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Economic Analysis, Egg Quality and Growth Parameters of Pullets Fed Graded Levels of Eggshell Meal

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ABSTRACT

Background and Objective: The use of local, cheap, and readily available materials, particularly those that are readily utilized by man, could serve as an economical source of calcium in livestock feeding. A 21-day feeding trial was conducted to investigate the effect of the use of ground chicken eggshells as a calcium source in layer diets on the economic analysis, egg quality, and growth parameters of pullets. **Materials and Methods:** The study specifically evaluated the growth, external eggshell quality, internal eggshell quality, and economic parameters of 60 Arbor Acres layers aged 24 weeks. The layers were housed in a conventional open-sided house containing 15 individual floor pens and acclimatized for 2 weeks. Thereafter, the initial weight of the layers was recorded before they were randomly assigned to 5 dietary treatments with 12 birds per treatment in a Completely Randomized Design (CRD). Each treatment group was further replicated 3 times with 4 birds per replicate. Diet 1 served as the control and did not contain eggshell meal. Diets 2, 3, 4, and 5 contained 1.0, 2.0, 3.0, and 4.0% of the eggshell meal, respectively. **Results:** The test diets 4 (23.53%) and 5 (27.45%) significantly ($p<0.05$) increased the weight of layers more than the control diet (5.88%). The percentage hen-day egg production for all the test diets 3, 4, and 5 was significantly ($p<0.05$) better than treatment diet 1. The feed cost/kg for the test diets 2, 3, 4, and 5 was significant ($p<0.005$) and more economical than treatment 1 (control diet). **Conclusion:** The eggshell meal significantly improved the growth parameters, egg quality traits, and the economics of egg production in laying chickens..

KEYWORDS

Economic analysis, growth parameters, egg shell, pullets, external egg qualities, internal egg qualities

INTRODUCTION

The search for unconventional feed ingredients that will not confer any deleterious effects on birds, serve as alternative sources of cheap protein, energy, and minerals, and drive down the escalating feed ingredients and feed costs, as well as bridge the animal protein gap, has attracted a lot of interest from researchers. As the sole practical substitute for traditional feedstuffs, the utilization of widely available,

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affordable, and locally sourced materials, especially those that are not easily used by humans, has drawn special attention[1-3]. The Nigerian feed mills and humans have long engaged in fierce competition over traditional feed ingredients, including fish meal, soy beans, and groundnuts. The high cost of feedstuffs has contributed to the poor performance of many poultry farmers and thus has led to the chronic deficits in the supply of animal protein to the citizenry[4].

The natural process of developing and laying an egg significantly diminishes the hen of her calcium reserves. Serious and potentially fatal complications could arise if there is no method to replace the calcium that is used. When egg production is at its highest, hens are particularly susceptible to cage layer fatigue issues, particularly if they are kept in cage systems with a high stocking density. The most crucial element in avoiding cage layer weariness is making sure the hens are getting enough calcium from their food. A calcium deficit may result from competition for calcium intake, inadequate calcium in the feed, the use of an inappropriate calcium source, or problems with calcium absorption brought on by a weak medullary bone matrix[5,6]. It can also be the consequence of the nutritionist's calculations and mixing errors during feed preparation. Thin egg shells and a decrease in egg production are signs of cage layer fatigue that can be observed during flock performance monitoring. Other signs, meanwhile, are severe and raise significant issues with animal welfare: Brittle bones, weakness, and dehydration or starvation-related death. Bone meal and limestone are the main sources of calcium in poultry feed. However, eggshells are a free "waste" product that may be obtained from hatcheries and other commercial users for little to no expense, unlike limestone and bone meal. To prevent feed rejection, it is a good idea to combine grower mash with layer mash when a change is being considered because the latter is higher in calcium than the former and the two are not equally palatable. It is advisable not to provide chickens with additional calcium until they start egg production. This is because the calcium requirement increases at the onset of egg production due to the requirement for eggshell formation. Hence, the change from grower to layer ration must be gradual.

