IJAS Iranian Journal of Applied Animal Science

Impact of Dietary Sodium Bentonite and Direct Application of Aluminum Sulfate to the Litter on Egg Quality Traits and Laying Performance of Nigerian Noiler Hens

Research Article

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Received on: 1 Dec 2023
Revised on: 2 Jun 2024
Accepted on: 8 Jul 2024
Online Published on: Sep 2024

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Online version is available on: www.ijas.ir

ABSTRACT

Impact of dietary sodium bentonite (NaB) and direct application of aluminum sulfate (alum) to the litter on egg quality traits and laying performance of Nigerian noiler hens was investigated. A total of 180 (16 weeks old) Nigerian Noiler hens were allotted to 6 treatments groups in a 3 × 2 factorial arrangement in completely randomized design (CRD) consisting of 5 replicates of 6 hens each. Treatments included: T1= 0 g NaB/kg + 0 g alum/3 kg litter, T2= 15 g NaB/kg + 0 g alum/3 kg litter, T3= 30 g NaB/kg + 0 g alum/3 kg litter, T4= 0 g NaB/kg + 400 g alum/3 kg litter, T5= 15 g NaB/kg + 400 g alum/3 kg litter and T6= 30 g NaB/kg diet + 400 g alum/3 kg litter. Sodium bentonite was included in the diet at 3 levels (0, 15 and 30 g/kg diet), while aluminum sulfate was applied to the litter at two levels (0 and 400 g/3 kg litter). Results showed that values of egg quality traits (yolk weight, yolk height, yolk diameter, albumen weight, albumen diameter, yolk index, yolk ratio, yolk/albumen ratio, egg length, egg width, shell weight, shell thickness and egg shape index, haugh units) were higher (P<0.05) in treatment groups compared to control group. Furthermore, laying performance indices (hen day egg production, egg weight, egg mass, number of eggs produced per hen and crates of egg produced per hen) improved higher (P<0.05) in treatment groups compared to control group. In summary, the study observed that dietary sodium bentonite and direct application of aluminum sulfate to the litter improved laying performance and egg quality traits of Nigerian Noiler hens. It was therefore, concluded that 15 g NaB/kg diet + 400 g alum/3 kg litter can be applied by egg producing farmers for the improvement of laying performance and egg quality traits.

KEY WORDS aluminum sulfate, egg quality, laying performance, noiler hens, sodium bentonite.

INTRODUCTION

Poultry sector is among the top sectors that provide sources of animal proteins for human utilization (FAO, 2010). Therefore, efforts towards increasing protein need of the increasing global human population through an investment in the farming of dual-purpose birds known as Noilers is encouraged. Noiler hens are fair egg producers (Farming Advice Digest, Nigeria). However, poultry industry is faced with a number of challenges, such as high rate of mortality and reduction in egg production despite their high productive potentials in producing high quality protein of animal origin to the teeming global human population. This may be as a result of the prohibition placed on the utilization of antibiotics by the European Union as growth promoting and therapeutic agents in 2006 (Choi, 2018). According to

Kumar *et al.* (2020) the ban on the use of antibiotics in animal production is based on the fact that meat and eggs may contain antibiotic residues and bacteria that are resistant to antibiotics, which may cause allergic reactions, an imbalance in the microbiota of intestines, and antibiotic resistance in people. De Kraker *et al.* (2016) claimed that antibiotic resistance has become big issue and predicted that 10 million people are expected to die globally from resistant diseases by the year 2050.

Therefore, farmers have to look for a safe, cheap and easily available alternative compound that will not only serve as replacements for antibiotics, but will also improve performance and litter quality during production. One of such compounds is sodium bentonite. Sodium bentonite is high-water absorption natural clay formed by the devitrification of volcanic ash (Moosavi, 2017). The interesting properties of bentonite (hydration, swelling, water absorption and viscosity) makes it a valuable material for various uses and applications (Reddy *et al.* 2017). Numerous studies have stated that bentonite has the potential to bind to pathogenic bacteria, improve gut health, and increase digestive enzyme secretion (Mgbeahuruike *et al.* 2021). Sodium bentonite promoting intestinal health in farm animals mostly relies on epithelium protection by forming a colloid that covers the intestinal mucosa, preventing irritation, lesions and binding to the bacteria, toxins and eliminate them along with faeces (Vila-Donat and Marín, 2018). Dietary supplementation of clays such as bentonite can moderate the processes of digestion and nutrient absorption by promoting a longer retention time of digester, allowing its greater digestion and absorption. Supplementation of 0.50 g/kg bentonite in the laying hen diet improved gut health and contributed to an increase in egg production (Chen *et al.* 2020). According to Nasir *et al.* (2000) when bentonite was added to the diets of laying hens, egg production and egg size increased by 15% and 10%, respectively. Salari *et al.* (2006) indicated that chickens fed diets containing sodium bentonite consumed more feed, had more weight gain and less feed conversion ratio.

Poultry industry is also faced with environmental problems, such as litter ammonia gas production and its volatilization from the litter. According to Munk *et al.* (2017) ammonia gas is a byproduct of bacteria degrading protein-rich substrates like animal dung. Accumulation of ammonia gas in poultry houses has been found to have a number of negative consequences on the environment, farm workers, and on the health of birds (Salim *et al.* 2014). Ammonia gas causes severe immune system deficiency especially in the first 21 days of bird's life (Shah *et al.* 2020). Sheikh *et al.* (2018) ammonia-induced ocular blindness, is particularly a harmful occurrence. Ammonia gas decreased egg production significantly at the concentration of 102 ppm (Charles and Payne, 1966). Acidic amendment, which makes litter pH acidic and introduce unfavorable medium for microbial degradation of nitrogen carrying organic matter in the litter to ammonia gas and its volatilization from the litter is among the approaches employed to maintain high litter quality. Chemical treatment of litter lower slitter pH and thus discouraging the activity and proliferation of microbes (bacteria, protozoa and fungi) in the litter (De Toledo *et al.* 2020; Ezenwosu *et al.* 2022). Chemical litter treatment act by lowering the pH, inhibits microbial growth and putrefaction activity in the conversion of nitrogen to ammonia in the litter (Ritz *et al.* 2005).

One of the chemical compounds that can be used as a litter acidifier to reducing ammonia gas emission during productionis aluminum sulfate, also known as alum. Aluminum sulfate is a salt with chemical formula $Al_2(SO_4)_3$. The addition of aluminum sulfate to chicken litter has been found to be a cost-effective method of lowering ammonia gas production (Moore *et al.* 1999). Rothrock *et al.* (2008) stated that alum reduced litter pH, which resulted in pathogen decrease and, ultimately, improved productivity. By litter treatment with aluminum sulfate, ammonia emission can be inhibited by lowering manure pH, moisture and thus, decreasing the conversion of ammonium ions to ammonia (Li *et al.* 2013). Sahoo *et al.* (2017) reported that litter moisture content was lower in litter treated with alum than the control group. Ammonia fluxes from the alum-treated litter were 70% lower than untreated litter (Moore and Edwards, 2007). According to Madrid *et al.* (2012) using alum as a top dressing for new litter significantly reduced indoor ammonia concentrations as compared to non-treated groups and Do *et al.* (2005) obtain similar findings for a multi-flock litter. It has been demonstrated that decreasing NH_3 levels in poultry houses as a result of litter treatment with aluminum sulfate improved chicken performance, including lower mortality rates and increased earnings for poultry producers (Moore *et al.* 2011). According to Eid *et al.* (2022) egg number and egg weight of hens on litter treated with alum improved significantly more than those on untreated litter. Sodium bentonite as a feed additive has also some beneficial effect on litter quality. In the gastrointestinal tract, clays such as sodium bentonites have the capacity to absorb water in an amount many times greater than their weight, preventing it from remaining free in the excreta. It has been demonstrated by Lemos *et al.* (2015), Schneider *et al.* (2017) and Yalçin *et al.* (2017) that by reducing the rate of digester passage and colloid formation, clay such as bentonite positively improves the consistency of chicken faeces. It has also been shown that clays help to reduce the volume of harmful gastrointestinal gases, off-site transport of odors, and other facility pollutants such as ammonia (Slamova *et al.* 2011). Since litter treatment with aluminum sulfate and sodium bentonite all have beneficial effect on litter quality, it is expected in the current study that they will help to curtain the rate of odorous gas production such as ammonia and thus improved performance of the bords. The study was therefore designed to investigate the Impact of dietary sodium bentonite and direct application of aluminum sulfate to the litter on egg quality traits and laying performance of Nigerian Noiler hens.

MATERIALS AND METHODS

Ethical consideration

The research was carried out in conformity with 13th, November, 2013 research policy established by the University of Nigeria, Nsukka.

Study site

The study was carried out at the Poultry Units of the Department of Animal Science Teaching and Research Farm, University of Nigeria. Nsukka lies within longitude 6˚ 45′E and 7˚ E and latitude 7˚ 12.5 ′N and on the altitude of 447 m above sea level. The climate of the study area is typically tropical, with relative humidity ranging from 65 to 80% and mean daily temperature of 26.8 ˚C (Okonkwo and Akubuo, 2007). According to the Metrological Center, Crop Science Department, University of Nigeria, Nsukka Enugu State, the yearly rainfall of the study area ranges from 1567.05 mm-1846.98 mm. The feeding trial lasted for 12 weeks.

