

Full Length Research Paper

Implications of diet and quality consistence of feed on poultry layers egg quality

S. Kodani^{1*}, D. Msamala², R. Chigumira², T. Shumba³ and P. Muzofa⁴

¹Department of Chemical Engineering, National University of Science and Technology, Zimbabwe, P.O. Box AC 939, Ascot, Bulawayo, Zimbabwe.

²Fertilizers, Farm Feeds and Remedies Institute, Department of Research and Specialist Services, Fifth Street Extension, P.O. Box CY550, Causeway, Harare, Zimbabwe.

³Henderson Research Institute, Department of Research and Specialist Services, Fifth Street Extension, P.O. Box CY550, Causeway, Harare, Zimbabwe.

⁴Biometrics and Computer Services Research Institute, Department of Research and Specialist Services, Fifth Street Extension, P.O. Box CY550, Causeway, Harare, Zimbabwe.

Received 26 January, 2022; Accepted 13 May, 2022

Impaction of different brands of commercial layers feeds on egg quality was assessed in a complete block design with five treatments in three blocks replicated with twenty birds each. Hyline birds and the deep litter system were used. Feed constituents from proximate analysis were linearly correlated to quality parameters measured on the eggs. Results showed that nutrition impacts on most egg quality parameters except for size, mass and numbers. Fat, calcium and copper impacted linearly as determinants in feed intake whereas fat, calcium manganese and copper correlated to egg white protein with reasonable linearity. Feed protein, fat, phosphate and zinc impacted directly on the yolk whereas fat, copper and zinc were linearly correlated to shell strength. Mathematical models from this data can be formulated for precise optimization of targeted traits in egg quality. It was concluded that fluctuations in feed quality has a toll on the hen and hence on egg quality.

Key words: Egg quality, diet, correlations.

INTRODUCTION

Feed accounts for over 70% of layers production costs. Energy and amino acids account for most of the cost of poultry feeds. They are also the main determinants of a success in production. According to Fisher (date unknown), the central tenet of poultry nutrition is in formulating feeds accurately and efficiently for these nutrients hence optimization is a must. It was also highlighted that feedstuff systems are evaluated for the

need to measure the replacement value of feedstuffs that is the relative ranking based on nutritional values or levels in various products and also that of relating animal performance to feed attributes. Lastly, the facilitation of the production and/or control of an animal performance were highlighted through nutrition. Feed mixtures are mostly designed by linear programming and additivity of scales with respect to animal performance is important.

*Corresponding author. E-mail: skodani6@yahoo.co.uk. Tel: +263-242-704541 or +263772489223.

This is the basis of this study, to determine the essential elements in the linearization process and to what extent they influence the quality parameters in egg production. Subject to cost benefit consideration, the most precise nutritional scales and tools in feed formulation were also recommended.

Nutrition plays a significant role in poultry eggs production. There is need to strike a balance between availability and sufficiency hence the need to follow the production trends and quality consistency in poultry feed production. Feeds must be formulated to address the correct energy, amino acids, vitamins, minerals and essential fatty acids demands of the birds for good yolk and shell structures. Yolk color and cholesterol content are the major factors considered in determining egg quality. Other parameters include feed consumption by the hens, egg size, shell structure, cracked shells, shell thickness and protein content of yolk and egg white. It is known that yolk color can be adjusted using pigments in feed material. According to the Xanthophyll-Wikipedia, the characteristic colour of egg yolk is due to the presence of a xanthophyll pigment. It is the typical colour of lutein or zeaxanthin of the xanthophylls, a division of the carotenoids group and like other carotenoids, are found in the highest quantity in the leaves of most green plants, where they act to modulate light energy. A high level of yellow maize, leaf or grass meal will ensure a good yolk colour. Zinc, magnesium and copper are well known minerals that are required by enzymes that facilitate development and mobilization of other elements for quality egg production.

Every stock feed commercialized in Zimbabwe has to be registered in accordance to the Fertilizers, Farm Feeds and Remedies Act Chapter 18:12. This Act is implemented by the Fertilizers, Farm Feeds and Remedies Institute (FFRI). For a brand to be registered, inspectors of the FFRI conduct quality checks on the nutritional composition of the feed. Packaging material and labelling are also other factors considered on registration. Manufacturers are not always reliable. They make avail a good sample for registration and thereafter start cutting corners in production to minimize costs. This then demands the system to keep check on production quality consistence to protect the farmers. It is a known fact that it is not nutrition alone that determines the quality or quantity of the measured variables. Other production factors include the breed and age of flock, type of feed, and incidence of disease, management control of the laying flock and in the handling of the eggs. Some egg properties are inherent and peculiar to a variety of hens. Some of these contrasted characteristics amongst hens of different varieties include colour, shell thickness and texture, incidence of blood spots and the amount of thick albumin. After first season of egg production, hens produce eggs of poorer shell quality and poorer egg white thickness, even though they might be larger in size. It is advisable to replace the hens after 12

to 18 months of laying. Diseases like Infectious Bronchitis and Newcastle can affect quality by causing hens to lay eggs with misshapen shells and poor quality thick white.

Feed has been identified as the major constraint in layer birds' production. Without optimization on nutrient balance of the feeds, there are significant material and economic losses on unnecessary nutrient loads and cost per unit nutrient. There is need to understand the correlation of certain essential nutrients in feeds to quality of the eggs. If a linear correlation is found, mathematical modelling is possible to come up with solutions that best optimize quality production. There is more profitability recognized in precision feeding hence the challenge to come up with understanding linear correlations to this regard and how they influence on quality production.

The aims of the study were to ascertain the influence of diet of four commercial layers feeds on egg quality parameters. Correlation data was used to interpret the influence of nutrition on egg quality. This data could be used in understanding the essential elements that contribute to egg quality and how these could be manipulated for optimization purposes through formulation of mathematical models whose solutions could revolutionize precise egg quality production.

Specific objectives

- i. To assess the implications of the nutritional composition of four commercial layers feeds as a direct linear correlation to egg quality parameters.
- ii. To enhance probable optimization of the egg production system through utilizing the nutritional composition of the diets.
- iii. To facilitate the prediction and/or control of animal performance given the nutritional composition of the feedstuff under use.

Output

- i. Key nutrients identification in the quality egg production process.
- ii. Profiles on performance of the study diets on egg quality determination

Outcome

- i. Optimized feeding systems
- ii. Precise egg quality production.

Impact

- i. Livestock production and development,
- ii. Food and nutrition security,

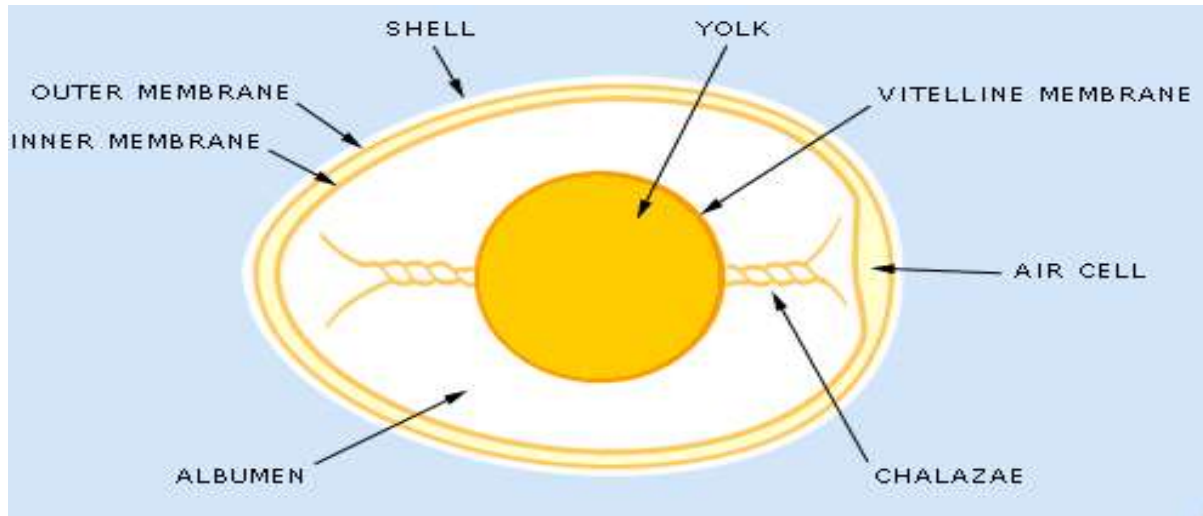


Figure 1. General structure of an egg showing the location of egg white and the yolk.
Source: Exploratorium (2021)

- iii. Employment creation,
- iv. Income generation.

