg) was significantly superior to that of Strain A (1.55±0.10Kg).

2) Egg weight of Strain A (48.75±0.17g) was significantly superior to Strain B (47.92±0.17g).

3) The genetic make-up for egg number seems to be similar for the two Strains. Values for egg number for Strain A (14.33±0.24) and Strain B (14.48±0.24) were statistically similar.

4) In Strain A, Richard model outperformed the other models in modeling body weight and egg weight with R^2 values of 0.89 and 0.93, respectively. The RMSE generated for Richard model for the two traits were 63.70 and 47.60, respectively.

5) Egg number of Strain A was best modeled by Exponential model with R^2 value of 0.93 and RMSE of 47.59.

6) The highest heritability estimates for BWT, ASM and EWT were recorded by Strain A. The values are 0.65±0.08, 0.48±9.24, and 0.34±0.15, respectively.

6.3 Recommendations

The following recommendations are therefore put forward:

- In view of the genetic variability recorded in BWT and EWT of the two genetic lines of Shikabrown®, Strain B is recommended for BWT and Strain A for EWT for maximum productivity.
- The suitable models that predicted BWT (Richard and Gompertz); EGGNO (Exponential), and EGGWT (Richard, Gompertz, Logistic, and Exponential) should be employed by poultry farmers for effective managerial practices.
- Strain B had longer egg length and egg width than Strain A, selection for egg length and egg width will invariably select eggs with heavier phenotypic weight. Based on these traits, Strain B should be employed as selection criteria to improve egg weight of Shikabrown®.

- High and positive h^2 estimate obtained for BWT and ASM in Strain A, suggests that Strain A possess high potential for increased BWT and can come into lay at an early age. High and positive h^2 estimate recorded for EGGNO in Strain B is recommended for improved performance and profitability.

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APPENDIX I

Effect of Age on body weight and egg weight

	BWT		EWT
Weeks	Mean±SE	N	Mean±SE
21	1.48 ± 0.02^{e}	200	48.00 ± 0.46^{bcd}
22	1.57 ± 0.02^{bcd}	200	48.73 ± 0.41^{bc}
23	1.57 ± 0.02^{bcd}	200	49.29 ± 0.42^{ab}
24	1.61 ± 0.02^{ab}	200	49.68 ± 0.41^{a}
25	1.61 ± 0.02^{ab}	196	49.63 ± 0.39^{a}
26	1.63 ± 0.02^{a}	196	49.89 ± 0.40^{a}
27	1.64 ± 0.02^{a}	196	49.90 ± 0.40^{a}
28	1.64 ± 0.02^{cde}	196	48.02 ± 0.38^{bcd}
29	1.54 ± 0.02^{de}	196	46.19 ± 0.45^{e}
30	1.59 ± 0.02^{abc}	194	46.76 ± 0.44^{de}
31	1.54 ± 0.02^{cde}	194	47.96 ± 0.45^{cd}
32	1.54 ± 0.02^{cde}	194	45.96 ± 0.48^{e}

Traits: BWT: Body weight, EWT: Egg weight, SE: Standard Error, N: Number, ^{abcde} Means with different superscripts on the same row are significantly different ($P<0.05$)