Characteristics of sodium bentonite and aluminum sulfate

Sodium bentonites are mineral clays with strong colloidal properties that absorb water rapidly and thus, resulting in swelling and a manifold increase in volume, giving rise to a thixotropic, gelatinous substance. Sodium bentonite used was produced by industrial minerals GmBH Construction and Specialties Germany. Aluminum sulfate is a salt with the formula $Al_2(SO4)_3$.

Experimental birds and management

A total of 180(16 weeks) old Noiler hens weighing 1700-1800 g at point of lay were allotted to 6 dietary treatments in a 3 × 2 factorial arrangement in a completely randomized design of 5 replicates of 6hens each. Treatments were as follows: T1= 0 g NaB/kg diet + 0 g alum/3 kg litter, T2= 15 g NaB/kg diet + 0 g alum/3 kg litter, T3= 30 g NaB/kg diet + 0 g alum/3 kg litter, T4= 0 g NaB/kg diet + 400 g alum/3 kg litter, T5= 15 g NaB/kg diet + 400 g alum/3 kg litter and T6= 30 g NaB/kg diet + 400 g alum/3 kg litter respectively. Litter materials used was wood shavings.

Treatment of the litter was done ones and the litter remained without being changed throughout the experimental periods.

Sensitive electronic scale of 0-6000 g capacity was used to weigh each 400 g alum used to treat the litter. Furthermore, 50% out of the 400 g aluminum sulfate used to treat the litter in each replicate in the various treatment combinations was spread on the bare floor first, while the remaining 50% was then mixed homogenously with the litter (new wood shavings) and gently spread equally. The reason for this is that microbial activity is higher beneath the litter than the top. Fresh drinking water and dietary treatments were provided continuously to the hens throughout the study. Schedules for vaccinations and other management practices for good flock health management practices were adhered to. The birds were housed in a well demarcated deed litter system and were looked after by a veterinarian throughout the experimental periods. The temperature of the experimental house was monitored using thermometer. Lighting was provided using a 200 v watt white bulbs. Picking of eggs were done twice a day (morning ang afternoon). For proper identification of eggs, daily collected eggs were marked with an indelible marker at the time of collection. Eggs were kept at room temperature in egg crates. At the end of each week throughout the time of the study, eggs laid by the hens in each replicate were counted and, 50% in each replicate were randomly selected for the evaluation of internal and external quality traits.

Experimental diet

The diet and its proximate compositions are shown in Tables 1. The chemical compositions of the basal diet were analyzed in accordance with the procedures of AOAC (2012).

Determination external egg quality

Egg length and width were determined using electronic vernier caliper. Electronic scale of 0-6000 g capacity was used for measuring shell weight after one day long drying at room temperature. Shell thickness was calculated using electronic vernier caliper as follows:

Shell thickness= (thickness of blunt part+thickness of equatorial part+thickness of sharp part) / 3

Egg shape index (%)= (egg width/egg length) × 100

Haugh Units (HU)= 100 $\log_{10}$ $(H+7.5–1.7W^{0.37})$

Determination of internal egg quality

Albumen weight (g)= egg weight – (yolk weight+shell weight).

Electronic scale (0.00 g) was used to measure yolk weight after its separation from albumen using yolk separator. The height of albumen and yolk were measured using P6085 spherometer (tripod electronic micrometer) with 0.01 mm accuracy in a flat dish.

Yolk index (%)= (yolk height/yolk diameter) × 100

Albumen length, albumen diameter and yolk diameter were measured using electronic vernier caliper.

Albumen index (%)= [albumen height / (minimal+maximal albumen diameter/2)] × 100
Albumen ratio (%)= yolk weight / albumen weight
Yolk ratio= (yolk weight/egg weight) × 100
Albumen ratio= (albumen weight/egg weight) × 100
Shell ratio= (shell weight/egg weight) × 100

Table 1 Ingredient and chemical compositions of the diet

Ingredients (%)	Percentage
Maize	44.00
Wheat middling	22.00
Palm kernel cake	12.00
Soybean meal	14.00
Oyster shell	2.00
Pail oil	2.00
Bone meal	3.00
Lysine	0.25
Methionine	0.25
Salt	0.25
Vitamin and mineral premix[1]	0.25
Total	100
Calculated composition	
Crude protein (%)	16.50
Metabolizable energy (kcal/kg)	2590.00
Calcium (%)	3.50
Phosphorous (%)	0.50
Chemical compositions (%)	
Crude fiber	6.45
Ether extract	3.50
Crude matter	91.00
Crude protein	16.45
Nitrogen free extract	64.95

[1] Vitamins and minerals premix compositions: vitamin A: 10 000000 IU; vitamin D_3: 2000000 IU; vitamin E: 10000 mg; vitamin K_3: 1000 mg; vitamin B_1: 1000 mg; vitamin B_2: 5000 mg; vitamin B_6: 1500 mg; vitamin B_{12}: 10 mg; Pantothenic acid 10000 mg; Niacin: 30000 mg; Biotin: 50 mg; Folic acid: 1000 mg; Choline 250 mg; Selenium: 100 mg; Copper: 4000 mg; Iron: 30000 mg; Manganese: 60000 mg; Zinc: 50000 mg; Iodine: 1000 mg; Cobalt: 100 mg and $CaCO_3$: 3000 g.

Laying performance

HDEP (%)= (total number of eggs produced during the period/total number of hen-days in the same period) × 100

Egg production per bird= total number of eggs laid during the period /number of birds for the period.
Average egg weight= total weights of all the egg laid in each replicate / number of eggs weighed.
Total crates of eggs laid per bird= total number of eggs laid per replicate / 30.
Egg mass (per hen per day in gram)= (per cent HDEP×average egg weight in grams) / 100

Experimental design and analysis

Data collected were subjected to way Analysis of Variance (ANOVA) and significant differences among the treatment means were separated using Duncan's New Multiple Range Test (Duncan, 1955) with the aid of IBM SPSS Statistics version 28 (IBM Corp. Released, 2021; SPSS, 2011) and accepted at 5% (P<0.05) level of probability.

The statistical model used to test the effect of treatments on the entire parameters determined was stated below:

$$X_{ijk}= \mu + A_i + B_j + (AB)_{ij} + \sum_{ijk}$$

Where:
A and B represents the two factors.
X_{ijk}: overall observation on effect of the treatments.
μ: mean of the population or overall mean.
A_i: impact of sodium bentonite.
B_j: impact of aluminum sulfate.
$(AB)_{ij}$: interaction of bentonite and aluminum sulfate.
$\sum_{ijk}$: experimental or random error.

RESULTS AND DISCUSSION

Results of the impact of the interaction of dietary of sodium bentonite and direct application of aluminum sulfate on weekly internal egg quality traits of Nigerian Noiler hens are shown in Table 2 a-d.

At week 2-6 and 8-11, values of yolk weight were significant (P<0.05) across the treatments with the values being higher (P<0.05) in treatment groups compared to control group. Values of yolk height were significant (P<0.05) among the treatments at week 2, 4 and 6 and the value improved higher in treatment groups compared to control group. Values of yolk diameter were significantly (P<0.05) influenced by the treatments at week 3, 7, 8, 9 and 12. Values of yolk diameter were lower in control group compared to treatment groups at week 3, 7, 8 and 12, while at week 9, value of yolk diameter obtained in T1 (control) was the same (P>0.05) with the values recorded in T2, T3, T5 and T6, but both were significantly lower than the value obtained in T4.

Albumen weight values were only significant (P<0.05) among the treatments at week 2-9 and 10-12 with the value recorded in T1 being lower compared to values recorded in treatment groups. Values of albumen diameter across the treatments were significant (P<0.05) at week 2-8 and 10-12 and value observed for hens on T1 was lower compared to values recorded in treatment groups. Values of albumen height were significant (P<0.05) only at week 1, 4-6 and 8 and the value was lower in T1 compared to treatment groups.

Table 2a Impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on weekly internal egg quality traits of Nigerian Noiler hens (12 weeks)

