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Effects of supplementing laying hen diets with different proprietary vitamin-mineral premixes and housing systems on egg properties and shelf-life stability

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Abstract

Egg quality and durability have been directly linked to the nutrition of laying hen thus, the effects of five different supplemental vitamin-mineral premixes (VmP) in the diets of laying hens housed in battery cage (BC) and deep litter (DL) on the egg properties and shelf life stability in 0, 7, 14, 21 and 28 days of egg storage (DOS) were investigated in this study. In a 4-week feeding trial, Bovans Nera Black laying hens (n=480) aged 71-week were allocated to five treatments in each housing system (HS) (BC and DL). Each treatment was replicated six times and a replicate comprised eight hens. The basal isocaloric and isonitrogenous diet was appropriately supplemented with 0.25% of any of the five proprietary VmP and the diets were offered with water ad libitum to respective experimental hens in both HS. The experiment was a 2x5x5 factorial arrangement in a completely randomized design (2 HS X 5VmP X 5DOS). Foaming capacity, foaming stability, viscosity, emulsion stability, least gelation concentration and shelf life stability of egg white and whole egg from both HS decreased significantly (P<0.05)in DOS while the thiobarbituric acid reactive substances (TBARS mg/MA/100g) increased in DOS. The TBARS of respective whole and egg white from hens fed VmP1 (0.048 and 0.051), 2 (0.049 and 0.054), 3(0.056 and 0.155), 4(0.156 and 0.156) and 5 (0.153 and 0.151) differed significantly (P<0.05). Interactions of HS X VmP, HS X DOS on all attributes of both whole and egg white, except specific gravity and emulsion capacity, were significantly different (P<0.05). Eggs deteriorated in DOS irrespective of dietary VmP or HS but much more for eggs from DL compared with BC.

Keywords: Dietary vitamin-mineral premixes, Whole or egg white, Laying hens, Thiobarbituric acid reactive substances, Functional properties

Introduction

Poultry egg is important in many spheres of the modern food industry (Montagne, 2001) and is widely used due to their multifunctional properties such as foaming, gelling and emulsification (Hernandez-Ledesma and Cha Chien, 2013). According to Beneda *et al.* (2014), egg, either as a whole or its constituents (egg yolk and white) is a key ingredient in many food products by virtue of its nutritional value and unique functional properties such as foaming, gelling and emulsification. Eggs also serve as a raw material for the pharmaceutical and cosmetic industries due to its peculiar functional properties (Matt *et al.*, 2009).

Egg quality and durability have been directly linked to the nutrition of laying hen (Patricio, 2003). The diet and housing system (HS) of the laying hens can greatly affect the nutritional quality and other properties of the eggs (Aro *et al.*, 2011). Among the dietary factors affecting the nutritional value of egg and keeping quality includes vitamins, minerals and fat (Hayat *et al.*, 2010). The quality of chicken eggs starts to decrease immediately after it is laid. These chemical changes in eggs can be delayed but not completely prevented (Theoron *et al.*, 2003). Specially, birds in cages require more attention for supplying vitamin-mineral premix (VmP) than those of floor housing because of more limited opportunity for coprophagy for birds raised on the deep litter (DL).

Therefore, vitamin and mineral are important in poultry production (Asaduzzaman *et al., 2005).* Studies have been carried out on the different commercial VmP (Ogunwole *et al.*, 2012) as well as management systems in poultry production (Alamprese *et al.*, 2012). However, in the recent times, studies have not been carried out on management systems and the relative effect of VmP on functional properties and keeping quality of table eggs laid by the hen at the late stage. A study conducted by Alamprese *et al.* (2012), was mainly on the effect of HS, diet, hen ages and storage on egg properties. The interactive effect of hen age, storage time and storage temperature on interior egg quality has also been evaluated (Hasan and Aylin, 2009). These studies were in other climes with dearth of information on what is obtainable here in the tropics. There was also no report on the effect of VmP used in formulating feed fed to birds as well as the interactive effect of VmP, HS and DOS on egg functional properties and shelf life stability in phases of laying. Therefore, this study was aimed at determining the functional properties of eggs produced in two HS using five different dietary VmP supplements in DOS.