Calcium is one of the key nutrients required for the production and optimal eggshell quality of laying hens[7]. According to Hisasaga *et al.*[8] calcium deficiency leads to decreased egg production, egg weight, egg specific gravity, feed consumption, bone density, and bone strength. Acceptability and market value of commercial table eggs are related to egg quality[8]. According to Cufadar *et al.*[9], the total number and quality of eggs produced, size, interior, and eggshell quality have, impact on the economy of the egg production enterprise. This explains, to some extent, why farmers grade their eggs. Sometimes the word “grading” is used to refer only to sorting eggs for size, but the term generally implies sorting for all the qualities taken into consideration in packing eggs for market. Nutrition and health influence the quality of commercial table eggs. Calcium is not only an important micronutrient for shell strength; it is also the main mineral component of the egg shell and also responsible for internal egg quality[9]. The present study evaluated the effect of eggshell meal as a source of dietary calcium on the economic analysis, growth performance, and egg quality traits of laying chickens.

MATERIALS AND METHODS

Study location: The study was carried out between December, 2022 and May, 2023 at the Poultry Unit of the Imo State Polytechnic Teaching and Research Farm, Umuagwo, Ohaji, Imo State, Nigeria. The site has the coordinates of Latitude 5°29’0”North and Longitude 7°2’0”East of Greenwich Meridian, altitude of 156 m (511 ft) and 12 km South of the Owerri Capital Territory. The annual relative humidity is 75%, with humidity reaching 90% in the rainy season. It has an average yearly rainfall of 172-190 mm, which is uniformly distributed. The area experiences maximum and minimum temperatures of 34, and 18°C, respectively. The dry season experiences two months of harmattan from late December to February. The hottest months are between January and March. The experimental site is located within the tropical evergreen rain forest belt of South-Eastern Nigeria[10]. The experiment lasted for 6 months.

Procurement of study materials: The major material, eggshells, was collected at no cost from a nearby hatchery located in Owerri West Local Government Area (LGA), Owerri, Imo State, Nigeria.

Production of eggshell meal: The shells were washed without removing the shell membranes and sterilized with boiled water for one hour and thirty minutes before sun drying. Thereafter, they were milled to obtain the eggshell meal. The eggshell meal was later subjected to mineral analysis to determine its mineral composition.

Chemical analysis: Proximate (protein, magnesium, sodium, calcium, potassium, and phosphorus) composition of egg shell meal was determined following the standard method of the Association of Official Analytical Chemists (AOAC)[11].

Feed formulation: Five experimental diets were formulated, consisting of graded levels of eggshell meal and other micronutrients at the recommended levels to meet the requirements of the birds as prescribed by Oluyemi and Roberts[12]. Diet 1 served as the control and did not contain eggshell meal. Diets 2, 3, 4, and 5 contained 1.0, 2.0, 3.0, and 4.0% of eggshell meal, respectively. The ingredients and calculated chemical analyses of the feeds are shown in Table 1.

Experimental design: A total of 60 Arbor Acres layers, aged 24 weeks, were housed in a conventional open-sided house containing 15 individual floor pens and acclimatized for 2 weeks. The layers were weighed at the beginning of the study, before placing them on the test diet. Later, they were randomly assigned to 5 dietary treatments with 12 birds per treatment in a Completely Randomized Design (CRD). Each treatment group was further replicated 3 times with 4 birds per replicate. Throughout the experimental period, the birds were provided with feed and water at all times, starting from 7.00 am daily for the 21 days the experimental trial lasted.

Table 1: Estimated nutrient composition of the experimental diets

Ingredient (%)	Control (0%)	Diet 2 (1.0%)	Diet 3 (2.0%)	Diet 4 (3.0%)	Diet 5 (4.0%)
Maize	50.00	50.00	50.00	50.00	50.00
Soybean meal	29.00	29.00	29.00	29.00	29.00
Vegetable oil	2.62	2.62	2.62	2.62	2.62
Ground eggshell	0	1	2	3	4
Wheat offal	7.99	8.00	7.00	6.00	5.00
Lysine	0.11	0.11	0.11	0.11	0.11
Methionine 99%	0.11	0.11	0.11	0.11	0.11
Limestone	8.22	8.22	8.22	8.22	8.22
Salt	0.38	0.38	0.38	0.38	0.38
Vitamin mineral premix[2]	0.50	0.50	0.50	0.50	0.50
Toxin Binder	0.60	0.60	0.60	0.60	0.60
Total	100.00	100.00	100.00	100.00	100.00
Calculated analysis (%)					
Crude protein	18.00	18.00	18.00	18.00	18.00
ME (kcal/kg)	2,806	2,802	2, 804	2, 806	2, 807
Crude fiber	3.63	3.65	3.66	3.66	3.66
Fat	5.96	5.96	5.97	5.99	5.99
Methionine	0.40	0.39	0.39	0.39	0.39
Lysine	1.14	1.12	1.11	1.11	1.10
Calcium	3.11	3.11	3.10	3.10	3.10
Total phosphorus	0.82	0.82	0.81	0.82	0.82
Available phosphorus	0.45	0.45	0.45	0.45	0.45
Cost/bag of feed	7729	7617	7603	7589	7574