Parameter	Treatments						SEM	P-values
	T1	T2	T3	T4	T5	T6		
Yolk weight (g)								
Week1	8.53	9.33	9.40	8.33	8.70	8.896	0.17	0.42
Week 2	9.78^{bc}	10.60^{ab}	11.35^{a}	10.63^{ab}	9.48^{bc}	9.73^{c}	0.20	0.10
Week 3	9.30^{b}	11.00^{a}	11.63^{a}	10.36^{ab}	10.63^{ab}	11.36^{a}	0.21	0.02
Week 4	10.50^{b}	11.93^{a}	11.60^{ab}	12.83^{a}	11.53^{ab}	11.76^{ab}	0.20	0.00
Week 5	11.63^{b}	13.76^{a}	13.63^{a}	12.36^{b}	13.53^{a}	13.80^{a}	0.18	0.02
Week 6	13.06^{b}	13.93^{ab}	14.43^{a}	13.16^{b}	14.26^{a}	13.66^{ab}	0.15	0.00
Week 7	13.83	14.13	14.03	13.83	13.93	14.66	0.10	0.15
Week 8	14.10^{b}	15.03^{a}	15.06^{a}	14.36^{ab}	15.96^{a}	14.93^{a}	0.10	0.01
Week 9	14.63^{c}	15.70^{a}	15.85^{c}	14.63^{c}	15.85^{a}	15.30^{ab}	0.11	0.00
Week 10	14.40^{c}	15.86^{a}	14.96^{bc}	14.73^{c}	15.80^{a}	15.60^{ab}	0.13	0.00
Week 11	14.76^{ab}	15.43^{ab}	15.33^{ab}	14.33^{b}	15.86^{a}	15.43^{ab}	0.15	0.05
Week 12	15.63	16.10	16.20	15.63	16.33	16.00	0.09	0.13
Yolk height (mm)								
Week 1	10.66	11.33	14.00	12.66	12.00	13.16	0.39	0.13
Week 2	12.83^{b}	14.40^{a}	12.16^{b}	12.66^{b}	12.83^{b}	13.33^{ab}	0.18	0.00
Week 3	12.66	13.66	13.00	12.93	12.33	13.66	0.17	0.14
Week 4	10.26^{b}	12.13^{a}	11.33^{ab}	12.33^{a}	15.00^{a}	12.33^{a}	0.21	0.03
Week 5	12.33	13.33	13.66	12.00	13.16	13.36	0.29	0.55
Week 6	12.64^{bc}	13.00^{b}	12.63^{bc}	12.30^{c}	14.06^{a}	13.63^{a}	0.12	0.00
Week 7	13.46	13.93	13.66	14.33	14.89	14.33	0.12	0.11
Week 8	13.70	14.96	14.83	14.50	14.66	15.30	0.16	0.44
Week 9	14.33	15.30	15.43	14.76	15.63	15.33	0.18	0.34
Week 10	15.26	15.93	16.60	16.66	15.63	16.13	0.18	0.22
Week 11	14.26	16.10	14.60	14.06	14.60	15.46	0.30	0.12
Week 12	15.33	15.33	15.43	14.66	16.06	16.01	0.20	0.20
Yolk diameter (mm)								
Week 1	31.01	31.37	30.91	33.15	32.31	31.92	0.41	0.44
Week 2	34.89	36.46	35.12	35.40	33.22	34.49	0.31	0.21
Week 3	34.24^{bc}	36.89^{ab}	38.91^{a}	33.59^{c}	36.81^{ab}	38.82^{a}	0.49	0.05
Week 4	31.73	32.90	35.12	35.03	33.91	35.35	0.61	0.33
Week 5	31.66	34.82	34.38	36.25	36.04	35.52	0.54	0.87
Week 6	34.53	35.00	35.60	34.00	36.00	38.00	1.14	0.40
Week 7	37.33^{b}	39.00^{ab}	40.66^{a}	38.66^{ab}	40.76^{a}	40.10^{a}	0.37	0.03
Week 8	38.00^{e}	39.66^{cd}	40.33^{bc}	39.00^{d}	40.66^{ab}	41.20^{a}	0.20	0.01
Week 9	40.33^{a}	41.00^{a}	41.33^{a}	38.00^{b}	41.93^{a}	41.00^{a}	0.33	0.01
Week 10	41.00	42.66	39.33	40.66	43.23	42.00	0.46	0.22
Week 11	40.33	41.33	42.00	40.66	41.66	42.00	0.23	0.44
Week 12	40.66^{c}	41.33^{bc}	42.00^{ab}	40.60^{c}	43.00^{a}	42.43^{ab}	0.21	0.04

T1: 0 g NaB/kg diet + 0 g alum/3 kg litter; T2: 15 g NaB/kg diet + 0 g alum/3 kg litter; T3: 30 g NaB/kg diet + 0 g alum/3 kg litter; T4: 0 g NaB/kg diet + 400 g alum/3 kg litter; T5: 15 g NaB/kg diet + 400 g alum/3 kg litter and T6: 30 g NaB/kg diet + 400 g alum/3 kg litter.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Albumen length values were significant (P<0.05) at week 6 and the value was lower in T1 compared to treatment groups. Values of albumenindex were significant (P<0.05) at week 2, 4-5 and 6 and treatment groups had higher values compared to control group (T1). Values of albumen ratio were significant (P<0.05) at week 3-5, 7 and 10. The values of albumen ratio were lower in T1 at week 3-5 compared to treatment groups, while at week 7 value recorded in T1 was similar with the value obtained in T3, T4 and T6, while both were significantly higher than the values recorded in T2 and T5, with T2 also similar with T3, T4, T6 and T5 also the same value with T6 and T4. At week 10, Albumen index value obtained in T2, T3, T4, T5 and T6 were similar (P<0.05), but significantly lower than the value recorded in T1 that had also the same values obtained in T3 and T5.

Table 2b Impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on weekly internal egg quality traits of Nigerian Noiler hens (12 weeks)

Parameter	Treatments						SEM	P-values
	T1	T2	T3	T4	T 5	T6		
Albumen weight (g)								
Week1	24.43	28.16	26.39	23.93	27.43	26.40	0.51	0.22
Week 2	25.69^{b}	26.06^{ab}	25.72^{b}	26.90^{ab}	22.66^{c}	29.00^{a}	0.49	0.03
Week 3	25.26^{c}	30.03^{ab}	26.66^{c}	26.16^{c}	32.40^{a}	29.3^{b}	0.53	0.00
Week 4	27.20^{c}	32.36^{ab}	33.53^{a}	30.70^{b}	30.60^{b}	32.41^{ab}	0.43	0.00
Week 5	26.66^{c}	30.13^{b}	34.56^{a}	29.50^{b}	31.66^{b}	31.33^{b}	0.48	0.00
Week 6	28.80^{b}	33.00^{a}	33.26^{a}	27.33^{b}	32.66^{a}	32.66^{a}	0.51	0.00
Week 7	29.00^{c}	32.32^{ab}	34.00^{a}	29.26^{c}	31.66^{b}	32.76^{ab}	0.39	0.01
Week 8	30.66^{c}	31.00^{c}	34.00^{a}	30.16^{c}	34.43^{a}	33.60^{ab}	0.46	0.00
Week 9	31.00^{b}	33.06^{a}	33.66^{a}	30.16^{b}	33.33^{a}	33.30^{a}	0.30	0.01
Week 10	32.00	33.03	34.33	31.00	33.33	33.30	0.36	0.33
Week 11	32.32^{b}	33.66^{a}	33.66^{a}	32.00^{b}	33.96^{a}	33.90^{a}	0.19	0.00
Week 12	32.66^{b}	33.66^{ab}	33.93^{a}	32.60^{b}	34.56^{a}	34.30^{a}	0.19	0.00
Albumen diameter (mm)								
Week 1	56.18	54.30	59.51	53.16	61.77	58.34	1.10	0.33
Week 2	62.50^{bc}	60.94^{c}	69.41^{a}	67.46^{ab}	61.96^{bc}	68.88^{a}	0.92	0.03
Week 3	62.18^{c}	65.58^{bc}	74.19^{a}	70.22^{ab}	64.85^{bc}	68.83^{ab}	0.98	0.05
Week 4	66.92^{b}	68.37^{b}	68.23^{b}	60.84^{c}	73.55^{a}	73.18^{a}	0.92	0.00
Week 5	66.67^{b}	69.28^{b}	78.09^{a}	72.17^{ab}	74.54^{ab}	71.59^{ab}	1.11	0.01
Week 6	74.33^{b}	75.44^{b}	78.00^{a}	74.16^{b}	78.58^{a}	75.33^{b}	0.40	0.00
Week 7	66.66^{ab}	69.00^{ab}	68.96^{ab}	66.00^{b}	71.33^{a}	71.66^{a}	0.56	0.01
Week 8	70.06^{c}	73.33^{a}	71.33^{c}	70.89^{bc}	71.00^{b}	71.13^{ab}	0.26	0.00
Week 9	71.00^{c}	72.30^{bc}	73.16^{ab}	70.70^{c}	74.46^{a}	73.93^{ab}	0.33	0.00
Week 10	71.66	73.50	71.60	69.56	74.33	73.00	0.77	0.97
Week 11	71.93	71.33	71.93	71.76	72.73	72.63	0.46	0.56
Week 12	71.66^{cd}	72.76^{bc}	73.10^{ab}	71.10^{d}	73.80^{ab}	74.13^{a}	0.24	0.00
Albumen height (mm)								
Week 1	6.33^{ab}	6.03^{ab}	5.66^{b}	6.66^{a}	6.66^{a}	7.00^{a}	0.11	0.01
Week 2	6.46	6.66	5.66	5.83	6.83	6.33	0.14	0.61
Week 3	5.53	6.00	6.00	6.33	6.16	9.93	0.13	0.12
Week 4	4.66^{b}	6.50^{a}	5.96^{a}	6.16^{a}	6.33^{a}	5.93^{a}	0.14	0.00
Week 5	5.53^{b}	5.66^{b}	5.66^{b}	5.60^{b}	6.66^{a}	6.66^{a}	0.13	0.00
Week 6	5.63^{c}	5.95^{bc}	6.00^{bc}	6.33^{ab}	6.66^{a}	6.23^{abc}	0.09	0.02
Week 7	6.13	6.26	6.33	6.40	6.60	6.23	0.06	0.11
Week 8	6.03^{b}	6.66^{a}	6.10^{b}	6.30^{b}	6.30^{ab}	6.40^{ab}	0.06	0.04
Week 9	6.96	6.73	7.00	6.86	7.30	7.03	0.08	0.23
Week 10	7.00	7.30	7.00	6.83	7.33	7.16	0.10	0.75
Week 11	6.66	7.00	7.00	6.50	7.33	7.33	0.11	0.11
Week 12	7.00	7.00	6.33	6.66	7.00	7.50	0.11	0.33

T1: 0 g NaB/kg diet + 0 g alum/3 kg litter; T2: 15 g NaB/kg diet + 0 g alum/3 kg litter; T3: 30 g NaB/kg diet + 0 g alum/3 kg litter; T4: 0 g NaB/kg diet + 400 g alum/3 kg litter; T5: 15 g NaB/kg diet + 400 g alum/3 kg litter and T6: 30 g NaB/kg diet + 400 g alum/3 kg litter.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Yolk ratio values were significant at week 1-7, 9 and 10 and the value was lower at week 1-6 and 9 in T1 compared to treatment groups, while at week 7, value of yolk ratio obtained in T1 was similar (P<0.05) with the value recorded in T4, but significantly higher than the value recorded in T2, T3, T5 and T6 with T4 had also similar value recorded in T6. At week 10, value of yolk ratio recorded in T1, T2, T4, T5 and T6 were similar (P>0.05), but significantly higher than the value obtained in T3 which also had similar values recorded in T2 and T6.