Materials and methods

Experimental site

The experiment was conducted at the Poultry Unit of the Teaching and Research Farm, University of Ibadan, situated in the derived savanna vegetation belt of Nigeria. The geographical location is longitude 7^0 27.05 North and latitude 3^0 53.74 of the Greenwich Meridian East at an altitude above 200m sea level. Average temperature and relative humidity of the location is about 23-25 ^{0}C and 60 %, respectively.

Experimental birds and management

Bovan Nera black hens (N=480) at week 51 (mid stage of laying) with a track record of medication, vaccination schedule and productive performance from one-day old were used for the experiment. Hens' management was under two HS (deep litter, DL and battery cage, BC) with equal exposure to similar environment all through the period of the experiment. Birds were randomly allotted to five dietary treatments. Each treatment was replicated six times with eight birds per replicate. Two hundred and forty hens were each raised in an open-sided DL house with average floor space area of each partitioned pen measuring 3.32m^2 and a conventional BC. The BC was a three tier cage each measuring 40 x 41 x 32 cm^3. The cages were arranged in rows placed on leg supports so the floors of the cages were about 61.00 to 91.44 cm above ground with a rectangular hollow in the middle to collect the droppings.

Experimental diets

Five isocaloric and isonitrogenous diets were formulated. Each diet was supplemented with one of the five proprietary VmP purposively selected among those most commonly used in formulating layer's feed and incorporated at 0.25%. Gross formulation of the experimental diet is shown in Table 1 while the composition of the different dietary VmP as indicated on their individual labels is shown in Table 2. Detailed dietary formulation of the experimental diets (Table 1) and composition of test vitamin-mineral premixes as shown on their labels (Table 2) have been documented elsewhere (Ogunwole *et al.,* 2015a, b).

Table 1: Gross composition (%) of the experimental laying chicken diets

Ingredients	T1	T2	T3	T4	T5
Maize	59.00	59.00	59.00	59.00	59.00
Soybean meal	24.37	24.37	24.37	24.37	24.37
Wheat bran	3.00	3.00	3.00	3.00	3.00
Palm kernel cake	3.00	3.00	3.00	3.00	3.00
Table salt	0.30	0.30	0.30	0.30	0.30
Di-calcium phosphate	0.11	0.11	0.11	0.11	0.11
Limestone	9.30	9.30	9.30	9.30	9.30
Biotronics	0.30	0.30	0.30	0.30	0.30
Mycofix	0.10	0.10	0.10	0.10	0.10
DL-Methionine	0.15	0.15	0.15	0.15	0.15
L-Lysine	0.12	0.12	0.12	0.12	0.12
VmP 1	0.25	-	-	-	-
VmP 2	-	0.25	-	-	-
VmP 3	-	-	0.25	-	-
VmP 4	-	-	-	0.25	-
VmP 5	-	-	-	-	0.25
Total	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**
Calculated nutrients					
ME (Kcal/kg)	2687.56	2687.56	2687.56	2687.56	2,687.56
Crude protein (%)	17.00	17.00	17.00	17.00	17.00
Crude fibre (%)	3.80	3.80	3.80	3.80	3.80
Fat (%)	3.59	3.59	3.59	3.59	3.59
Lysine (%)	0.97	0.97	0.97	0.97	0.97
Methionine+Cystein (%)	0.71	0.71	0.71	0.71	0.71
Calcium (%)	3.68	3.68	3.68	3.68	3.68
Available Phosphorus (%)	0.40	0.40	0.40	0.40	0.40

VmP = Vitamin-mineral premix; ME = Metabolizable Energy. T1, T2, T3, T4 and T5: Respective experimental diets supplemented with the different proprietary vitamin-mineral premixes