[2]Vitamin/Mineral Premix: Source: Bio-organics® high potency vitamins and trace mineral premix for layers Vitamin A: 12, 000,000 iu, Vitamin D3: 2,500,000 iu, Vitamin E: 20,0000 mg, Vitamin K3: 2,000 mg, Vitamin B1: 2,000 mg, Vitamin. B2: 5,000 mg, Niacin: 30,000 mg, Pantothenic Acid: 11,000 mg, Vitamin. B6: 4000 mg, Vitamin B12: 15 mg, Folic Acid: 1,500 mg, Biotin H2: 60 mg, Choline chloride: 220,000 mg, Cobalt: 200 mg, Copper 3,000 mg, Iron: 20,000 mg, Manganese: 50,000 mg, Selenium: 1,000 mg, Zinc: 40,000mg, and Antioxidant: 1,250 mg

Data collection: The initial live weight of the birds was measured at the inception of the experiment and subsequently measured on a weekly basis to evaluate weight changes. The initial weight was the weight of the birds before the experiment began. The final weight was the weight of the birds at the end of the experiment. Weight gain was computed by subtracting the initial weight from the final weight. Mortality was computed by the number of dead birds divided by the total number of birds and multiplied by 100. The daily feed intake was measured by subtracting the weight of leftover feed from the weight of feed given in the previous day, usually between 7 am and 7: 30 am. The feed conversion ratio was calculated for each replicate by dividing the daily feed intake by the daily weight gain. Eggs were collected twice daily, morning and evening, to calculate the percentage hen-day egg production and for egg quality characteristics analysis. The egg quality parameters measured were specific gravity, Haugh Unit, yolk index, albumen index, shape index, shell thickness, and yolk color. The eggs were weighed after collection, and the average weight of each group was determined.

Cost analysis: The cost of feed per kilogram of diet was calculated using the current prevailing market prices of feed ingredients. The total feed intake was computed by multiplying the daily feed intake by the number of days of the experiment.

Feed intake per bird for the 21 days that the birds were on the experimental diet was used to multiply the cost of feed consumed per bird. The mean daily weight gain per bird was calculated by dividing the mean weight gain by the 21 days the experiment lasted. The mean daily feed intake per bird was estimated by summing all feed consumed and dividing the result by the number of birds that ate the meal. Feed conversion ratio was calculated as kilogram feed divided by kilogram of eggs laid, hen-day-egg production was calculated as the number of eggs produced in a day divided by the number of birds alive on the day under consideration and multiplied by 100%, and feed cost per kilogram was calculated as the kilogram of feed fed multiplied by the feed cost. For the purpose of analyzing the quality of the eggs, five eggs were chosen from each treatment group on the seventh, fourteenth, and twenty-first days of each week.

Determination of quality characteristics: The specific gravity (SG) method involves immersing groups of eggs in saline solutions of progressively higher SG and removing those that float in each solution. As well as the alternative method measuring the weight of each egg in air, immerse the egg in water and reweigh it, and then estimate the SG by Archimedes principle: SG = (weight in air)+(difference between weights in air and water)[14] were the methods used in determining egg quality. The Haugh unit was calculated as described by Haugh, using the following formula: Haugh unit $=100\times\log$ (Albumen height$+7.57-1.7\times$egg weight$^{0.37}$).