Yolk/albumen ratio values were significant (P<0.05) at week 2-3, 5, 7 and 9 with the value higher significantly in treatment groups compared to control group at week 2-3 and 7. At week 5 yolk/albumen ratio value recorded in T1, T2, T4, T5 and T6 were similar (P>0.05), but significantly higher than the value recorded in T3 which also had similar values obtained in T4 and T5. At week 9, yolk/albumen values recorded in T1, T2, T4 and T6 were similar (P>0.05), but significantly higher than the values obtained in T3 and T5 which also had similar value recorded in T6.

Table 2c Impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on weekly internal egg quality traits of Nigerian Noiler hens (12 weeks)

Parameter	Treatments						SEM[2]	P-values
	T1	T2	T3	T4	T 5	T6		
Albumen length (mm)								
Week1	65.39	61.94	71.95	68.84	68.07	71.31	1.43	0.19
Week 2	74.52	70.49	76.90	80.52	72.40	74.22	1.98	0.23
Week 3	72.44	74.48	76.96	73.76	72.48	74.33	0.61	0.16
Week 4	74.66	75.97	79.00	72.30	79.36	82.26	1.24	0.32
Week 5	80.81	82.62	84.80	79.66	88.26	83.26	1.68	0.54
Week 6	83.33[bc]	85.00[abc]	91.00[a]	78.2.36[c]	85.66[ab]	90.00[ab]	0.07	0.02
Week 7	74.23	80.00	74.33	73.96	81.33	81.33	2.37	0.22
Week 8	76.43	77.16	77.83	71.66	79.58	74.56	2.25	0.76
Week 9	84.44	84.96	84.33	78.33	85.00	87.00	1.90	0.17
Week 10	81.66	84.33	89.33	79.32	89.33	85.66	1.56	0.19
Week 11	84.00	88.66	85.33	80.86	84.86	91.00	1.42	0.45
Week 12	85.66	89.66	88.00	89.00	90.33	88.33	1.57	0.76
Yolk index (%)								
Week 1	33.95	38.07	40.10	39.43	40.02	41.00	1.01	0.32
Week 2	36.90	39.60	34.81	35.86	38.54	38.78	0.58	0.96
Week 3	36.98	37.01	33.72	38.45	33.61	35.05	0.60	0.65
Week 4	32.31	34.07	32.30	35.62	36.01	34.95	0.46	0.43
Week 5	37.67	38.43	31.91	33.40	38.15	37.31	0.83	0.74
Week 6	38.00	38.61	37.15	37.89	40.89	36.99	1.40	0.97
Week 7	36.11	35.99	33.65	37.03	34.38	34.74	0.40	0.32
Week 8	36.06	37.75	36.81	40.76	35.40	36.94	0.56	0.38
Week 9	35.50	37.37	37.30	38.94	37.22	37.50	0.46	0.11
Week 10	35.23	36.86	38.94	37.25	39.37	38.50	0.36	0.98
Week 11	35.36	38.94	34.73	35.16	34.94	36.81	0.67	0.78
Week 12	37.70	38.47	36.41	36.17	39.67	37.68	0.51	0.22
Albumen index (%)								
Week 1	10.40	11.00	10.04	11.03	10.33	10.90	0.23	0.32
Week 2	9.51[ab]	10.13[a]	7.84[b]	7.97[b]	10.15[a]	8.78[ab]	0.26	0.00
Week 3	8.24	8.56	7.93	8.61	9.03	8.26	0.20	0.22
Week 4	7.28[cd]	8.97[ab]	8.13[bcd]	9.52[a]	8.33[abc]	6.99[d]	0.21	0.04
Week 5	7.54[b]	7.52[b]	6.98[b]	7.01[b]	7.94[ab]	8.57[a]	0.14	0.01
Week 6	7.15[b]	7.45[b]	7.07[b]	8.34[a]	8.78[a]	7.54[b]	0.13	0.00
Week 7	8.62	8.68	8.91	12.18	8.74	8.40	0.45	0.21
Week 8	8.24	8.87	8.26	8.63	8.30	8.40	0.11	0.52
Week 9	8.84	8.78	8.97	9.23	9.17	8.73	0.15	0.98
Week 10	8.93	9.27	8.75	9.19	9.25	9.06	0.15	0.67
Week 11	8.55	8.74	8.92	8.50	9.31	9.01	0.14	0.21
Week 12	8.44	8.63	7.85	8.32	8.55	9.25	0.13	0.33

T1: 0 g NaB/kg diet + 0 g alum/3 kg litter; T2: 15 g NaB/kg diet + 0 g alum/3 kg litter; T3: 30 g NaB/kg diet + 0 g alum/3 kg litter; T4: 0 g NaB/kg diet + 400 g alum/3 kg litter; T5: 15 g NaB/kg diet + 400 g alum/3 kg litter and T6: 30 g NaB/kg diet + 400 g alum/3 kg litter.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

The impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on weekly external egg quality traits of Nigerian Noiler hens are presented in Table 3 a-c.

At week 2-3, 8-9 and 11 values of egg length were significant (P<0.05) with T1 having the lowest (P<0.05) value among the treatments. Values of egg width were significantly influenced by the treatments at week 1-2 and week 9. At week 1, egg width values in T1, T3, T4, T5 and T6 were the same (P>0.05), but both were significantly lower than the value recorded in T2 which was also similar with the values recorded in T1 and T6. At week 2, egg width value recorded in T1 did not differ (P>0.05) from the values obtainedin T2, T3, T4 and T6, but significantly higher than the value recorded in T5. At week 9, egg width value recorded in T1 was lower than the values recorded in treatment groups. Shell weight values were significant (P<0.05) at week 2-3, 6-9 and 11-12 among the treatments, but values recorded in treatment groups were higher compared to the value recorded in T1 (control).

Table 2d Impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on weekly internal egg quality traits of Nigerian Noiler hens (12 weeks)

Parameter	Treatments						SEM	P-values
	T1	T2	T3	T4	T 5	T6		
Albumen ratio (%)								
Week1	58.88	64.59	62.09	62.58	58.20	63.28	1.12	0.97
Week 2	58.74	60.47	57.35	62.90	57.41	63.91	0.84	0.21
Week 3	54.00[c]	63.04[b]	56.87[bc]	59.12[bc]	73.72[a]	63.12[b]	1.30	0.00
Week 4	57.66[b]	66.70[a]	71.67[a]	67.35[a]	67.70[a]	65.89[a]	1.11	0.00
Week 5	61.04[ab]	61.22[ab]	62.98[a]	61.04[ab]	62.99[a]	59.91[b]	0.32	0.01
Week 6	60.35	61.85	62.75	58.09	59.01	60.55	0.58	0.32
Week 7	63.19[a]	60.54[bc]	62.68[ab]	61.82[abc]	59.79[c]	61.54[abc]	0.32	0.04
Week 8	57.48	61.67	58.05	58.24	59.00	58.31	0.84	0.75
Week 9	59.29	60.17	56.34	54.67	56.00	64.21	1.21	0.57
Week 10	63.40[a]	58.90[b]	61.61[ab]	59.60[b]	60.30[ab]	58.23[b]	0.50	0.02
Week 11	58.08	59.05	56.90	56.78	55.86	56.32	0.57	0.64
Week 12	57.76	55.76	54.13	54.12	54.29	56.34	0.50	0.20
Yolk ratio (%)								
Week 1	20.55[ab]	21.23[a]	22.02[a]	21.45[a]	18.65[b]	25.57[a]	0.31	0.00
Week 2	21.76[bc]	23.08[abc]	25.46[a]	24.80[ab]	24.03[ab]	20.59[c]	0.48	0.00
Week 3	19.99[b]	23.35[a]	24.92[a]	23.41[a]	24.46[a]	24.38[a]	0.49	0.00
Week 4	22.25[b]	24.55[b]	24.38[b]	27.87[a]	25.45[ab]	24.07[b]	0.48	0.03
Week 5	26.63[ab]	27.87[a]	25.10[b]	25.59[b]	26.88[ab]	26.36[ab]	0.26	0.02
Week 6	27.42[b]	25.97[bcd]	27.23[bc]	29.80[a]	25.77[cd]	25.14[d]	0.31	0.00
Week 7	30.09[a]	26.76[cd]	25.84[d]	29.04[ab]	26.67[cd]	27.73[bc]	0.30	0.00
Week 8	26.45	27.01	25.84	26.49	25.76	25.85	0.34	0.54
Week 9	28.03[ab]	28.52[a]	25.57[c]	26.35[bc]	24.62[c]	26.38[bc]	0.31	0.04
Week 10	28.49[a]	28.32[ab]	26.85[b]	28.77[a]	28.71[a]	27.32[ab]	0.22	0.04
Week 11	26.51	27.56	25.00	25.26	26.32	25.6	0.25	0.013
Week 12	27.56	26.51	25.84	26.02	25.14	26.25	0.23	0.81
Yolk/albumin ratio (%)								
Week 1	34.93	33.16	35.37	35.17	32.14	33.99	0.47	0.76
Week 2	37.09[bc]	38.45[bc]	44.72[a]	39.52[bc]	42.09[ab]	35.56[c]	0.80	0.01
Week 3	36.67[cd]	36.69[cd]	43.91[a]	41.28[ab]	33.00[d]	38.59[bc]	0.80	0.05
Week 4	38.60	37.05	34.61	41.97	37.75	36.48	0.73	0.12
Week 5	43.63[a]	45.66[a]	31.63[b]	41.89[ab]	42.79[ab]	44.30[a]	0.55	0.04
Week 6	45.58	42.31	43.46	48.47	43.75	42.02	0.74	0.31
Week 7	40.68[b]	43.73[ab]	41,25[b]	47.88[a]	44.22[ab]	44.81[ab]	0.66	0.01
Week 8	45.98	43.79	44.28	45.42	43.75	45.19	0.28	0.11
Week 9	47.24[a]	47.50[a]	43.84[b]	47.60[a]	43.61[b]	46.01[ab]	0.50	0.03
Week 10	45.14	48.34	43.60	47.50	47.59	46.60	0.57	0.15
Week 11	45.69	45.97	42.60	44.00	46.68	45.65	0.57	0.35
Week 12	47.95	47.82	47.76	47.97	46.31	46.73	0.41	0.79