Table 2: Gross composition of test ingredient vitamin-mineral layer premixes

	Test proprietary vitamin-mineral premixes				
Vitamins & Minerals	1	2	3	4	5
Vitamin A (IU)	10,000,000	10,000,000	10,000,000	12,000,000	10,000,000
Vitamin D3 (IU)	2,000,000	2,000,000	2,000,000	2,400,000	2,000,000
Vitamin E (IU)	12,000	12,000	12,000	12,000	23,000
Vitamin K (mg)	2,000	2,000	2,000	2,000	2,000
Vitamin B1 (mg)	1,500	1,500	1,500	1,500	3,000
Vitamin B2 (mg)	5,000	4,000	5,000	4,000	6,000
Vitamin B6 (mg)	1,500	1,500	1,500	1,800	5,000
Vitamin B12 (mg)	10	10	10	10	25
Niacin (mg)	15,000	15,000	15,000	25,000	50,000
Pantothenic acid (mg)	5,000	5,000	5,000	5,000	10,000
Folic acid (mg)	600	500	600	500	1,000
Biotin (mg)	20	20	20	25	50
Choline chloride (mg)	150,000	100,000	150,000	240	400,000
Manganese (mg)	80,000	75,000	75,000	80,000	120,000
Zinc (mg)	60,000	50,000	50,000	50,000	80,000
Iron (mg)	40,000	20,000	25,000	20,000	100,000
Copper (mg)	8,000	5,000	5,000	5,000	8,500
Iodine (mg)	1,000	1,000	1,000	1,200	1,500
Selenium (mg)	150	200	100	200	120
Cobalt (mg)	250	500	400	200	300
Antioxidant (mg)	100,000	125,000	125,000	125,000	120,000

Experimental design and model

The experiment was a 2x5x5 factorial arrangement in a completely randomized design which comprised two HS (BC and DL), five different VmP and five (0, 7, 14, 21, and 28) different DOS of eggs obtained from the birds fed the five VmP.

Parameters measured

A total of 459 freshly laid eggs (eggs per treatment) were collected and labeled appropriately for analysis and 45 eggs each were analyzed within 48 hours of the respective days (0, 7. 14, 21 and 28) of storage. Storage durations were selected to simulate likely days of consumer storage of shell eggs. Three eggs per treatment were manually cracked with the yolks and chalazae removed using an egg yolk separator and the albumen pooled together to take measurements of parameters on the egg white. Another three were manually broken and pooled together to take measurements of parameters on the whole egg.

Functional properties

Foam capacity (FC) and stability

Foam capacity and **stability** were evaluated according to the method of Coffman and Garcia (1997), with slight modifications. 50 mL of each pool of eggs was whipped with 100 mL distilled water for 5 min in a Kenwood blender at speed setting 1-li" and was poured into a 250 mL graduated cylinder.

Volume Increase (%) was calculated using the equation:

$$\text{Volume Increase (\%) V} = \frac{\text{Volume after whipping (mL)} - \text{Volume before whipping (mL)} \times 100}{\text{Volume before whipping (mL)}}$$

Foam stability was measured with a graduated cylinder after the foam had been allowed to rest for one hour, as described by Lomakina and Mikova (2006), using a small volume. Foam stability was measured in the same vessel as the volume of released fluid at the bottom one hour after whipping. Foam stability was calculated as:

Foam stability (%) = Vs/ Vt x 100

Where Vs is the volume of the liquid albumen separated and Vt is the total volume of albumen originating the volume of foam transferred into the conical vessel. This process was carried out for egg albumen and whole egg, and repeated on 0, 7, 14, 21 and 28 DOS. All measurements were taken in triplicates.

Gelation properties

Gelation properties were evaluated using the method described by Coffman and Garcia (1977). Sample suspensions of 2-20% were prepared in distilled water. 10 mL of each of the prepared dispersions was transferred into a test tube. It was heated in a boiling water bath for 1hr, followed by rapid cooling in a bath of cold water. The test tubes were further cooled at 4^{o}C for 2h.