LITERATURE REVIEW

Structure of the egg

The general structure of the egg is made up of an inner and outer membrane as shown in Figure 1. These are made of keratin, a structural protein also found in human hair. Egg white is also called Albumen and is made up of up to forty (40) different proteins which are the major constituents according to the Exploratorium (2021). The yolk contains more proteins than the egg white. The chalazae are opaque ropes of egg white and hold the yolk in position at the center of the egg as depicted in Figure 1. They attach the yolk's casing to the membrane lining the egg shell. The vitelline membrane surrounds the yolk.

The fluid mosaic model

At biochemical level, the cell membrane is composed primarily of phospholipids and proteins. Since there is an aqueous environment on each side of the membrane, the hydrophobic parts of the molecule "huddles together", in the center of the membrane leaving the polar ends exposed to water on both surfaces. This results in the formation of a double layer of phospholipids in the cell membrane. The selective functions and selective transport properties of the membrane are believed to be due to its protein content. Some proteins are found partially submerged on each side of the membrane whilst

others span the membrane completely from one side to the other. Since the membrane is not solid, phospholipids and proteins are free to move. The proteins move within the "phospholipid sea" and are not uniformly distributed but rather a mosaic pattern popularly known as "The Fluid Mosaic Model", as depicted in Figure 2.

The definition of egg quality

Egg quality is an important criterion for layers farmers and has important economic implications to the success or failure of the enterprise. It is directly related to nutrition of the hens and the wellbeing of their digestive function. Different breeds of poultry have been used for egg production including traditional roadrunners and they produce different quality parameters as depicted in Table 1. Quality of eggs is hence defined in terms of the physical and biochemical standards. Eggshell cleanliness, thickness, shape and integrity will influence the downgrading rate. Dirty, soft, weak or cracked shells are all signs of poor quality hence such eggs are eliminated during collection by the farmers. Outwards appearance is very important for the farmer-consumer interaction. Nature of albumen and yolk are key to good quality. These are mainly constituted of lipoproteins, minerals, vitamins, and other nutrients vital to the food industry. Albumen aspects and quality are associated with egg freshness. Storage times, high temperature, hens age or antioxidant status favor the degradation of albumen protein.

Egg white is low in calories and fat free unlike the egg yolk which carries the cholesterol, fat and saturated fat of the egg. The white contains the bulky of the egg's proteins, about 4 g of protein whereas the yolk just

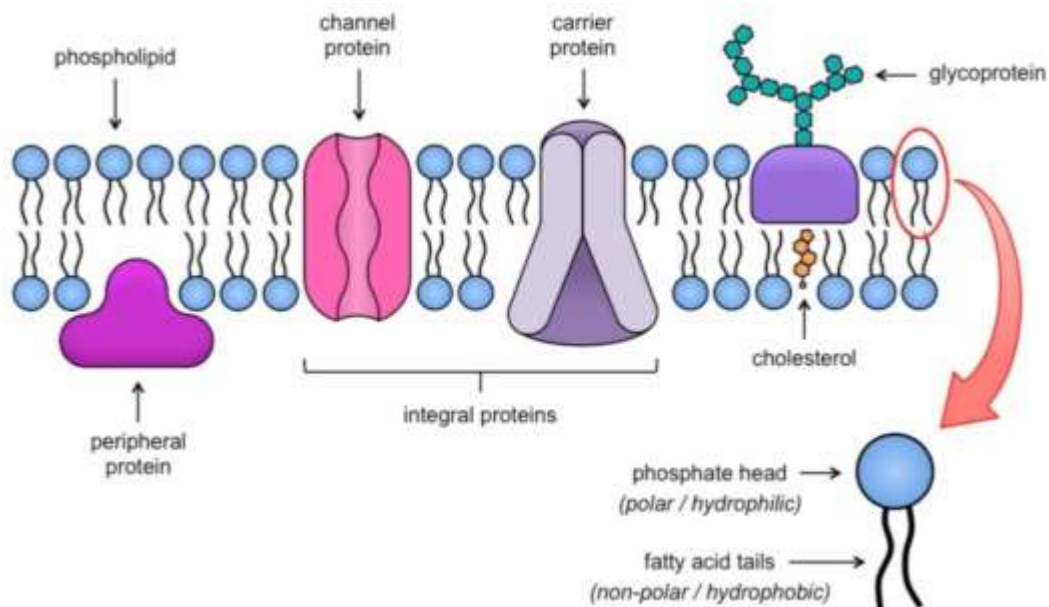


Figure 2. The fluid mosaic model.
Source: Fluid-Mosaic Model (lb.bioninja.com.au)

Table 1. Eggs quality parameters for some breeds of chicken.

Trait	Nigerian Local	Isa Brown	Ethiopian Local	White Leghorn
Egg weight (g)	40.6	59.2	46	64
Yolk, %	36.9	26.3	36.8	34
Albumen %	52.6	62.8	49.6	53
Shell thickness (mm)	0.3	0.35	0.35	N/A
Yolk Index	0.36	0.46	N/A	N/A
Albumen Index	0.09	0.12	N/A	N/A
Haugh Unit	79.8	89.9	N/A	N/A
Fertility, %	N/A	N/A	56.4	46
Hatchability, %	N/A	N/A	42.1	24.1

Source: FAO (2021).

carries about 2.7 g of protein. The yolk contains many nutrients as compared to the egg white as depicted in Table 2.

Protein in poultry nutrition

Amino acids are the building blocks for proteins and are derived from the diet of the birds. They fulfill a number of diverse functions including acting as precursors of many important non-protein body constituents. Body proteins are in a dynamic state of synthesis and degradation hence need for a regular adequate intake of dietary amino acids. Inadequate amino acids in the diet results in reduction or cessation of growth or productivity and withdrawal of protein from less vital body tissues to

maintain the functions of more vital tissues according to NAP.edu/10766 (1994). Genetics play a big role in determining body size, growth rate and egg production therefore meaning different breeds, types and strains of poultry have different requirements for amino acids. This emanates from differences in efficiency of digestion, nutrient absorption and metabolism of absorbed nutrients as quoted from the National Research Council (1975). The quantitative needs of amino acids by poultry must be met by a balanced source to obtain maximum productivity thus factors that affect feed consumption will affect quantitative intakes of amino acids and proteins. It will also influence the dietary concentration of these nutrients needed to provide adequate nutrition. These requirements for amino acids and proteins will be intended to support maximum production but the economics of it should be

Table 2. Some characteristics of the definition of a quality egg.

Nutrient	White	Yolk	%Total in White	% Total in Yolk
Protein	3.6 g	2.7 g	57	43
Fat	0.05 g	4.5 g	1	99
Calcium	2.3 mg	21.9 mg	9.50	90.50
Magnesium	3.6 mg	0.85 mg	80.80	19.20
Iron	0.03 mg	0.4 mg	6.20	93.80
Phosphorus	5 mg	66.3 mg	7	93
Potassium	53.8 mg	18.5 mg	74.40	25.60
Sodium	54.8 mg	8.2 mg	87	13
Zinc	0.01 mg	0.4 mg	0.20	99.80
Copper	0.008 mg	0.013 mg	38	62
Manganese	0.004	0.009 mg	30.80	69.20
Selenium	6.6 mcg	9.5 mcg	41	59
Thiamin	0.01 mg	0.03 mg	3.20	96.80
Riboflavin	0.145 mg	0.09 mg	61.70	48.30
Niacin	0.035 mg	0.004 mg	11	9.30
Pantothenic acid	0.63 mg	0.51 mg	3.30	89
B6	0.002 mg	0.059 mg	5	96.70
Folate	1.3 mcg	24.8 mcg	8.30	100
Vitamin A	0 IU	0.331 mcg	0	100
Vitamin E	0 mg	245 IU	0	100
Vitamin D	0 IU	0.684 mg	0	100
Vitamin K	0 IU	18.3 IU	0	100
DHA and AA	0 mg	94 mg	0	100
Carotenoids	0 mcg	21 mcg	0	100

Source: USDA.

rationalized.