T1: 0 g NaB/kg diet + 0 g alum/3 kg litter; T2: 15 g NaB/kg diet + 0 g alum/3 kg litter; T3: 30 g NaB/kg diet + 0 g alum/3 kg litter; T4: 0 g NaB/kg diet + 400 g alum/3 kg litter; T5: 15 g NaB/kg diet + 400 g alum/3 kg litter and T6: 30 g NaB/kg diet + 400 g alum/3 kg litter.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Values of shell thickness among the treatments were significant (P<0.05) at week 1-3 and the values recorded treatment group were higher than the value obtained in control group. Values of egg shape index at week 1, 3 and 5 were significant (P<0.05) with the value lower in control group compared to the values recorded in treatment groups at week 1 and 5. At week 3, value of egg shape index obtained in T1, T2, T4 and T6 were similar (P>0.05), but significantly higher than the values recorded in T3 and T5, with T3 also having similar values recorded in T2, T4 and T6.

Values of shell ratio were significant (P<0.05) at week 5-7 and 11. At week 5, shell ratio value recorded in T1 was the highest (P<0.05) among the treatments. At week 6, shell ratio values obtained in T1 and T4 were similar (P>0.05), but significantly higher than the values recorded in T2, T3, T5 and T6 respectively.

At week 7, values of shell ratio obtained in T1, T2, T5 and T6 were the same, but significantly higher than the values recorded in T3 and T4, with T3 also having similar values recorded in T1, T5, T6 and T4 also similar to the value recorded in T1.

Table 3a Impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on weekly external egg quality traits of Nigerian Noiler hens (12 weeks)

Parameter	Treatments						SEM	P-values
	T1	T2	T3	T4	T 5	T6		
Egg length (mm)								
Week1	49.69	49.15	48.30	48.80	48.48	49.20	0.21	0.21
Week 2	49.38^{ab}	50.34^{ab}	49.77^{ab}	50.33^{a}	48.34^{b}	50.47^{a}	0.29	0.00
Week 3	50.31^{c}	51.32^{bc}	53.02^{ab}	51.40^{bc}	53.81^{a}	51.63^{bc}	0.31	0.03
Week 4	50.57	51.03	51.12	50.49	50.45	52.22	0.61	0.17
Week 5	49.90	52.91	50.71	50.60	53.01	51.35	0.52	0.88
Week 6	51.51	54.13	53.89	51.56	54.27	54.03	0.58	0.45
Week 7	51.83	53.33	54.00	51.00	53.33	53.36	0.39	0.31
Week 8	53.34^{bc}	55.45^{ab}	54.06^{abc}	52.36^{c}	54.66^{abc}	56.00^{a}	0.36	0.05
Week 9	52.66^{b}	55.33^{ab}	54.20^{b}	53.33^{b}	58.33^{a}	58.33^{a}	0.53	0.00
Week 10	53.93	55.33	55.86	52.99	55.07	56.10	0.44	0.76
Week 11	53.63^{b}	54.66^{ab}	57.33^{a}	53.33^{b}	56.60^{ab}	56.33^{ab}	0.46	0.00
Week 12	53.23	54.33	57.00	54.33	55.00	56.66	0.42	0.19
Egg width (mm)								
Week 1	39.04^{ab}	39.16^{a}	37.06^{b}	37.19^{b}	37.33^{b}	38.02^{ab}	0.20	0.00
Week 2	38.49^{a}	38.85^{a}	38.59^{a}	39.45^{a}	36.86^{b}	38.25^{a}	0.21	0.00
Week 3	39.26	40.92	39.08	39.04	41.93	39.38	0.43	0.37
Week 4	38.68	38.71	39.63	38.84	38.79	39.79	0.39	0.91
Week 5	37.66	41.43	39.04	40.33	39.73	39.33	0.41	0.11
Week 6	39.18	41.61	40.95	40.47	41.00	40.90	0.27	0.21
Week 7	39.85	40.20	40.26	39.26	40.33	40.66	0.30	0.67
Week 8	40.35	41.33	39.96	40.69	40.66	41.00	0.33	0.32
Week 9	40.84^{c}	42.00^{ab}	41.33^{bc}	41.00^{bc}	43.00^{a}	42.00^{ab}	0.24	0.03
Week 10	40.62	42.59	42.22	41.03	41.66	41.66	0.27	0.97
Week 11	40.66	41.66	41.30	40.60	41,00	40.62	0.56	0.31
Week 12	40.33	41.33	41.66	41.00	41.66	55.65	0.46	0.11
Shell weight (g)								
Week 1	4.16	4.16	3.96	3.90	4.30	4.30	0.07	0.12
Week 2	4.16^{ab}	4.13^{ab}	4.30^{a}	4.50^{a}	3.73^{b}	4.63^{a}	0.07	0.03
Week 3	3.93^{c}	5.01^{a}	4.46^{b}	4.60^{ab}	4.53^{ab}	4.70^{ab}	0.08	0.00
Week 4	4.23	4.76	4.63	4.80	4.70	5.00	0.11	0.31
Week 5	4.91	4.60	4.86	4.96	4.93	4.96	0.04	0.19
Week 6	4.96^{bc}	5.10^{bc}	5.03^{bc}	4.86^{c}	5.70^{a}	5.23^{b}	0.06	0.00
Week 7	4.73^{b}	5.56^{b}	5.33^{b}	4.43^{a}	5.56^{b}	5.50^{b}	0.08	0.00
Week 8	5.30^{bc}	5.36^{abc}	5.86^{a}	4.96^{bc}	5.70^{ab}	5.86^{a}	0.08	0.03
Week 9	5.10^{c}	5.30^{bc}	5.30^{bc}	5.03^{c}	5.80^{a}	5.70^{ab}	0.07	0.00
Week 10	5.20	4.96	5.30	5.30	5.54	5.00	0.08	0.18
Week 11	5.26^{b}	5.36^{ab}	5.53^{a}	5.30^{b}	5.70^{ab}	5.30^{ab}	0.06	0.02
Week 12	5.33^{bc}	5.53^{ab}	5.06^{c}	5.83^{a}	5.70^{ab}	5.70^{ab}	0.07	0.01

T1: 0 g NaB/kg diet + 0 g alum/3 kg litter; T2: 15 g NaB/kg diet + 0 g alum/3 kg litter; T3: 30 g NaB/kg diet + 0 g alum/3 kg litter; T4: 0 g NaB/kg diet + 400 g alum/3 kg litter; T5: 15 g NaB/kg diet + 400 g alum/3 kg litter and T6: 30 g NaB/kg diet + 400 g alum/3 kg litter.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

At week 11, shell ratio values recorded in T1, T2, T3 and T5 were similar (P>0.05), but significantly higher than the values obtained in T4 and T6, with T4 also being the same with T1, T2, T3, while T6 also had the same value obtained in T3. Haugh unit values were significant (P<0.05) at week 1, 4-6, 9 and 12. Haugh unit values recorded at week 4-5 and 6 were lower in T1 compared to treatment groups. At week 1, Values of Haugh unit recorded in T1, T4 and T6 were the same (P>0.05), but significantly higher than the values obtained in T2, T3 and T5, with T2 also similar with T1, T3, T4 and T5. At week 9, values of Haugh unit obtained in T1, T4, T5 and T6 were similar (P>0.05), but significantly higher than the values recorded in T2 and T3 which were also similar to the values recorded in T4, T5 and T6. At week 12, Haugh unit values recorded in T1, T2, T4, T5 and T6 were similar (P>0.05), but significantly higher than the value obtained in T3 which was also the same with the values obtained in T2, T4 and T5.