The height to width ratio of the yolk is known as the yolk index. The computation was performed according to Lee *et al.*[13]. The albumen height (mm) was divided by the albumen length (mm) plus the albumen breadth (mm), and the result was multiplied by 100 to get the albumen index. After the eggshells were cleaned and allowed to air dry for three days, five multiple measurements were made at the broad and narrow poles, as well as at the equator of each shell, using vernier calipers to measure the thickness of the shells. The five measurements were arithmetically averaged to determine the shell thickness. Anderson *et al.*[14] equation was used to obtain the shape index. The shape index was calculated with the values obtained from the measurements of the width and height of the eggs, which were done by using vernier calipers.

Ethical consideration: All aspects of the study were approved and based on the guidelines of the Animal Care and Use Committee of the Imo State Polytechnic, Umuagwo, Ohaji, Imo State, Nigeria.

Statistical analysis: All data collected were subjected to statistical analysis using a one-way analysis of variance (ANOVA) contained in Statistical Package for the Social Sciences (SPSS)[15] inc.16.0 evaluation version for Windows. Significant mean levels ($p<0.05$) were separated using least significant difference (LSD).

RESULTS AND DISCUSSION

The nutrient composition of egg shell meal was presented in Table 2. The sample contains high amounts of protein (5.2%) and calcium (34.71%) and low levels of sodium, magnesium, potassium, and phosphorus. The estimated nutrient composition of test diets presented in Table 1 was calculated with an established feed composition[13]. Table 1 reveals minimal to no difference in the quantity and nutrient composition of test diets and the control. It also revealed a lower cost per bag of the test diets compared to the control diet (conventional feed).

Growth indices

Initial body weight (kg) and final body weight (kg): Table 3 shows the effects of chicken eggshell meal on initial body weight (kg) and final body weight (kg) of 24 week old layer birds. The average initial body weights were almost similar ($p>0.05$) in all four treatments, whereas the average final body weight for treatments 4 and 5 was significantly ($p<0.05$) different from treatments 1, 2, and 3. The significantly ($p<0.05$) highest average final body weight of layers was observed in the group fed diet 5 (1.95 kg), while the lowest (1.62 kg) was observed in the control diet, but comparable with the values 1.62 and 1.73 kg recorded for layers offered diets 2 and 3, respectively. This result is in contrast with the findings of Gongruttananun[16], who reported no significant difference in body weight of Rhode Island female chickens fed eggshell as a calcium source.

The results on growth performance also revealed that birds on diets 4 and 5 recorded significantly more weight gain ($p<0.05$) than those on diets 3 and 2, while those on the control diet had the least average body weight gain. This result suggests that eggshell meals at 4 and 5% inclusion levels could improve the birds' body weight gain, although further study is necessary to unravel the mechanism behind this claim.

Hen-day egg production (%): The hen-day egg production is an indicator of how well the live birds are doing on the farm. In this study, the hen-day egg production (Table 3) was significantly ($p>0.05$) higher in eggshell-supplemented diets (diets 2-4) than the control diets. The maximum egg laying percentage

Table 2: Protein and mineral composition of egg shell meal

Mineral	Amount (%)
Crude protein	5.20
Magnesium	0.365
Sodium	0.7
Calcium	34.71
Potassium	0.078
Phosphorus	0.001

Table 3: Effects of ground chicken eggshells on growth indices of 24 week old layer birds

Parameter	Control (0% eggshell meal)	Diet 2 (1.0% eggshell meal)	Diet 3 (2.0% eggshell meal)	Diet 4 (3.0% eggshell meal)	Diet 5 (4.0% eggshell meal)	SEM
Initial body weight (kg)	1.53^a	1.53^a	1.54^a	1.53^a	1.53^a	0.002
Final body weight (kg)	1.62^b	1.67^b	1.73^b	1.89^a	1.95^a	0.064
Body weight gaian (kg)	0.09^c	0.14^b	0.19^b	0.360^a	0.42^a	0.064
Hen day egg production (%)	70.17^b	74.45^a	75.22^a	75.22^a	75.30^a	0.988
Egg weight (g)	58.11^b	58.86^b	59.11	59.35^a	59.40^a	0.235
Average feed intake (g/bird/day)	90.30^a	86.20^b	85.10^c	84.90^c	84.15^d	1.093
Feed conversion ratio (FCR)	1.54^a	1.46^a	1.44^a	1.43^a	1.42^a	0.022

[a,b,c,d]Mean values within rows without a common superscript are significantly different ($p<0.05$) and SEM: Standard Error Mean

was recorded in diets 3, 4, and 5 (75.22, 75.22, and 75.30%, respectively), and the minimum egg laying percentage was recorded in treatment diet 1 (control) (70.17%). This result aligned with the findings of Jahan *et al.*[17], who observed a significant increase in egg production in turkeys offered eggshell and limestone-supplemented diets than those fed limestone-based diets.