Fat in poultry nutrition

Mateos and Sell (1981) noted that high level fat often leads to more mechanical energy that cannot be accounted for, from the summation of ingredients. Research has shown that high fat feeding increased intestinal retention time of feed hence allowing a more complete digestion and absorption of the non-lipid constituents. According to Tabeidian et al. (2010), administration of different fat levels to broiler diets significantly ($P < 0.01$) increased food intake (FI), feed efficiency (FE), carcass weight (CW), abdominal fat (AF) and diet cost (DC) in broiler birds. Linoleic and linolenic acids were considered as essential fatty acids. The double bonds position in these polyunsaturated fatty acids (PUFA) is unique and not found in fowl according to NAP.edu/10766 (1994). These essential fatty acids are converted to long chain PUFA in poultry. Membrane phospholipids contain greater proportion of PUFA than do triacylglycerol. Linoleic acid is the only essential fatty acid for which a dietary requirement has been demonstrated. According to Tabeidian et al. (2010), a combination of 2%

of animal fat and 1 or 2% of calcium provides the greatest performance in broiler chickens.

Trace elements in poultry nutrition

Trace elements play a vital role in the egg forming process especially the egg shell. According to the Poultry World (2021), zinc, copper and manganese have been proven to be the most important elements in the egg shell forming process. They possess both catalytic and structural functions. Zinc catalyzes carbonic anhydrase which helps deposit calcium in shell matrix. Copper functions in collagen formation on eggshell membranes. Manganese helps deposit proteins in the eggshell matrix. Dietary Mn deficiency did not affect the egg performance of layers as observed by Xiao et al. (2014). Dietary Mn supplementation significantly improved the breaking strength, thickness, and fracture toughness of eggshells ($P < 0.05$). In photographs of eggshell ultrastructure by Xiao et al. (2014), the size of mammillary cones and cracks in the outer surface were decreased by dietary Mn supplementation. Studies by Trouw Nutrition in the Netherlands showed that zinc, copper and manganese if availed as superior sources can result in improved egg

Table 3. Effects of water temperature on layer performance.

Parameter	Water Temperature (°C)	
	33	2
Feed/Bird/Day (g)	63.8	75.8
Egg production (%)	81	93
Egg weight (g)	49	48.5

Source: Poultry World (2013)

production and reduced cracked eggs according to Poultry World (2021). When talking about trace elements, the most important thing to consider is the source and availability to the blood stream that matters. Oversupply leads to toxicity of the birds and its systems as well as environmental waste. Too much calcium may result in kidney damage resulting in wet manure during laying period. Chances are the birds lay more eggs with deformed egg shells.

According to Mongin (1975), a number of factors may lead to a decreased or low phosphate in feed intake. These include human errors as the major contributor to phosphate presence and levels in diet. He noted that decreased phosphate in feed intake may arise from low egg white, palatability of feed, water quality, run system (free range), use of kitchen leftovers to feed chickens, birds going to top production, not enough phosphate given and also diseases. Increased phosphate intake may be induced by human errors too like on recording and weighing. The production of high egg weight might also result in increased phosphate intake. Parasites, luxurious consumption, wastage, lost eggs (no shells), feed accumulation, rats, mice and wild birds may result in increased phosphate intake. The proper dietary balance of sodium, potassium and chloride is necessary for growth, bone development, eggshell quality and amino acid utilization but an ideal balance among these electrolytes has not been defined for a wide range of environmental situation.

Shafy and McDonal (1991) reported that increasing dietary calcium caused a defect in absorption of other minerals particularly magnesium, manganese and zinc which were used in the study. Calcium assigned, according to their initial body weights, react with fat in the digestive tract resulting in the formation of calcium soaps which are excreted. Inclusion of appropriate levels of calcium and phosphorus to diets improved feed conversion and weight gain than groups which had calcium shortage, which reduced food intake, weight loss and delayed and chemical compositions of the diet are shown in sexual maturation in broiler chickens.

Water in poultry nutrition

Water quality and quantity has some influence on layers

performance. A simple look at temperature influence shows the typical layer performance shown in Table 3. Factors attributed to feed nature and water on feed intake include physical form of the feed, feed flavor, anti-nutritional factors, feed wastage, water supply, body factor, volume of gastro intestinal tract, taste buds, genes, hormones, and feather cover of the birds.

Effects of body weight on egg quality

Body weight of the birds plays a significant role in determining production. It is emphasized that the breeding companies should indicate what the weight of their pullets would be at the end of the rearing period like at 18 weeks. Large discrepancies in body weight are not recommended as it is detrimental to production. If uniformity becomes too low, flock might be affected during laying period hence affecting productivity. This may arise in the form of an irregular start in production hence can have consequences of having the peak production sooner or later than expected. Hens lay heavier eggs as they age according to Chang (2021), and also increase in body weight but the egg shell becomes increasingly thinner. Ability of the hens to absorb calcium in the gut reduces, hence ageing flocks may encounter a high incidence of shell problems. Shell problems can be controlled in older birds by decreasing protein and amino acids as the birds age to control body weight and achieve target egg weights.

Factors determining feed intake

Feed consumption in layers depends on a number of factors some of which are beyond the control of the farmers. Some of these factors include the age, type, metabolizing energy (ME), feed structure, temperature, feeding space, health of birds, water quality and quantity and housing system. According to Jacobs (2021), a balanced diet is necessary for optimal growth and production of the layers. Ingredients used in different types of feeds are similar but proportions added vary depending on the particular chickens being fed. Heat stress reduces feed intake and limits amount of absorbed calcium for eggshell formation hence should be taken into

the equation as well. Quality of the fat is essential because high consumption of animal fats containing large amounts of saturated fatty acids such as palmitic and stearic acids are associated with high intake of calcium. It causes a type of reaction between fatty acid and calcium which results in the formation of insoluble soap and non-use of nutrients by poultry. Eventually it will be excreted through faeces or it can be deposited as abdominal fat. It does not significantly affect food intake in birds fed diet containing high levels of fat intake and calcium. Poultry World (2013), divided factors affecting feed intake into management practices and micro environmental factors.

In environmental considerations, some of the factors considered for optimization were flock size, stocking rate, temperature, lighting, and noise. Temperature stood out as possessing the most striking effects on feed intake especially at the brooding stage. The relationship was described as a mathematical relationship $ME = 1690 - 2.1T$, where ME is metabolizing energy and T is the ambient temperature. This is due primarily to the partitioning of ME consumed, with the greater part of it being deposited as fat and the lesser part as protein. Heat stress does not only affect feed intake and utilization but also has negative impacts on the carcass quality.

Product acceptability on the market

FAO (2021) noted that quality is the determining factor to acceptability of a product by the market. Preservation of this quality has been observed to be a function of the physical structure and chemical composition of the egg in storage. The weight of a local breed chicken egg is about 35 g as compared to 58 g of commercial hybrid lay eggs. The shell comprises approximately 11% of the whole egg and the rest is the edible portion. The yolk comprises 36% of the edible portion. Shell colour is not a determinant of egg quality though consumers have their preferences. Eggs of unusual shape can easily be damaged hence reduce market value of the product. According to Jonsson et al. (2010), the colour of the egg yolk is considered to be an important factor in determining the acceptability of a product to the consumer. Synthetic carotenoids were widely used for several years, but consumers' concern with regard to synthetic additives and an increasing interest for natural alternatives have led to the use of, for example, paprika powder. Local yolk colour preferences should be considered for marketing purposes.