Least gelation concentration

The least gelation concentration was determined as the concentration of sample from the inverted test tube which did not slip or fall. This process was carried out for egg albumen and whole egg, and repeated on 0, 7, 14, 21 and 28 DOS. All measurements were in triplicates.

Emulsion capacity and stability

Emulsion capacity

Preparation of the **emulsion capacity was carried out according to the** method of Beuchat (1997) with some modifications. 50 mL of egg sample and 100 mL distilled water was blended for 30 seconds in a Philip's blender at 1600 rpm. While blending continued, vegetable oil was added in 5 mL portions from a burette. Blending did not stop until the emulsion breakpoint, a separation into two livers, was reached.Emulsification determinations were carried out at room temperature (28 ºC). Emulsion capacity was expressed as the amount of oil emulsified and held per gram of sample (Beuchat, 1977). This process was carried out for egg albumen and whole egg, and repeated on 0, 7, 14, 21 and 28 DOS. All measurements were in triplicates.

Emulsion stability

The emulsion stability was determined using the sample prepared for emulsion capacity measurement. Samples were heated for 15 min at 85 ºC cooled and divided evenly into to 50 mL centrifuge tubes. Samples were then centrifuged at 1100 rpm for 5min. The emulsion stability was expressed as percentage of emulsifying activity remaining after heating. This process was carried out for egg albumen and whole egg, and repeated on 0, 7, 14, 21 and 28 DOS. All measurements were taken in triplicates.

Viscosity

The viscosity was measured using a viscometer. An arm of the viscometer was filled with some quantity of egg sample. A finger was used to cover the measuring arm of the viscometer which has two marks (one above and another below, point A and B). The finger was released and the time taken for the egg sample to move from point A to B was noted and the viscosity was measured as follows:

$V = tK$

Where v = viscosity,

t = time taken and

K= constant.

This process was carried out for egg albumen and whole egg, and repeated on 0, 7, 14, 21 and 28 DOS.

Degree of lipid oxidation was estimated in egg albumen and whole egg, and repeated on 0, 7, 14, 21 and 28 DOS in triplicates as described (Pensel, 1990). The TBA of each sample was calculated with the formula. TBA mg MA/g=KxO.D. 530 nm where k=9.242, MA=Malonaldehyde.

Specific gravity

The specific gravity was measured using a pycnometer (specific gravity bottle). Empty pycnometer was first weighed and the weight noted. Water was poured into the bottle and weighed after which the egg sample was poured into the bottle and also weighed. The specific gravity was then calculated with the formula:

$$\text{Specific gravity} = \frac{Ws}{Ww}$$

Where Ws is the weight of the sample and Ww is the weight of water.

This process was carried out for egg albumen and whole egg, and repeated on 0, 7, 14, 21 and 28 DOS. All measurements were in triplicates.

Statistical analysis

Data were subjected to analysis of variance using the General Linear Model procedures (SAS, 2012). Means were separated using Least Significant Difference test of the same software at $\alpha_{0.05}$.

Results

Specific gravity and functional properties of egg white

Effect of five proprietary VmP, HS and DOS on the specific gravity and functional properties of egg white is shown in Table 3. The specific gravity of eggs differed significantly (P<0.05) between the BC and DL. However, there was no significant effect (P>0.05) of VmP and DOS on specific gravity of egg white.

Both HS (DL and BC) and VmP affected foaming capacity of egg white significantly (P<0.05). Foaming capacity of egg white from hens fed VmP 3 (62.88 %) was significantly higher (P<0.05) compared with those on VmP 1 (24.68), 2 (41.06), 4 (43.55) and 5 (33.15%) which in turn differed significantly (P<0.05) from one another. The DOS had significant effect (P<0.05) on foaming capacity of egg white.