Average feed intake (g/bird/day): Feed consumption in poultry is regulated by nutrient density in the diet, and more specifically, birds consume feed to fulfill the requirements of energy and protein. The average feed intake (g/bird/day) is shown in Table 3. The result from the present study shows that feed intake decreases as the inclusion rate of ground eggshells increases. The layers placed on diet 1 (the control) had the highest significant ($p<0.05$) average daily feed intake than those fed eggshell-supplemented diets. The respective numerical values were 90.30, 86.20, 85.10, 84.90, and 84.15g/bird/day for treatment diets 1, 2, 3, 4, and 5. This result shows that eggshell meal may have an interference with the feed intake of laying chickens however, this does not translate to a decline in production. On the other hand, Gongruttananun[16] found that eggshell meal did not interfere with the feed intake of laying chickens.

Feed conversion ratio (FCR): Throughout the 3-week period of this experiment, feed conversion ratio (FCR) was not significant ($p>0.05$) among all the treatment diets (Table 3). The values were 1.54, 1.46, 1.44, 1.43, and 1.42 recorded for treatments 1, 2, 3, 4 and 5, respectively. Nevertheless, the birds placed on eggshell meal-supplemented diets had lower FCR than the control. Feed conversion ratio is the ratio between feed intake and the number of eggs produced. The lower the feed conversion ratio, the more advantageous it is to the farmers. That means that it takes less feed to produce a crate of eggs. Birds that were the best in feed conversion provided the greatest return on money invested. It is, therefore, an important production parameter in the commercial layer industry. Hence, this result suggests that layers placed on diets 2-5 performed better than those on the control diet. Gongruttananun[16] also noted no significant difference in FCR of Rhode Island layers fed eggshell-based diets.

External egg quality traits: The external egg quality traits of 24 week old layer birds fed ground chicken eggshells are shown in Table 4. According to Biesiada-Drzazga *et al.*[18], external egg quality is determined by characteristics like egg weight, egg specific gravity, shape index, and shell thickness.

Average egg weight (g): The average egg weights, as shown in Table 4 were significantly ($p<0.05$) higher in eggs of birds fed diets 3, 4, and 5 (59.21, 59.35 and 59.40 g, respectively) than the eggs from birds placed on the control (58.11 g) and diet 2 (58.86 g). Differences among treatment diets 3, 4, and 5 were not significant ($p>0.05$). Chick weight is expressed as the percentage of egg weight; the larger the egg, the bigger the chick. The results from the present study confirmed the findings of Gongruttananun[16], who reported that dried chicken eggshells could be used as the sole calcium source in layer diets without detrimental effects on egg weight.

Table 4: Effects of chicken eggshells on the egg quality traits of 24 week old layer birds

Egg quality parameter	Treatment					
External	Control (0%)	Diet 2 (1%)	Diet 3 (2%)	Diet 4 (3%)	Diet 5 (4%)	SEM
Egg weight (g)	58.11^b	58.86^b	59.21^a	59.350^a	59.40^a	0.235
Shell thickness (mm)	0.32^a	0.32^a	0.32^a	0.32^a	0.32^a	0.854
Egg specific gravity	1.075^a	1.075^a	1.075^a	1.074^a	1.074^a	0.289
Shape Index	70.00^b	72.38^a	71.85^a	72.85^a	72.85^a	0.530
Internal						
Albumen height (mm)	6.21^b	6.32^b	6.51^a	6.62^a	6.68^a	0.091
Yolk index	0.34^b	0.42^a	0.45^a	0.46^a	0.47^a	0.242
Egg yolk colour	7.0^a	7.0^a	7.1^a	7.1^a	7.1^a	0.245
Haugh units	76.6^b	76.73^b	77.46^b	78.01^a	78.34^a	0.342