Preserving quality of the egg

Interior quality of eggs deteriorate at a rate determined by storage conditions such as temperature, relative humidity and presence of strong smelling substances or other food items in the storage place and also the time of storage

according to FAO (2021). This is due to loss of moisture, carbon dioxide and absorption of some volatile substances from the environment. A weight loss of 2 to 3% of eggs in marketing is normal due to loss in moisture. This can be prevented by coating the eggs with oil or other substances. The ideal storage condition for eggs is minus one degree Celsius and between 80 and 85% relative humidity. There is risk of mold spoilage when the humidity is too high. Paper pulp egg trays or other substances that readily absorb moisture will accelerate moisture losses from eggs. Microbiological spoilage can also occur if the eggs are washed. This allows microorganisms on the shell to penetrate and multiply inside. Common indicators are green, black and red "rots", mustiness and sourness. Yolks are easily tainted by strong odors, from such sources as disinfectants, soaps, diesel, kerosene, petrol, varnish and wood preservatives. Other foods such as onion and citrus products can taint eggs after only a few days of exposure.

METHODOLOGY

This study was carried out at Henderson Research Station Poultry Section in Zimbabwe. This station was chosen from its proximity to the researchers and also availability of the necessary infrastructure for this study. Randomized complete block design (RCBD) was chosen for this study and five (5) treatments were given in three blocks with replicas of twenty (20) birds each. Deep litter was chosen as the production method of choice considering the size of flock under study. The deep litter houses were partitioned into 12 plots measuring 4.2 m² each. Dry grass and later wood shavings were used as the deep litter. This was turned weekly and replaced monthly. The point of lay Hyline brown layers birds were purchased from a reputable supplier and study was run over four months. Four (4) randomly selected commercial layer's feeds from reputable, well established manufacturers were picked as the diets for this study. The feed was picked periodically from the suppliers. Each feed was analyzed for full feed nutritional composition before feeding the birds and results collated. Protein content of egg yolk and white, feed intake, number of eggs cracking and egg size were measured and results collated. A linear correlation was sought between the nutrients in the diets and egg quality parameters. Correlation data was plotted on scatter diagrams to find R² values as second order linear relationships. Linearization was considered handy in this study because it could be used in formulating mathematical models that could be used in optimizing production system.

Correlation was considered as a measure of the intensity of the straight line relationship between the two variables, that is the independent variable (feed nutritional levels) and the dependent variable (egg quality parameters). The magnitude of R² values does not imply causality. It shows the association between two variables. It does not tell that there is no relationship between the two variables under study no matter how small. When R² falls between 0.01 and 0.33, there is a low linear correlation. It is medium when between 0.34 and 0.66 and high when greater than or equal to 0.67 but lower than or equal to 0.99.

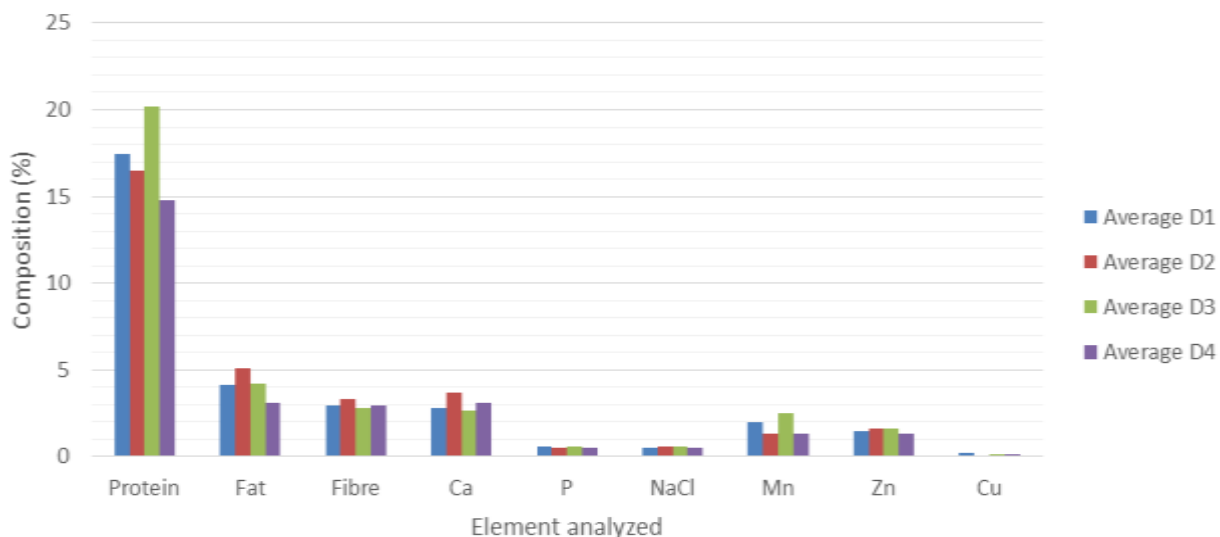
RESULTS AND DISCUSSION

There is a significant difference between and within diets at 95% confidence limit with reference to nutritional composition as depicted in Table 4. Within batch, p

Table 4. Summary of within and between diet nutritional compositions.

Nutrient	SAZ standard	Diet 1	Diet 2	Diet 3	Diet 4	P-value (Diet)	P-value (Batch)
Moisture (% w/w)	12 (max)	8.07	8.57	8.55	9.6	0.14	0.031
C. Protein (% w/w)	16 (min)	19.11	16.49	20.22	15.89	0.018	0.168
C. Fat (% w/w)	8 (max)	4.13	5.06	4.18	3.07	<0.001	<0.001
C. Fibre (% w/w)	7 (max)	2.94	3.23	2.84	2.93	0.003	0.232
Ash (% w/w)	-	12.87	14.68	12.07	13.07	0.009	<0.001
Ca (% w/w)	3.0-4.0	2.79	3.68	2.63	2.96	<0.001	<0.001
P (% w/w)	0.4-0.6	0.57	0.54	0.61	0.51	0.003	0.003
NaCl (% w/w)	0.25-0.5	0.55	0.55	0.59	0.5	0.115	<0.001
Mn (mg/kg)	75 (min)	191	121	253	74	<0.001	0.396
Zn (mg/kg)	45 (min)	148	162	156	134	<0.001	0.013

Source: Authors Results

**Figure 3.** Average nutritional composition of the four diets.
Source: Authors Results

values ranged from < 0.001 to 0.115 in sodium chloride (NaCl). Between batches, p values ranged from < 0.001 to 0.396. The average nutrient levels within the feeds fell within recommended levels specified by the Standards Association of Zimbabwe. Within batch NaCl (p range), fat within and between diets (p values of 0.001), Ca for both within and between range < 0.001, P for within and between range (0.03), Mn within batch (p range is <0.001), and Zn within and between range (p values of < 0.001 and 0.013). A comparison of nutrient composition of different batches of the same diet showed significant differences in levels of some elements proving inconsistency in quality of feed maintenance during manufacturing from batch to batch and amongst the different manufacturers.

All diets had on average sufficient average crude protein levels, as stipulated by the Standards Association

of Zimbabwe, Zimbabwe Standards ZWS517:2021. Crude protein levels are ranged from 20.22% in diet 3 and 14.80% in diet 4. There is no significant difference between batches for fiber and manganese with p values of 0.232 and 0.396, respectively. Batches showed NaCl consistency but lots of variations on other elements.