Table 3b Impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on weekly external egg quality traits of Nigerian Noiler hens (12 weeks)

Parameter	Treatments[1]						SEM	P-values
	T1	T2	T3	T4	T 5	T6		
Shell thickness (mm)								
Week1	0.45[b]	0.41[b]	0.42[b]	0.41[b]	0.53[a]	0.54[a]	0.01	0.00
Week 2	0.32[b]	0.55[a]	0.49[a]	0.47[a]	0.34[b]	0.35[b]	0.02	0.00
Week 3	0.43[bc]	0.52[ab]	0.38[c]	0.57[a]	0.43[bc]	0.45[bc]	0.01	0.01
Week 4	0.41	0.44	0.51	0.40	0.46	0.46	0.02	0.53
Week 5	0.37	0.51	0.45	0.41	0.49	0.50	0.01	0.24
Week 6	0.39	0.39	0.52	0.53	0.50	0.41	0.02	0.39
Week 7	0.53	0.56	0.47	0.53	0.47	0.54	0.02	0.83
Week 8	0.47	0.51	0.56	0.57	0.42	0.48	0.02	0.36
Week 9	0.47	0.45	0.50	0.49	0.50	0.43	0.02	0.87
Week 10	0.45	0.57	0.51	0.59	0.49	0.53	0.02	0.23
Week 11	0.50	0.50	0.50	0.40	0.50	0.50	0.02	0.11
Week 12	0.49	0.54	0.52	0.53	0.57	0.59	0.02	0.31
Egg shape index (%)								
Week 1	76.57[b]	79.79[a]	76.73[b]	76.23[b]	77.03[b]	77.39[b]	0.34	0.00
Week 2	77.27	77.12	77.09	76.74	75.80	75.81	0.24	0.71
Week 3	78.06[a]	76.48[ab]	73.81[bc]	76.02[ab]	71.75[c]	76.13[ab]	0.48	0.03
Week 4	76.49	76.14	77.22	77.42	76.92	76.36	0.46	0.23
Week 5	75.45[c]	78.29[b]	77.12[bc]	80.72[a]	74.96[c]	76,86[bc]	0.42	0.00
Week 6	76.09	77.27	76.14	79.35	75.59	75.76	0.69	0.20
Week 7	77.91	76.06	74.48	76.98	75.64	75.93	0.58	0.41
Week 8	75.69	74.74	73.88	77.83	74.63	73.18	0.70	0.98
Week 9	76.05	76.04	76.53	76.85	72.78	72.61	0.66	0.46
Week 10	75.28	76.80	75.67	77.61	75.85	74.37	0.53	0.13
Week 11	75.81	75.73	72.16	75.65	72.14	72.52	1.11	0.90
Week 12	74.23	75.92	73.45	75.59	74.65	73.99	1.12	0.31
Shell ratio (%)								
Week 1	10.05	9.49	9.44	9.90	9.18	10.37	0.13	0.12
Week 2	9.29	9.01	9.38	10.53	9.40	10.23	0.17	0.71
Week 3	8.93	9.68	9.96	10.60	9.47	9.70	0.16	0.98
Week 4	8.93	9.59	9.96	10.44	10.34	10.28	0.26	0.23
Week 5	11.26[a]	9.03[c]	8.96[c]	10.27[b]	9.80[bc]	9.48[bc]	0.17	0.04
Week 6	10.42[a]	9.56[b]	9.50[b]	9.57[a]	10.29[b]	9.68[b]	0.10	0.00
Week 7	9.93[abc]	10.54[a]	9.80[bc]	9.36[c]	10.03[ab]	10.39[ab]	0.10	0.00
Week 8	9.86	9.65	9.74	9.53	9.68	9.78	0.09	0.23
Week 9	9.46	9.56	9.03	9.05	9.52	9.75	0.09	0.22
Week 10	10.28	8.86	9.54	10.21	9.38	8.79	0.20	0.51
Week 11	9.45[ab]	9.41[ab]	9.35[abc]	8.86[bc]	9.62[a]	8.76[c]	0.09	0.00
Week 12	9.39	9.17	8.08	7.79	8.73	9.14	0.18	0.21

T1: 0 g NaB/kg diet + 0 g alum/3 kg litter; T2: 15 g NaB/kg diet + 0 g alum/3 kg litter; T3: 30 g NaB/kg diet + 0 g alum/3 kg litter; T4: 0 g NaB/kg diet + 400 g alum/3 kg litter; T5: 15 g NaB/kg diet + 400 g alum/3 kg litter and T6: 30 g NaB/kg diet + 400 g alum/3 kg litter.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 4 shows impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on general external egg quality traits of Nigerian Noiler hens. Egg length values of T1 and T4 were the same (P>0.05), but lower than values obtained in T2, T3, T5 and T6 respectively. Egg width values of T2, T3, T4, T5 and T6 were the same (P>0.05), but significantly higher than the value recorded in T1 (control). Value of shell weight recorded in T1 and T4 were the same (P>0.05), but significantlylower than the values obtained in T2, T3, T5 and T6 respectively.

Egg shape index value of T6 was the lowest (P<0.05) among the treatments. Table 5 show the impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on general internal egg quality traits of Nigerian Noiler hens. Yolk weight values of T1 and T4 were the same (P>0.05), but significantly lower than the values recorded in T2, T3, T5 and T6. Values of yolk height recorded in T2 and T6 were the same (P>0.05), but both were significantly higher than the values obtained in T1, T3, T4 and T5, with T2 also the same with the values obtained in T1, T3, T4 and T5.

Table 3c Impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on weekly external egg quality traits of Nigerian Noiler hens (12 weeks)

Parameter	Treatments						SEM	P-values
	T1	T2	T3	T4	T 5	T6		
Haugh units								
Week1	84.88[ab]	83.48[bc]	80.34[c]	87.10[ab]	84.49[bc]	88.86[a]	0.66	0.01
Week 2	83.78	85.45	79.21	81.02	86.65	83.07	1.02	0.22
Week 3	77.37	74.14	80.63	83.32	83.08	80.28	1.15	0.98
Week 4	70.33[b]	83.11[a]	80.68[a]	82.17[a]	80.31[a]	79.58[a]	0.95	0.00
Week 5	78.99[bc]	77.46[bc]	75.63[c]	77.12[bc]	86.05[a]	82.83[ab]	0.92	0.04
Week 6	78.01[ab]	78.26[ab]	73.35[b]	82.97[a]	82.26[a]	79.80[a]	0.91	0.00
Week 7	82.10	81.58	80.45	83.33	82.62	80.62	0.42	0.34
Week 8	78.55	82.14	77.17	79.71	78.43	79.49	0.60	0.31
Week 9	88.57[a]	82.67[b]	87.42[b]	84.62[ab]	84.68[ab]	84.64[ab]	0.60	0.05
Week 10	85.97	86.06	84.02	84.54	86.50	84.60	0.62	0.29
Week 11	75.81	75.73	72.16	75.65	72.14	72.52	1.11	0.16
Week 12	83.71[a]	82.62[ab]	77.50[b]	80.66[ab]	81.91[ab]	85.77[a]	0.76	0.02

T1: 0 g NaB/kg diet + 0 g alum/3 kg litter; T2: 15 g NaB/kg diet + 0 g alum/3 kg litter; T3: 30 g NaB/kg diet + 0 g alum/3 kg litter; T4: 0 g NaB/kg diet + 400 g alum/3 kg litter; T5: 15 g NaB/kg diet + 400 g alum/3 kg litter and T6: 30 g NaB/kg diet + 400 g alum/3 kg litter.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 4 Impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on general external egg quality traits of Nigerian Noiler hens (12 weeks)

Parameter	Treatments						SEM	P-values
	T1	T2	T3	T4	T 5	T6		
Egg length (mm)	51.78[c]	52.99[b]	53.27[ab]	51.58[c]	53.61[ab]	53.85[a]	0.17	0.01
Egg width (mm)	39.48[b]	40.66[a]	40.08[ab]	39.95[ab]	40.42[a]	40.30[a]	0.11	0.03
Shell weight (g)	4.71[b]	5.08[a]	4.91[ab]	4.72[b]	5.01[a]	5.10[a]	0.03	0.00
Shell thickness (mm)	0.42	0.49	0.48	0.49	0.47	0.47	0.09	0.63
Egg shape index (%)	76.23[bc]	76.71[ab]	75.26[cd]	77.72[a]	75.38[cd]	74.94[e]	0.23	0.04
Shell ratio (%)	9.60	9.77	9.52	9.71	9.67	9.50	0.04	0.12
Haugh units	79.62	81.99	79.22	80.67	82.79	84.70	0.69	0.23

T1: 0 g NaB/kg diet + 0 g alum/3 kg litter; T2: 15 g NaB/kg diet + 0 g alum/3 kg litter; T3: 30 g NaB/kg diet + 0 g alum/3 kg litter; T4: 0 g NaB/kg diet + 400 g alum/3 kg litter; T5: 15 g NaB/kg diet + 400 g alum/3 kg litter and T6: 30 g NaB/kg diet + 400 g alum/3 kg litter.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 5 Impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on general internal egg quality traits of Nigerian Noiler hens (12 weeks)