^{a,b,c,d}Mean values within rows without a common superscript are significantly different ($P<0.05$) and SEM: Standard Error Mean

Shell thickness (mm): Shell thickness is an important external egg quality factor, which is dependent on dietary regimen among many factors. From Table 4, it can be observed that the shell thickness of eggs from layers in all the dietary groups is statistically ($p>0.05$) similar throughout the experimental periods. This shows that calcium in the eggshells can be utilized by the birds as efficiently as calcium in limestone. Gongruttananun[16] demonstrated in a study involving eggshell calcium effects on egg quality and calcium digestibility in first or third cycle laying hens that calcium digestibility in particulate eggshells was comparable to that in fine limestone. The mean eggshell thickness values were 0.32, 0.32, 0.32, 0.32, and 0.32 mm at 0, 1, 2, 3, and 4% levels of inclusion of ground eggshell. The above findings closely approximate the findings of researchers for thin shells (0.28-0.30 mm) and medium shells (0.33-0.36 mm).

Egg specific gravity: Specific gravity is the ratio of the weight of an object to the weight of an equal volume of water. It indicates the quantity of shell relative to other components of the egg. Specific gravity and eggshell thickness are highly positively correlated; therefore, drying of the eggshell before use aided the measurement of egg thickness and eggshell quality. In this report, just like eggshell thickness, the specific gravity was not significantly ($p>0.05$) different among layers fed all the dietary treatments. The egg specific gravity values for treatments 1, 2, 3, 4, and 5 were 1.075, 1.075, 1.075, 1.074, and 1.074, respectively (Table 4). This result is in agreement with the findings of Gongruttananun[16], who observed no significant difference in egg specific gravity of Rhode Island layers fed eggshell meal as a calcium source.

Shape index: Egg shape index (Table 4) is the ratio of egg width to egg length multiplied by 100, and it is an important criterion in determining egg quality. The shape index of birds fed with 1.0, 2.0, 3.0, and 4.0% eggshell meal (Diets 2, 3, 4, and 5) was significantly higher ($p<0.05$) than those fed with 0% eggshell meal (Diet 1). This suggests that the inclusion of eggshell meal in the diet of layer birds can improve their egg shape index. A high egg shape index is often associated with better egg quality, as it indicates a stronger, more stable egg structure[19]. Therefore, a higher shape index recorded for eggs from eggshell supplemented groups implies better egg quality than those in the control group. Shape index values of 70.00, 72.38, 71.85, 72.85, and 72.85 were recorded for treatments 1, 2, 3, 4, and 5, respectively.

Internal egg quality traits: The internal egg quality traits of 24 week old layer birds fed ground chicken eggshells are also shown in Table 5. According to Sinha *et al.*[19], the internal egg quality characteristics are determined by Haugh unit, albumen index, yolk index, and yolk color.

Haugh unit (HU): Haugh unit measurement is an important industry measure of egg quality based on the height of its egg white (albumen) and egg weight; the higher the HU, the better the quality of the egg (fresher, higher quality eggs have thicker whites). Eggs from layers fed diets 4 and 5 had significantly ($p<0.05$) higher haugh units (78.01 and 78.34%, respectively) than those in groups 3, 2 and 1 (Table 4). Generally, the Haugh unit ranged from 76.60 to 78.34%, which is indicative of the freshness of the eggs from the layers used for this experiment. The values in this finding are lower than those reported by Sinha *et al.*[19] for eggs stored between 5 and 21°C, however, it also suggests that eggshell meal only had a positive influence on the egg quality.

Albumen height: The albumen height of birds fed with 2.0, 3.0, and 4.0% eggshell meal (Diets 3, 4, and 5) was significantly higher ($p<0.05$) than those fed with 0 and 1.0% eggshell meal (Diets 1 and 2) as depicted in Table 4. This suggests that the inclusion of eggshell meal in the diet of layer birds can improve the thickness and stability of the egg albumen[20]. This result indicated that eggs from birds placed on diets 3-5 are of better quality than those from diets 1 and 2.