There was no consistency in phosphate levels of the four diets within and between batches with p values of 0.003 in both cases. The phosphates ranged from 0.37 to 0.63 which is slightly lower than the stipulated 0.8 minimum for layer feeds. In batch to batch analysis, diet 4 fell short on crude protein (CP) in batches 1, 3 and 4. Diet 3 maintained a consistency of high crude protein levels well above the minimum threshold. Diet 1 had slightly lower crude protein levels below the minimum threshold as depicted in Figure 3. Calcium levels were consistent for diet 2 only which demonstrated a high level of meeting

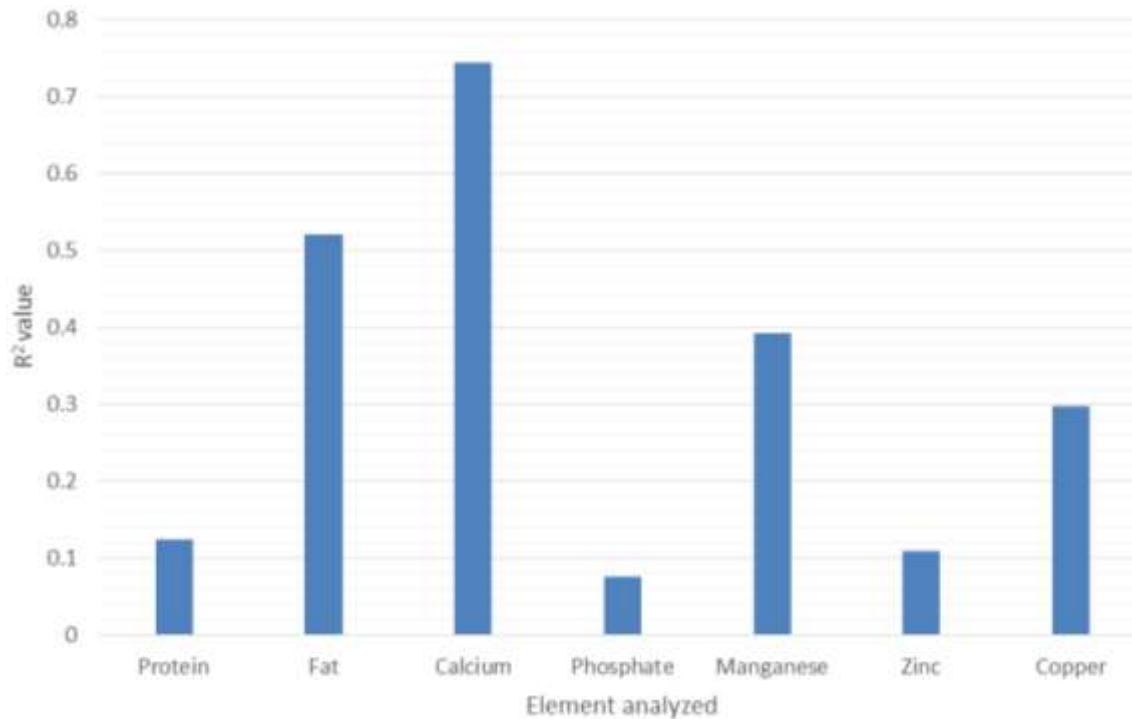


Figure 4. Relationship between nutrient composition of diet and egg white protein content.
Source: Authors Results

specifications in batches 1, 3 and 4. The rest fell short of the specified minimum threshold for calcium in layers feeds.

Calcium, fat, manganese and copper have high to very high linear correlation to egg white protein as depicted in Figure 4. There is a high degree of a second order linear correlation between dietary nutrition composition and fat in egg white fat as depicted in Figure 2. The fat is largely deposited as phospholipid hence the trend in Figure 4 tally with literature of the structural composition of the fluid mosaic model. Calcium has the highest R² value of 0.745. Manganese with its role of depositing proteins and copper in collagen formation, this combination helps promote the role of egg white in securing the yolk.

There is a direct protein deposition from the diets in yolk formation unlike the egg white protein formation as depicted in the medium correlation in Figure 5 for protein, fat and zinc. In contrast to egg white correlations to feed, the yolk protein has a significant linear correlation to zinc. The zinc helps in direct protein deposition to the yolk during its conception and the proportion of lipid to protein proves a high correlation to feed nutrients.

Zinc catalyzes protein deposition in shell matrix which is also directly in yolk protein formation as depicted by the direct linear correlation in Figure 5. Zinc is the most direct element linearly correlated to yolk protein formation. Zinc deficiency affects the quality of the epithelium due to its role in protein synthesis. Zinc plays a role in magnum deposition of albumen and in the

isthmus where egg shell membranes are produced.

Copper followed by fat showed the highest linear correlation between nutrient composition and cracking of eggs as indicated in Figure 6. Using a second order linear correlation plot, the two had very high probability of influencing a direct correlation to cracking of eggs with R² value of 0.91 and 0.64, respectively. This supports the assertion by Fox (date unknown) that the main function of copper is in collagen formation, a strengthening material, a fibrous protein which provides tensile strength to connective tissue and is a support system to egg strength. Copper is used in the synthesis of phospholipids and also connective tissue metabolism.

Figure 7 shows that copper, fat and calcium have significant direct linear correlations to amount of consumed food per bird per day which here is termed feed intake. Results in Figure 7 tally well with observations by Tabeidian et al. (2010), that there is a synergistic relationship between fat and calcium. They observed that interaction of calcium and fat levels on feed intake was not significant. Pekel (2011) observed that supplementation of a diet with 250 ppm of copper sulphate improved egg production but decreased egg weight ($p < 0.05$) and feed intake ($p < 0.01$). This tallies well with observations in Figure 7. R² value for copper indicates it directly affects feed intake with a high linear correlation. Shortage of calcium results in reduced feed intake and weight loss of the hens. Increased calcium intake decreases absorption of some other minerals like

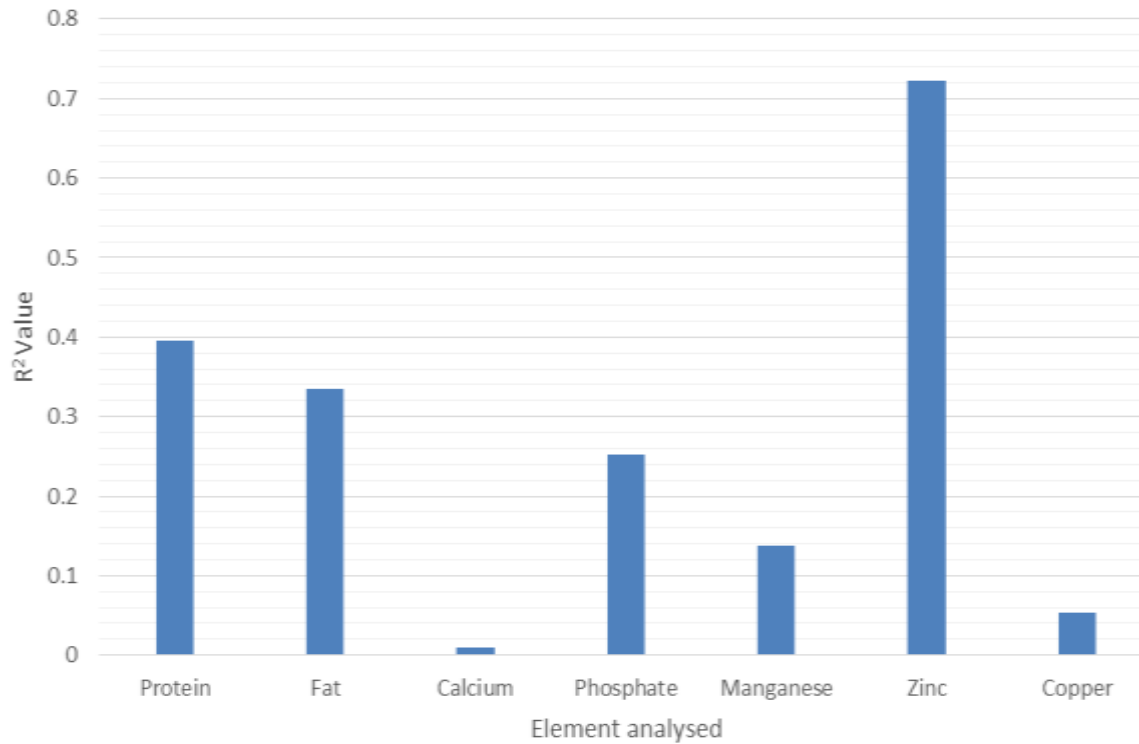


Figure 5. Relationship between nutrient composition of diet and yolk protein content.
Source: Authors Results