Parameter	Treatments						SEM	P-values
	T1	T2	T3	T4	T 5	T6		
Yolk weight (g)	12.49[c]	13.60[a]	13.59[a]	12.93[bc]	13.40[a]	13.36[ab]	0.08	0.00
Yolk height (mm)	13.14[bc]	14.11[ab]	13.20[bc]	12.80[b]	13.01[b]	14.33[a]	0.16	0.00
Yolk diameter (mm)	35.22[c]	36.53[bc]	37.02[abc]	38.08[ab]	38.16[ab]	38.63[a]	0.31	0.04
Albumen weight (g)	28.86[b]	31.65[a]	31.97[a]	29.14[b]	31.55[a]	31.86[a]	0.24	0.00
Albumen diameter (mm)	67.66[b]	68.47[b]	71.46[a]	68.66[b]	71.47[a]	71.13[a]	0.36	0.03
Albumen height (mm)	5.93	6.45	6.19	6.07	6.56	7.06	0.12	0.54
Albumen length (mm)	77.84	77.96	81.95	76.45	82.27	82.58	0.78	0.22
Yolk index (%)	37.39[ab]	38.33[a]	35.78[abc]	34.67[bc]	34.07[c]	34.08[abc]	0.44	0.05
Albumen index (%)	11.13	11.81	10.88	11.52	11.53	12.51	0.27	0.12
Albumen ratio (%)	58.87	60.85	65.74	59.96	60.89	59.55	1.03	0.53
Yolk ratio (%)	25.47[b]	26.15[ab]	24.69[b]	27.30[a]	25.86[ab]	24.88[b]	0.23	0.03
Yolk/albumen ratio (%)	43.28[b]	43.96[bc]	42.48[bc]	44.37[a]	42.49[bc]	42.19[c]	0.17	0.02

T1: 0 g NaB/kg diet + 0 g alum/3 kg litter; T2: 15 g NaB/kg diet + 0 g alum/3 kg litter; T3: 30 g NaB/kg diet + 0 g alum/3 kg litter; T4: 0 g NaB/kg diet + 400 g alum/3 kg litter; T5: 15 g NaB/kg diet + 400 g alum/3 kg litter and T6: 30 g NaB/kg diet + 400 g alum/3 kg litter.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

Table 6 Impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on laying performance of Nigerian Noiler hens (12 weeks)

Parameter	Treatments						SEM	P-values
	T1	T2	T3	T4	T 5	T6		
Hen day egg production (%)	42.72^{b}	57.37^{a}	54.07^{a}	57.06^{a}	52.50^{ab}	49.06^{ab}	1.54	0.01
Average egg weight	48.90^{b}	52.09^{a}	53.25^{a}	49.41^{b}	52.74^{a}	53.02^{a}	0.47	0.00
Number of egg produced/bird	37.43^{b}	49.51^{a}	45.27^{ab}	50.59^{a}	43.02^{ab}	42.28^{ab}	1.36	0.02
Egg mass	20.87^{b}	29.27^{a}	28.85^{a}	26.75^{a}	27.71^{a}	27.40^{a}	0.82	0.00
Crates of produced/bird	1.24^{b}	1.67^{a}	1.50^{ab}	1.64^{a}	1.45^{ab}	1.40^{ab}	0.04	0.01

T1: 0 g NaB/kg diet + 0 g alum/3 kg litter; T2: 15 g NaB/kg diet + 0 g alum/3 kg litter; T3: 30 g NaB/kg diet + 0 g alum/3 kg litter; T4: 0 g NaB/kg diet + 400 g alum/3 kg litter; T5: 15 g NaB/kg diet + 400 g alum/3 kg litter and T6: 30 g NaB/kg diet + 400 g alum/3 kg litter.
The means within the same row with at least one common letter, do not have significant difference (P>0.05).
SEM: standard error of the means.

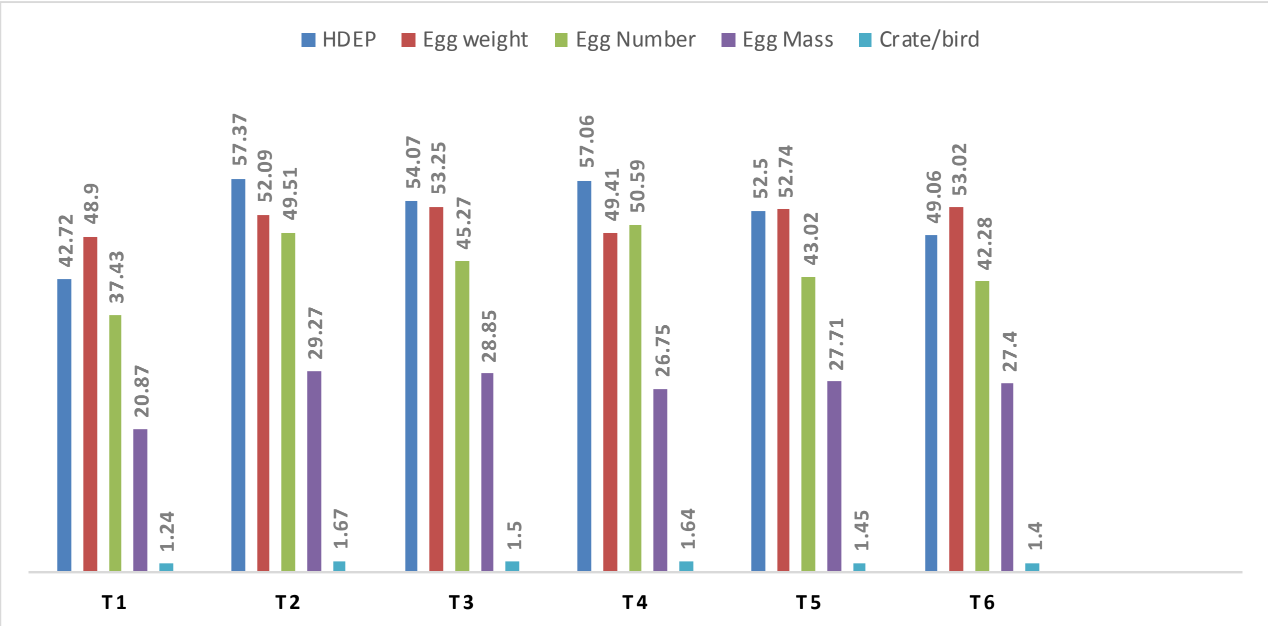

Figure 1 Impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on laying performance of Nigerian Noiler hens

Values of yolk diameter obtained in T3, T4, T5 and T6 (P>0.05), but significantly higher than the values recorded in T1 and T2, with T2 also the same with the values obtained in T1, T3, T4 and T5. Value of albumen weight recorded in T1 was the lowest (P<0.05) among the treatments. Values of albumen diameter obtained in T1 did not differ (P<0.05) from the value recorded in T2, but significantly lower than the values recorded in T3-T6.

Values of yolk index observed in T1, T2, T3 and T6 were similar (P>0.05), but significantly lower than the values obtained in T4 and T5 which also had similar values recorded in T3, T6 and T4 further had the same value with T1. Values of yolk ratio in T2 was similar (P>0.05) with the values obtained in T4 and T5, but significantly higher than the values obtained in T1, T3, and T6 which were also the same with the values recorded in T2 and T5.

Value of yolk/albumen ratio recorded in T4 was the highest among the treatments.

Table 6 and Figure 1 show Impact of the interaction of dietary sodium bentonite and direct application of aluminum sulfate to the litter on laying performance of Nigerian Noiler hens. Hen day egg production significantly improved (P<0.05) higher in favor of the treatment group compared to control group. Egg weight value of treatment 1 (control) and treatment 4 were the same (P>0.05), but lower than values recorded in T2, T3, T5 and T6. Number of eggs produced per bird, egg mass and number of crates laid per bird values were lower (P<0.05) in control birds than in treatment group.

The improvement in laying performance observed in favor of the treatment groups could be connected to the dietary sodium bentonite that contains some minerals in high quantity that improves egg production (Gul *et al.* 2016). The results were in comparable with the report that egg production and egg mass were improved significantly by dietary sodium bentonite (Gilani *et al.* 2013; Yenice *et al.* 2015). Also, in similar results, Gilani *et al.* (2013) working on commercial Hy-Line W-36 hens from 51-63 weeks of age found hen-day egg production and daily egg mass improved in hens fed diet containing 10 g/kg sodium bentonite compared to control group. Clay groups such as sodium bentonite contain anionic structure including alkali metal ions and trace elements, which are considered mineral supplies for animals (Suzanne *et al.* 2017) and promote egg production (Gul *et al.* 2016). These trace elements and metal ions play crucial roles in egg production and improvement in egg quality parameters. Metal ions act as cofactors (help molecules) which are required for the normal functioning of hormones and enzymes that maintain growth and egg production (Smith *et al.* 2018). High minerals such as calcium, iron, magnesium, iodine, zinc, and selenium that are found in bentonite are necessary to support the production of hormones such as prolactin, follicle- stimulating hormone and luteinizing that supports egg production capacity of hens (Smith *et al.* 2018). Saçakli *et al.* (2015) claimed that enhancement in egg production and egg weight as a result of sodium bentonite supplementation may be related to a reduction in feed transit along the gut which increased time for more feed digestion and nutrient absorption. Increase in nutrient absorption such as energy, protein and linoleic acid have been proven as the most nutrients required for egg production and enhancement of egg weight (Godbert *et al.* 2019). Therefore, improvement of egg production in the current study could be related to improved energy and protein absorption and utilization brought about by sodium bentonite in the feed via extended feed passage time along the gut. According to Monks (1992) sodium bentonite absorbs fluid in the GIT of animals and thus making the contents thickened and their movement slower along the intestines. This allows more time for the animal to extract maximum nutrients from the feed that will eventually supports production performance. Bentonite was reported to have caused increase in the villi heights (Chen *et al.* 2020). This is an indication of a greater luminal absorptive surface area for nutrients and thus leading to an improvement in laying capacity of hens. Research has shown that dietary bentonite enhanced intestinal health, which resulted in increased laying performance in hens (Gul *et al.* 2016; Chen *et al.* 2020). Keeping the integrity of gut in farm animals using dietary manipulation is essential for boosting their performance. Animals with healthy gut will eat more, have better nutrient digestibility, increased nutrient absorption, utilization and thus better production performance. Furthermore, characteristics of bentonite such asit is essential for reducing oxidative stress, improving liver function, and boosting lymphocyte growth improves performance of farm animals (Kanana *et al.* 2019). Reduction in oxidative stress which has detrimental effect in laying birds as a result of bentonite supplementation will culminate into increase in egg production and quality. Egg shape index and fall within the normal range of 72-76 among the treatments except treatment 4 that had 77.72 (Table 4). Domestic hen eggs that are unusual in shape, such as those that are long and narrow, round, or flat-sided, cannot be placed in grade AA (nearly perfect) or A (slightly worse than AA) since an egg is generally oval in shape (72-76). Egg shape index are considered as sharp, normal (standard) and round if they have an SI value of <72, between 72 and 76, and >76, respectively (Sarica and Erensayin, 2004). Round eggs and unusually long eggs have poor appearances and do not fit well in egg cartons; therefore, they are much more likely to be broken during the shipment than the eggs of normal shape (Sarica and Erensayin, 2009).