The HS, VmP and DOS significantly affected (P<0.05) the foaming stability of egg white. Birds fed VMP 2 had significantly higher foaming stability (70.63) compared with those from VMP 1 (40.77), 3 (64.29), 4 (31.61) and 5 (25.17). Viscosity was higher (P<0.05) in egg white from DL (27.82) than those from BC (26.90). Viscosity was highest (P<0.05) in eggs from hens fed VmP1 (33.62) compared with those on VmP 2 (28.28), 3 (27.29), 4 (24.71) and 5 (22.81). Viscosity in storage day zero was higher (47.97) (P<0.05) than those on days 7 (27.09), 14 (23.87), 21 (20.71) and 28 (17.15)

Interaction between HS and treatment, HS and DOS and HS and VmP and DOS on foaming capacity, foaming stability and viscosity were highly significant (P<0.01). However, the interactions were not significant (P>0.05) for specific gravity of egg white.

Table 3: Effect of housing systems, vitamin- mineral premixes and duration of storage on specific gravity and functional properties of egg white

	Factors	Specific gravity (g/cm^3)	Foaming capacity (%)	Foaming instability (%)	Viscosity (CentiStokes)
Housing system	Battery Cage	1.18^a	41.62^a	46.23^b	26.90^b
	Deep litter	1.12^b	40.50^b	46.76^a	27.82^a
	SEM	0.02	0.03	0.02	0.03
Vitamin-mineral premix	1	1.15^a	24.68^e	40.77^c	33.62^a
	2	1.15^a	41.06^c	70.63^a	28.28^b
	3	1.17^a	62.88^a	64.29^b	27.29^c
	4	1.14^a	43.55^b	31.61^d	24.71^d
	5	1.14^a	33.15^d	25.17^e	22.89^e
	SEM	0.02	0.04	0.04	0.03
Duration of storage	0	1.19^a	58.55^a	60.64^a	47.97^a
	7	1.13^a	41.91^b	41.99^d	27.09^b
	14	1.14^a	37.35^c	49.22^b	23.87^c
	21	1.17^a	35.35^d	43.15^c	20.21^d
	28	1.12^a	32.15^e	37.47^e	17.15^e
	SEM	0.02	0.04	0.04	0.05
	Source of variation				
	HS	0.001	<0.001	<0.001	<0.001
	Treatment	0.584^{NS}	<0.001	<0.001	<0.001
	DOS	0.059^{NS}	<0.001	<0.001	<0.001
	HS*Treatment	0.593^{NS}	<0.001	<0.001	<0.001
	HS*DOS	0.313^{NS}	<0.001	<0.001	<0.001
	Treatment*DOS	0.440^{NS}	<0.001	<0.001	<0.001
	HS*Treatment*DOS	0.444^{NS}	<0.001	<0.001	<0.001

$^{a-e}$ Means in the same column with different superscripts are significantly different (P<0.05).. SEM- standard error of mean. NS- not significant. 1 cSt (centistoke) = 1mm²/s, HS= Housing system, DOS=Duration of storage

Functional properties and oxidative stability of egg white

Effect of five proprietary VmP, HS and DOS on functional properties and oxidative stability of egg white are shown in Table 4. Emulsion capacity (0.33) and stability (16.71) of eggs from DL were higher than those from BC (0.25 and 14.92, respectively). Emulsion capacity was highest in eggs of hens fed VmP3 (0.32) which was similar (P>0.05) to those fed VmP1 (0.35) but higher (P<0.05) than in eggs from hens on VmP 2 (0.29), 4 (0.24) and 5 (0.24). Emulsion stability was significantly affected (P<0.05) by VmP and DOS. Emulsion stability was least on 28 (10.18) and highest at 0 (28.47) DOS.

Eggs from hens on DL had higher least

gelation concentration (6.08) and oxidative stability (0.06) (P<0.05) compared with those from BC (5.13 and 0.04, respectively). The least gelation concentration and oxidative stability increased significantly in DOS. Oxidative stability were significantly different at 0 (0.008), 7 (0.019), 14 (0.051), 21 (0.078) and 28 (0.102mg/MA/100g) DOS.