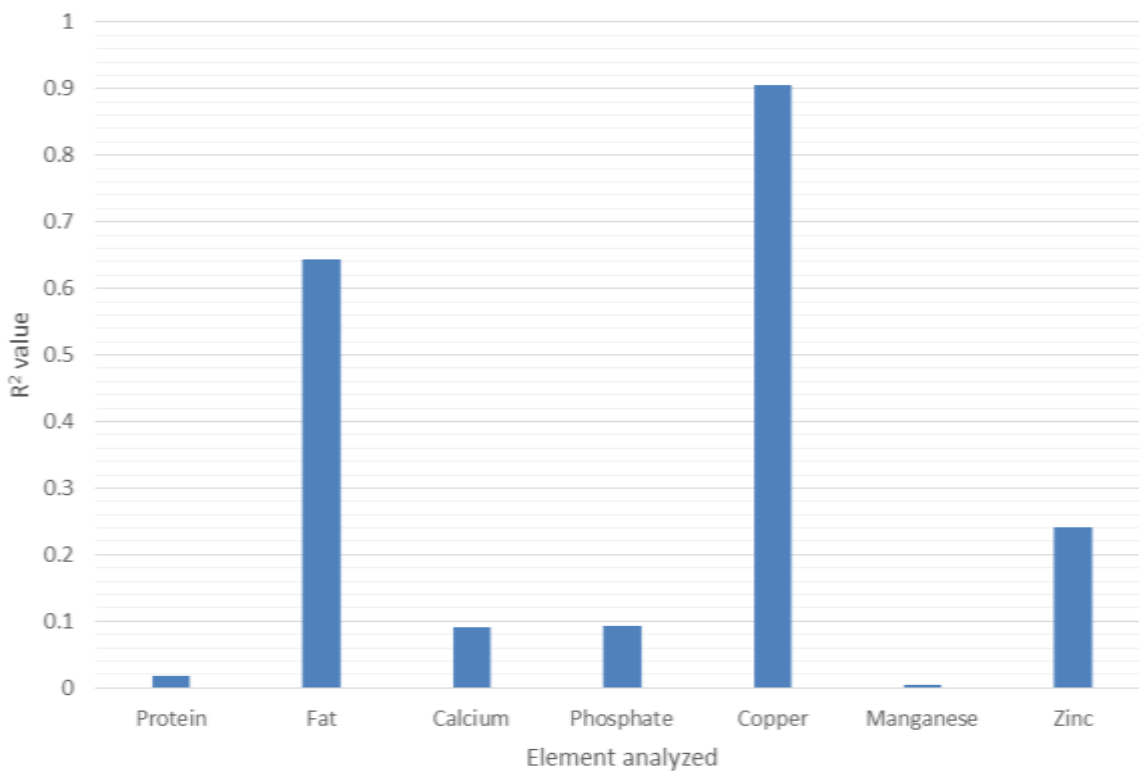


Figure 6. Relationship between nutrient levels in feed to percentage of cracking eggs.
Source: Authors Results

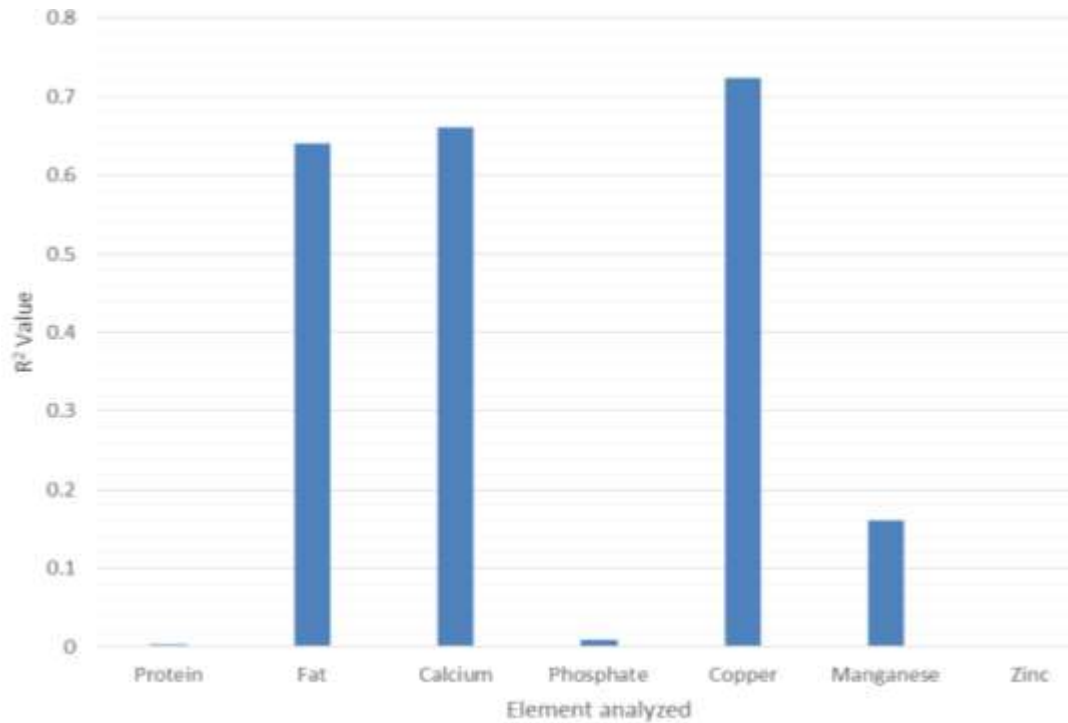


Figure 7. Relationship between nutrient levels in diets to feed intake.
Source: Authors Results

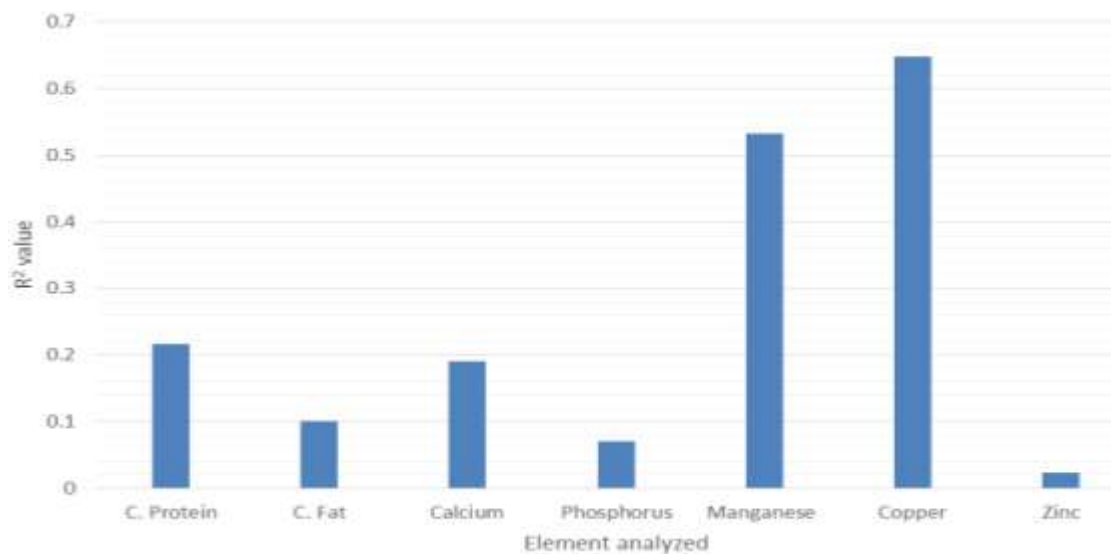


Figure 8. Correlation between feed nutrients analyzed and food conversion ratio (FCR).
Source: Authors Results

magnesium, manganese and zinc hence seem not to have a significantly high level of correlation to feed intake as depicted in Figure 7. The opposite is true in the feed conversion ratio as depicted in Figure 8.