Table 5: Economic analysis of eggs produced with conventional and test diets

Parameter (N)	Control (0%)	Diet 2 (1.0%)	Diet 3 (2.0%)	Diet 4 (3.0%)	Diet 5 (4.0%)	SEM
Feed cost/25 kg bag	7849[a]	7617[b]	7603[b]	7589[b]	7574[b]	27.593
Feed cost/ kg	313.96[a]	304.68[b]	304.12[b]	303.56[b]	302.96[b]	1.104
Feed cost/kg egg	1.54[a]	1.46[a]	1.44[a]	1.43[a]	1.42[a]	0.022
Cost of feed/kg feed intake (₦)	315.50[a]	306.14[b]	305.56[b]	304.99[b]	304.38[b]	1.125
Hen day egg production (%)	70.17[a]	74.45a[b]	75.22[b]	75.22[b]	75.30[b]	0.988

[a,b]Mean values within rows without a common superscript are significantly different ($p<0.05$) and SEM: Standard Error Mean

Yolk index: Yolk index is the measure of the freshness of an egg. As the egg deteriorates, the yolk index decreases. It is the measure of the standing- up of the yolk and declines slowly with the passage of time during the storage period[20]. In this experiment, the eggs were collected twice daily, morning and evening, for egg quality characteristics analysis, and, therefore, storage time was short, and egg quality deterioration did not apply. The yolk index in Table 4 showed that eggs of layers offered diets 2-5 had significantly ($p<0.05$) higher yolk index than those on diet 1. This suggests better egg quality because a high egg yolk index is often associated with improved nutritional quality, as the yolk is a rich source of essential fatty acids, vitamins, and minerals[21]. The yolk index scores range of 0.34 to 0.47 obtained in this study approximates the findings of Sinha *et al.*[19].

Yolk colour: This is an indicator of the hen's diet. Yolk colour is one of the main criteria by which consumers judge the quality of eggs. In this study, yolk colour was not significantly ($p>0.05$) different among all treatments. The yolk colour scores 7.0, 7.0, 7.1, 7.1 and 7.1 were recorded for treatment diets 1, 2, 3, 4, and 5, respectively. The findings were below the yolk color scores of 8, 10, 12, and 14 reported by Bovšková *et al.*[22].

Economic analysis: The economic analysis of the production of 24 week old Arbor Acres layers fed graded levels of ground chicken eggshells is shown in Table 5. The feed cost per kg bag was significantly ($p<0.05$) highest in treatment 1. Feed cost/kg bag for treatment diets 2, 3, 4, and 5 were not significantly ($p<0.05$) different from one another. The feed used (kg) to produce a kg of egg was not significant ($p>0.05$) across all treatment diets, with the control diet numerically poorer (1.54 kg feed/kg egg produced). The cost of feed/kg egg decreased numerically with an increase in the inclusion rate. The cost of feed per kg feed intake (₦/kg) for treatment diets 2, 3, 4, and 5 was significantly ($p<0.05$) less expensive than treatment 1. The respective values for treatments 1, 2, 3, 4, and 5 were ₦315.15, ₦306.14, ₦305.56, ₦304.99, and ₦304.38, respectively. The percentage hen day egg production for all treatment diets 3, 4, and 5 was significantly ($p<0.05$) better than treatment diet 1.

CONCLUSION

The present study revealed no deleterious effect of chicken eggshells on egg production, economics, and parameters of egg production, including internal and external quality traits. It rather improved the body weight gain of layers fed with test diets 4 and 5. Thus, this study unraveled the potential of eggshell meal as a replacement for limestone and/or bone meal in laying chicken feed. In the long run, this will have a positive impact on the cost of laying chicken feed production. Therefore, eggshells could be used as the sole calcium source in layer diets. However, when using chicken eggshells in layer feed formulation, attention must be paid to the appropriate particle size of the eggshell, as this may influence the retention time of calcium in the digestive tract.

SIGNIFICANCE STATEMENT

This study aimed to investigate the economics of pullet production using eggshell meal as a replacement for conventional calcium sources (limestone and bone meal). It was observed that the use of eggshell meal significantly reduced the cost of production and, at the same time, increased the growth performance, egg production, and egg quality. Thus, this study uncovered the potential of eggshell as a source of dietary calcium in pullet production.

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