Interactions of HS X treatment (HS and DOS) X HS X VmP and DOS on emulsion capacity, emulsion stability, least gelation concentration and oxidative stability (TBARS) of egg white were highly significant (P<0.01) except for the interaction of HS X treatment which was not significant for emulsion capacity.

Effect of housing system and vitamin-mineral premix on egg white characteristics

Effect of HS and VmP on functional and physical attributes of egg under two HS in DOS is shown in Table 5. Specific gravity was not significantly affected (P>0.05) by the different VmP in BC. Eggs from hens fed VmP1 and 2 in DL were not statistically different from those on VmP1, 2, 3, 4 and 5 in BC. The FC, foaming stability, viscosity and emulsion stability were significantly different across all VmP X HS except the interaction of BC X VmP3 (15.90), DL X VmP4 (15.89) and BC X VmP1 (15.82) which were similar (P>0.05). Highest FC was observed in the interaction of DL X VmP3 (71.12) which was significantly different (P<0.05) from others across the two HS and was lowest in BC X VmP1 (25.29). Highest foaming stability was observed in the interaction between BC X VmP3 (70.12) which was significantly different (P<0.05) from the other values across the two HS. However, lowest value was observed in BC X VmP5 (19.11). Emulsion capacity in DL X VmP1 (0.39) was highest and significantly different (P<0.05) from others. However, BC X VmP2, BC X VmP3 and DL X VmP 4 with values of 0.27, respectively were similar (P>0.05). The highest oxidative stability was observed in DL X VmP5 (0.062) and lowest in BC X VmP1 (0.039). Oxidative stability was similar (P>0.05) in eggs from BC X VmP1, 2 and 3.

Effect of housing system and duration of storage on egg white

Effect of HS and DOS on egg white attributes is shown in Table 6. Effect of HS and DOS on specific gravity was not significantly different (P>0.05). Specific gravity of eggs from hens in BC at zero DOS was higher and significantly different (P<0.05) from those in DL at 7, 21 and 28 DOS, but similar (P>0.05) to other in both HS. FC, foaming stability, viscosity, emulsion capacity and emulsion stability decreased significantly (P<0.05) in both BC and DL with increase in DOS from 48.06 to 36.21, 63.7 to 35.81, 46.80 to 16.64, 0.43 to 0.15 and 28.12 to 8.53, respectively in BC and from 69.04 to 28.10, 57.42 to 39.12, 49.13 to 17.67 0.64 to 0.17 and 28.81 to11.83, respectively in DL. The FC, foaming stability, viscosity, emulsion capacity and emulsion stability of eggs from DL were higher than those from BC at all DOS and were significantly different (P<0.05) except for the emulsion capacity at 21 and 28 DOS in BC which were similar (P>0.05). The relationships of FC in egg white in the DOS resulted in quadratic equation as shown in equation 1 below which shows progressive decrease in FC of egg white in DOS.

$Y = 3E - 05x^4 - 0.0032x^3 + 0.0974x^2 - 1.3084x + 48.06$ (R^2=0.0996)………Equation 1

Also, the relationship of egg white viscosity as influenced in the DOS is represented by equation 2 below which showed significant quadratic decrease (P>0.05) in the viscosity of egg white with increased DOS

$$Y=0.0004x^4-0.0261x^3+0.6142x^2-6.1313x+46.804\ (R^2=0.8793)$$..Equation 2

Least gelation concentration and TBARS increased significantly (P<0.05) in DOS both in BC and DL. Highest least gelation concentration (9.60) and TBARS (0.12) were observed in eggs from DL at 28 DOS which differed significantly (P<0.05) from others. Lowest least gelation concentration was in eggs from BC at zero DOS while lowest TBARS was in eggs from DL at zero DOS. The relationship of TBARS in egg white in the different DOS is represented in equation 3 which revealed that TBARS in egg white increased significantly (P<0.05) in DOS.

$$Y=3E\text{-}07x^4-2E\text{-}05x^3+0.000x^2-0.0018x+0.0065\ (R^2=0.9319)$$....Equation 3