Tabeidian et al. (2010) observed that a 2% dietary fat

resulted in a higher feed intake ($p < 0.05$) body weight change and feed efficiency ($p < 0.01$). Higher calcium inclusions had no significant effect on improving feed intake, body weight and feed efficiency ($p < 0.05$). The interaction between fat and calcium for feed intake, final

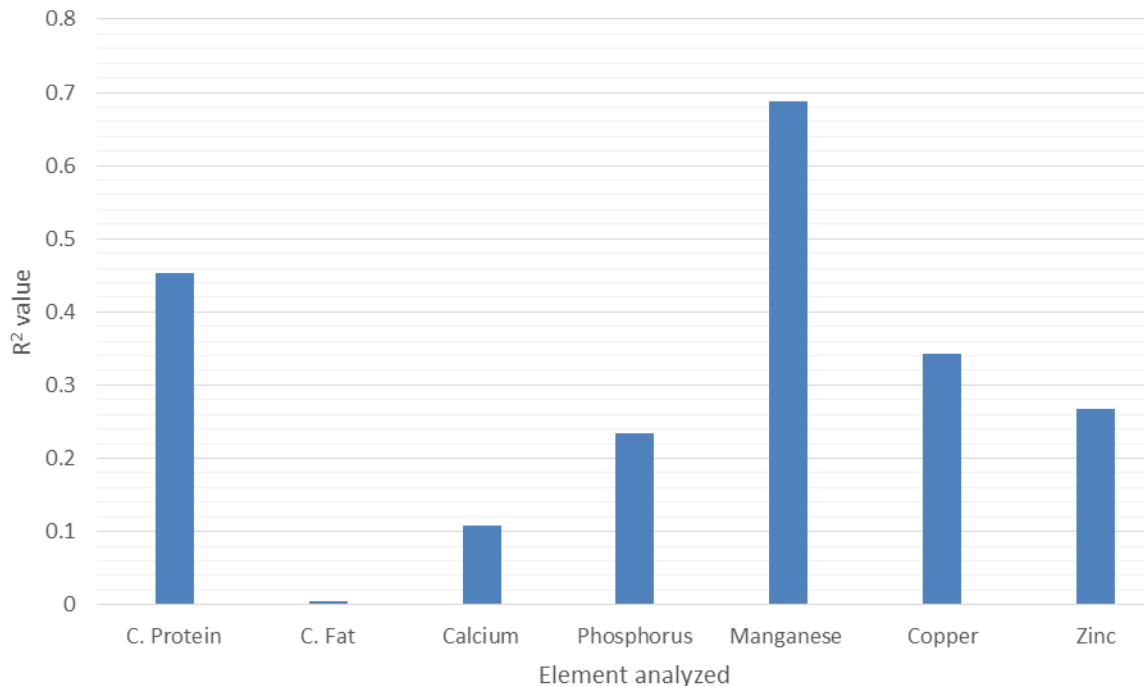


Figure 9. Correlation between feed nutrients analyzed and mean egg mass.
Source: Authors Results

body weight gain and feed efficiency was not significant. Appropriate levels of calcium and phosphate help in improving feed conversion and weight gain of the hens.

Manganese and copper have a high direct linear correlation to feed conversion ratio as depicted in Figure 8. This is in line with the functional and structural roles these two play hence the very high correlation.

Jonsson et al. (2010) noted that, generally diet had no significant effect ($P < 0.05$) on laying percentage, egg mass, eggs per hen housed, feed intake, FCR, mortality, live weight at 51 or 72 weeks, or proportion of misplaced, cracked or dirty eggs. This is contrary to this observation that somehow manganese and crude protein in feed have a role with a high linear correlation to mean egg mass. Diet showed a tendency ($P < 0.06$) to significantly affect egg weight. This is also supported by Tabeidian et al. (2011).

There is low correlation between crude protein, manganese and copper to number of eggs produced as depicted in Figure 10. This proves to a significant extent that diet has no significant effect on number of eggs produced and also on average number of eggs per hen housed. Manganese helps deposit proteins in the eggshell matrix and as age of flock increases, more manganese action is required to keep up with increasing egg size and weight and also to keep up with balancing shell weight ratio as depicted in Figure 10 with high manganese correlation. This in some way is determining and maintaining egg quality in a significant way.

As second order linear relationship, none of the

elements under study had a significant direct correlation to egg size as depicted in Figure 11. Mathematical modelling using linear relationships cannot be used for optimizing egg size using diet with the prescribed nutritional composition. The range of R^2 values was from 0.01 to 0.019, which is too trivial to be considered significant.

The major difference between the two diets is in manganese as depicted in Table 5. Data in Figure 3 was used to come up with Table 5. Egg size has been noted to be an inherent property of the hen or breed hence none of the elements under study can be manipulated to optimize on egg size. No small eggs were observed within the period under review. Diet 3 produced the largest number of large eggs per bird, that is 85 and Diet 1 produced the least number of eggs that is 74, that is on average.

Conclusion

There is no consistency in feed quality maintenance from the manufacturers ($p < 0.01$ at 95% CI). From correlation results displayed in this study, it is visible that fluctuations in diet nutritional composition can impact on egg quality. Egg size is an inherent trait that is centered on the breed of hens. Feed intake, protein content of egg white, yolk, and egg shell strength could be optimized by playing around with nutrients in feed. The elements that can be used for the optimization are fat, calcium copper,

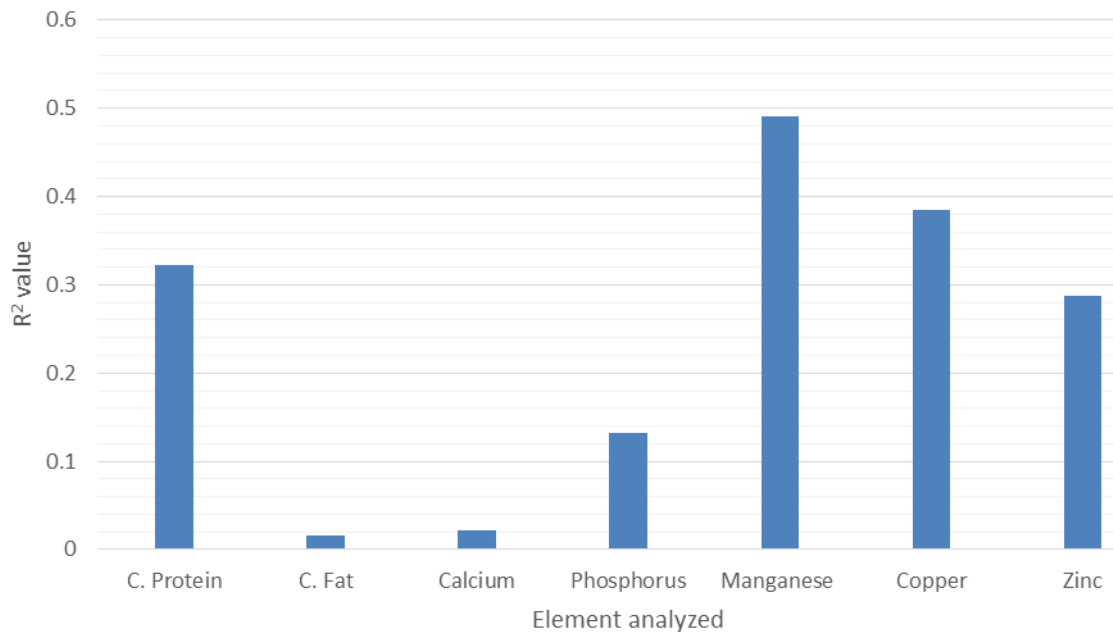


Figure 10. Correlation between feed nutrients and number of eggs produced.
Source: Authors Results