Internal and external egg quality traits improved (P<0.05) significantly in treatment group compared to control group. This could be traceable to dietary sodium bentonite. The higher an increase in egg size, the higher an increase in its length and width. Therefore, increased yolk and albumen quality may be connected to improved weight of eggs observed in treated groups compared to control. It may be scientifically correct to assert that egg size or weight is positively correlated with its yolk, shell, albumen weights and height of its albumen, yolk and diameter of its yolk and albumen. In other words, large eggs present significantly greater yolk height, yolk diameter, yolk weight, albumen height, albumen weight and eggshell weight values than small eggs (Table 4-6). In similar results, Choi (2018) observed that 0.5 percent inclusion of bentonite in the diet of 74-week-old laying hens enhanced shell thickness and Haugh units. In weekly external egg quality (Table 3c), Haugh units improved more in birds on bentonite diet, while in general external egg quality parameters (Table 4), Haugh unit values were not significant (P>0.05), but numerically, birds on diet containing sodium bentonite had higher Haugh unit values. Similarly, Lim *et al.* (2017) showed that adding 0.2 to 0.8 percent of a silicate-based mineral to the rations of laying birds resulted in higher albumen heights and Haugh units when compared to control group. Haugh unit and albumen height are important indices for determining quality of eggs. This claim is supported by Nasir *et al.* (2000) who observed that sodium bentonite when added to the diets of laying hens increased egg production and egg size increased by 15% and 10%, respectively. Improved shell thickness and albumen height observed in birds on bentonite diet in the current study agrees with the report of Chen *et al.* (2020) who stated that dietary montmorillonite greatly improved thickness of shell, weight and albumen height. Sodium bentonite in the diet of hen has positive effect of the egg quality due to its high mineral content, ion exchange capacity, and calcium affinity (Elliott *et al.* 2019). According to Choi (2018) most important mineral content of sodium bentonite is calcium which promotes calcium absorption in hens and thereby leading to improvement in various eggshell traits as observed in the current study. Calcium is the main mineral component of eggshells and is also responsible for internal egg quality as observed in treatment group in the current research results (Table 4-5). Eggshell quality is a vital factor in poultry production because large numbers of eggs with defective shells can lead to great economic losses. In general, external egg quality traits (Table 4), egg shell thickness values were not significant (P>0.05), but numerically, treated group had higher values for egg shell thickness and significantly had higher egg shell weights (Table 4). Therefore, in the context of a farm, these improvements in shell quality in treated groups will prevent damage from handling and to preserve eggs during transport from farm to market compared to control group. Furthermore, dietary bentonite increases alkaline phosphatase that has responsible for bone mineralization and phytate degradation in the small intestine (Kriseldi *et al.* 2021) and thus improving calcium and phosphorus availability used for eggshell formation. Calcium intake is the main factor that determines eggshell quality since the main component of eggshells is calcium with the composition of calcium carbonate (98.2%), magnesium (0.9%), and phosphorus (0.9%) (Shwetha *et al.* 2018). In the current study, albumen and yolk quality traits improved higherin treatment group compared to control group. This is connected to high mineral content of sodium bentonite such as calcium. According to Qu *et al.* (2018) dietary inclusion of silicate-based minerals increased yolk index and shell thickness. Calcium has a significant impact on egg albumen quality. Albumen height and Haugh unit increase in the presence of more calcium levels in the diet (Chang *et al.* 2019).

Furthermore, even though the determination of litter ammonia gas production during the feeding trial was not part of the current study, however, decreased egg quality and egg production traits observed incontrol groups compared to treatment groups could be traceable to high level of litter ammonia gas production during the feeding trial. Research showed that ammonia gas decreased egg production significantly for 7 weeks when hens were exposed to ammonia at concentration of 102 ppm (Charles and Payne, 1966) and adversely affected egg quality (Cotterill and Winter, 1953). Laying performance and egg quality traits in hens can be negatively affected as a results of ammonia gas stress-inducing nature. This assertion is supported by Aziz and Barnes (2009), who found that broilers raised in environments with high ammonia concentrations had an increase in malonaldehyde levels in their blood (a key biomarker used to detect stress in farm animals) compared to control group. Ammonia-induced oxidative stress can result in reduced production (St-Pierre, 2001). Ammonia concentration up to 100 ppm within poultry pens had a significant negative effect on the laying capacity of hens. Charles and Payne (1966) reared pullets in an ammoniated atmosphere from 11-18 weeks of age and observed that these birds tended to lay fewer eggs. Research findings indicated that hens in facility with high ammonia gas production had lower productive performance and poor egg quality traits, but this may depend on bird age and ammonia level and duration.

However, animal welfare scientists as a result of the various negative impacts of ammonia gas on birds have therefore, emphasized the importance of enhancing litter conditions since litter is the major source of ammonia (Averós *et al.* 2013). Control of pollutants such as ammonia gas during production by the application of litter treatment with aluminum sulfate and dietary sodium bentonite that also has positive effect on litter quality are being encouraged since ammonia gas remains a veritable threatfarm animal productivity (Salim *et al.* 2014). Therefore, in the light of the above statements, improved egg quality and laying performance observed in treatment groups could be linked to dietary sodium bentonite and litter treatment with alum which might have interacted and created a healthy microclimate conditions that led to the observed increase in performance in favor of the treatment group. Animals in pens with less pollution as a result of reduced production of ammonia gas will have an increase in activity that will culminate into better performance compared to those in pens with increased litter ammonia gas production. Dietary sodium bentonite can help to reduce some litter pH and moisture which are one of the main culprits in litter ammonia gas production. Safaeikatouli *et al.* (2011) observed that on the 14th day of their study, the litter pH in the treatment group with 15 g sodium bentonite kg^{-1} feed significantly diminished compared to control. The same authors also observed that N_2 content of litter was significantly lower in treatment with 30 g sodium bentonite kg^{-1} feed on 21st and 42nd day of feeding trials compared to the control and treatments with 15 and 30 g sodium bentonite kg^{-1} feed on 28th and 35th day significantly decreased litter moisture compared to the control treatment. Furthermore, litter ammonia gas production and its volatilization from the litter can be decreased by the use of litter treatment with alum. When the pH of litter is below 7, ammonia gas production tends to decrease, but noticeably elevated when the pH is over 8

(Reece *et al.* 1979). According to Rothrock *et al.* (2008) alum treated litter decreased litter pH during production. Li *et al.* (2013) discovered that litter treatment with aluminum sulfate can inhibit % of litter ammonia gas emission by bringing down the litter pH and moisture. According to Madrid *et al.* (2012) using alum as a top dressing for new litter significantly reduced indoor ammonia concentrations as compared to non-treated groups. Literature evidence shows that reducing NH_3 levels in poultry pens due to treatment of litter with alum enhanced chicken performance, including reduced mortality and increased earnings for farmers (Moore *et al.* 2011). Eid *et al.* (2022) reported that egg number and egg weight of hens on litter treated with alum improved significantly higher than those on untreated litter.

CONCLUSION

The impact of sodium bentonite as a clay mineral additive and aluminum sulfate as a litter management protocol on egg quality and laying performance of Noiler hens was investigated. Internal and external egg quality improved significantly in favor of the treatment group. Furthermore, laying performance traits such as hen day egg production, egg weight, egg mass, number of eggs produced per bird and crates of egg produced per bird were higher in treatment group compared to control group. It was concluded that 15 and 30 percent sodium bentonite inclusion in the diet of laying birds and litter treatment with aluminum sulfate at 400g /3kg litter improved laying performance and egg quality traits of the hens and therefore, 15 g sodium bentonite + 400 g alum/3 kg litter can be applied by egg producing farmers.

ACKNOWLEDGEMENT

The authors wish to acknowledge the Head of the Department of Animal Science, University of Nigeria, Nsukka, Professor N.S. Machebe and Professor A.E. Onyimonyi for their support towards making this research a success.

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