Table 4: Effect of housing systems, vitamin-mineral premixes and duration of storage on functional properties and oxidative stability of egg white

	Factors	Emulsion capacity (%)	Emulsion stability (%)	Least Gelation Concentration	TBARS (mg/MA/100g)
Housing system	Battery cage	0.25^{b}	14.92^{b}	5.13^{b}	0.04^{b}
	Deep litter	0.33^{a}	16.71^{a}	6.08^{a}	0.06^{a}
	SEM	0.01	0.03	0.01	0.000
Vitamin-Mineral Premix	1	0.35^{a}	17.49^{a}	3.80^{e}	0.048^{e}
	2	0.29^{b}	16.60^{b}	4.90^{d}	0.051^{c}
	3	0.32^{ab}	15.18^{c}	5.4^{c}	0.049^{d}
	4	0.24^{c}	15.26^{c}	6.50^{b}	0.054^{b}
	5	0.24^{c}	14.53^{d}	7.42^{a}	0.056^{a}
	SEM	0.02	0.05	0.01	0.000
Duration of Storage	0	0.54^{a}	28.47^{a}	2.82^{e}	0.008^{e}
	7	0.33^{b}	17.33^{b}	3.80^{d}	0.019^{d}
	14	0.23^{c}	11.94^{c}	5.40^{c}	0.051^{c}
	21	0.18^{cd}	11.15^{d}	7.00^{b}	0.078^{b}
	28	0.16^{d}	10.18^{e}	9.00^{a}	0.102^{a}
	SEM	0.02	0.05	0.01	0.000
	Source of variation				
	HS	<0.001	<0.001	<0.001	<0.001
	Treatment	<0.001	<0.001	<0.001	<0.001
	Storage time	<0.001	<0.001	<0.001	<0.001
	HS*Treatment	0.485^{NS}	<0.001	<0.001	<0.001
	HS*DOS	<0.001	<0.001	<0.001	<0.001
	Treatment*DOS	0.001	<0.001	<0.001	<0.001

[a-e] Means in the same column with different superscripts are significantly different (P<0.05). SEM - standard error of mean. NS- not significant HS= Housing system, DOS=Duration of storage

Table 5: Effect of housing system and vitamin-mineral premix on egg white characteristics

Housing system	VMP	SG (g/cm^3)	FC (%)	FS (%)	VS (Centistokes)	EC (%)	ES (%)	LGC	TBARS (mg/MA/100g)
	1	1.18^{a}	25.29^{h}	21.90^{i}	32.53^{b}	0.30^{bc}	15.82^{cd}	3.20^{i}	0.039^{f}
	2	1.17^{a}	50.69^{c}	94.67^{a}	28.34^{c}	0.27^{cde}	15.60^{d}	4.80^{g}	0.041^{f}
Battery cage	3	1.22^{a}	54.64^{b}	70.12^{b}	26.80^{e}	0.27^{cde}	14.47^{f}	4.80^{g}	0.040^{f}
	4	1.15^{a}	46.20^{d}	25.33^{h}	24.05^{g}	0.21^{de}	14.60^{f}	6.20^{d}	0.048^{e}
	5	1.16^{a}	31.29^{g}	19.11^{j}	22.76^{i}	0.20^{e}	14.10^{g}	6.63^{c}	0.050^{e}
	1	1.13^{ab}	24.07^{i}	59.64^{c}	34.71^{a}	0.39^{a}	19.17^{a}	4.40^{h}	0.056^{d}
	2	1.13^{a}	31.42^{g}	46.59^{e}	28.21^{c}	0.32^{abc}	17.60^{b}	5.00^{f}	0.061^{b}
Deep litter	3	1.12^{c}	71.12^{a}	58.46^{d}	27.77^{d}	0.37^{ab}	15.89^{c}	6.00^{e}	0.059^{c}
	4	1.12^{bc}	40.89^{e}	37.89f	25.37^{f}	0.27^{cde}	15.90^{c}	6.80^{b}	0.059b^{c}
	5	1.12^{c}	35.01^{f}	31.22^{g}	23.03^{h}	0.29^{cd}	14.97^{e}	8.20^{a}	0.062^{a}
	SEM	0.01	1.69	2.25	0.95	0.01	0.57	0.23	0.00