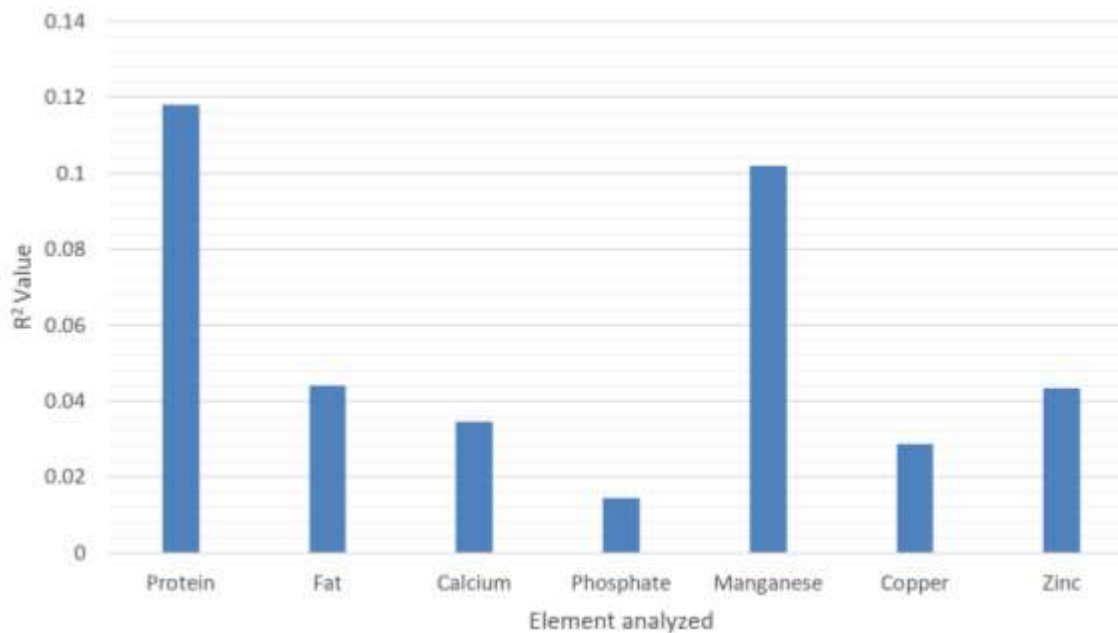


Figure 11. Correlation between nutrient levels in feed and egg size.
Source: Authors Results

manganese and zinc. Fat, copper ($R^2 = 0.91$) and zinc have a high correlation to cracking of eggs. Generally, it is not possible to optimize all the positive traits at once but one can make do with those traits that are of significance to their intentions for a particular client.

Breeders can come up with hens that have almost all the positive traits. Diet makes up for the breeders' deficit in trait optimization to suit a particular market. That is precision feeding and can have a big impact on the egg industry. If consistency in nutrient supply determines

Table 5. Comparison of Diet 3 to Diet 1 nutrient traits in explaining prolonged production of large eggs.

Trait	Diet 3	Diet 1
CP Content	Comparable	Comparable
Phosphorus content	Comparable	Comparable
Sodium Chloride	Comparable	Comparable
Calcium content	Comparable	comparable
Manganese content	Highest*	High*
Zinc content	Comparable	Comparable

Source: Authors Results

quality, fluctuations will have a toll on the physiology of the hen hence quality impaction on the egg.

RECOMMENDATIONS

Quantity alone does not suffice to meet the protein demands of the chickens. There is need to qualify and quantify the amino acids making up the proteins. Those that act as the limiting amino acids can be supplemented in one way or another especially through addition of synthetic amino acids. Dietary requirements for proteins and essential amino acids should be stated to ensure that all amino acids needed physiologically are provided. This study was kind of impartial and required an investigation into the influence of the other parameters that defines egg quality like albumen quality and aspects, shell deformation, shell breaking strength, albumen height, shell percentage and proportion of blood and meat spots. These parameters are much influenced by nutrition hence should be taken into consideration in defining quality of the egg in relation to feed. Metabolizing energy, feed structure, temperature, feeding space, health of hens, water quality and quantity, and housing effects has to be characterized again since they contribute to a systems productivity and production. These should be understood and optimized to get the best out of the hens. Last but not least, there is need to come up with a mathematical model to strike a balance on nutritional demand for a particular trait. A cost benefit analysis needs to be done in the context of egg quality production through this precision feed technology.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors express their profound gratitude to the role played by the Fertilizers, Farm Feeds and Remedies

Institute for its unwavering support from conception to completion of this study. Special thanks go to Ms. Nozipo Nziramasanga, the Head of Institute and also the Registrar for Fertilizers, Farm Feeds and Remedies for allowing the budgets, time and other resource channelization towards this study. They also pay respect due to the head of Henderson Research Institute for allowing this study to commence within his area of jurisdiction.

ABBREVIATIONS

AF, Abdominal fat; **Ca**, calcium; **CaPO₄**, calcium phosphate; **CI**, confidence Interval; **Cu**, copper; **CW**, carcass weight; **DC**, diet cost; **FAO**, Food and Agricultural Organization; **FCR**, food conversion ratio; **FE**, feed Efficiency; **FI**, feed intake; **Mn**, manganese; **NaCl**, sodium chloride; **NAP**, National Academic Press; **P**, phosphorus; **PUFA**, poly unsaturated fatty acids; **RCBD**, random complete block display.

REFERENCES

- Chang A (2021). The importance of nutrition on eggshell quality in broiler breeders. <https://www.thepoultrysite.com/articles/the-importance-of-nutrition-on-egg-shell-quality-in-broiler-breeders>
- Jacobs J (2021). Feeding chickens for egg production in small and backyard flocks. <https://poultry.extension.org/articles/feeds-and-feeding-of-poultry/feeding-chickens-for-egg-production/>;
- Exploratorium (2021). Science of an eggs: Anatomy of an egg. <https://www.exploratorium.edu/cooking/eggs/eggcomposition.html>;
- Food and Agriculture Organization (FAO) (2021). Small scale poultry production. Chapter 9: Marketing. <https://www.fao.org/3/y5169e/y5169e0a.htm>,
- Fisher C (Date Unknown). Energy and amino acid systems for formulating poultry feeds. In Proceedings of the 15th European Symposium on poultry nutrition, Balatonfüred, Hungary, 25-29 September, 2005 2005 (pp. 446-450). World's Poultry Science Association (WPSA).
- Fox IS (date unknown). Perspectives on human Biology. Wm. C Brown Publishers. ISBN 0-617-10785-x.
- Jonsson L, Wall H, Tauson R (2010). Production and egg quality in layers fed organic diets with mussel meal.
- Mateos GG, Sell JL (1981). Nature of the extra metabolic effect of supplemental fat in diets for laying hens. Poultry Science 60(8):1925-1930.

- Mongin P (1981). Recent advances in dietary anion-cation balance: applications in poultry. *Proceedings of the Nutrition Society* 40(3):285-294.
- NAP.edu/10766 (1994). *Nutrient Requirement of Poultry*, Ninth Edition, The National Academic Press, Chapter 1: Components of poultry diets. <https://www.nap.edu/read/2114/chapter/3>.
- National Research Council (1975). *World Hunger: Approaches to Engineering Actions: Report of a Seminar*. Washington, DC: The National Academies Press. <https://doi.org/10.17226/18516>.
- Pekel AY (2011). Effects of different dietary copper sources on laying hen performance and egg yolk cholesterol. *Journal of Applied Poultry Research* 20(4):506-513. <https://doi.org/10.3382/japr.2010-00313>
- Poultry World (2013). Factors affecting feed intake of chickens. <https://www.poultryworld.net/health-nutrition/factors-affecting-feed-intake-of-chickens/>
- Poultry World (2021). Improving shell quality and egg quantity with the right minerals. Nutrition Publication Editor: Brockotter Fabian. <https://www.poultryworld.net/health-nutrition/improving-shell-quality-and-egg-quantity-with-the-right-minerals/>
- Shafy TM, McDonal MW (1991). Effects of dietary calcium available phosphorus concentration on digesta pH and on the availability of calcium, iron, magnesium and zinc from the Intestinal Contents of Meat Chickens. *British Poultry Science* 32(1):185-194.
- Tabeidian SA, Ghafoori M, Bahrami Y, Chekani-Azar S, Toghyani M (2010). Effects of of different levels of dietary fat on broiler performance and production cost with emphasis on calcium and phosphorus absorption. *Global Veterinary* 5(1):54-60.
- Xanthophyll - Wikipedia: <https://en.wikipedia.org/wiki/Xanthophyll>
- Xiao JF, Zhang YN, Wu SG, Zhang HJ, Yue HY, Qi GH (2014). Manganese supplementation enhances the synthesis of glycosaminoglycan in eggshell membrane: A strategy to improve eggshell quality in laying hens. *Poultry Science* 93(2):380-388. <https://doi.org/10.3382/ps.2013-03354>.