[a-j] Means in the same column with different superscripts are significantly different (P<0.05). SEM- standard error of mean. VMP = Vitamin-mineral premix. SG= Specific gravity, FC = Foaming capacity, FS= Foaming stability, VS = Viscosity, EC = Emulsion capacity, ES = Emulsion stability, LGC = Least gelation concentration, TBARS = Thiobarbituric acid reactive substance. 1 cSt (centistoke) = 1mm^2/s.

Table 6: Effect of housing system and duration of storage on egg white characteristics

Housing system	Duration of Storage	SG (g/cm^3)	FC (%)	FS (%)	VS (centistokes)	EC (%)	ES (%)	LGC	TBARS (mg/MA/100g)
Battery cage	Day 0	1.23^{a}	48.06^{b}	63.87^{a}	46.80^{b}	0.43^{b}	28.12^{b}	2.83^{i}	0.007^{i}
	Day 7	1.15^{ab}	42.66^{c}	49.83^{d}	25.93^{d}	0.30^{cd}	16.57^{d}	4.40^{f}	0.014^{g}
	Day 14	1.15^{ab}	41.28^{d}	42.71^{f}	24.26^{e}	0.22^{ef}	11.27^{h}	4.00^{g}	0.042^{e}
	Day 21	1.22^{ab}	39.91^{e}	38.91^{g}	20.85^{g}	0.15^{f}	10.11^{i}	6.00^{e}	0.068^{c}
	Day 28	1.14^{ab}	36.21^{f}	35.81^{h}	16.64^{d}	0.15^{f}	8.53^{j}	8.40^{b}	0.088^{b}
Deep litter	Day 0	1.14^{ab}	69.04^{a}	57.42^{b}	49.13^{a}	0.64^{a}	28.81^{a}	2.80^{i}	0.011^{h}
	Day 7	1.12^{b}	41.17^{d}	34.15^{i}	28.24^{c}	0.37^{bc}	18.09^{c}	3.20^{h}	0.024f
	Day 14	1.12^{ab}	33.43^{g}	55.73^{c}	23.48^{f}	0.24^{de}	12.61^{e}	6.80^{d}	0.060^{d}
	Day 21	1.12^{b}	30.78^{h}	47.39^{e}	19.58^{h}	0.22^{ef}	12.19^{f}	8.00^{c}	0.088^{b}
	Day 28	1.11^{b}	28.10^{i}	39.12^{g}	17.67^{i}	0.17^{ef}	11.83^{g}	9.60^{a}	0.12^{a}
	SEM	0.01	1.69	2.25	0.95	0.01	0.57	0.23	0.00

[a-i] Means in the same column with different superscripts are significantly different (P<0.05). SEM- Standard error of Mean. VMP = Vitamin-mineral premix. SG = Specific gravity, FC = Foaming capacity, FS= Foaming stability, VS = Viscosity, EC = Emulsion capacity, ES = Emulsion stability, LGC = Least gelation concentration, TBARS = Thiobarbituric acid reactive substance. 1 cSt (centistoke) = $1mm^2/s$.

Specific gravity and functional properties of the whole egg

Effect of five different proprietary VmP, HS and DOS on foaming capacity of the whole egg is shown in Table 7. There were significant differences (P<0.05) in specific gravity of eggs from DL and BC. Specific gravity of eggs from hens fed VmP1 was similar to those of VmP 2, 3 and 5 but differed significantly from those on VmP4, which was similar (P>0.05) to those on VmP3 and 5. Specific gravity was highest at zero DOS and differed significantly from values in other DOS. At 7 and 14 DOS, specific gravity was similar which however, differed at 21 and 28 DOS.

The FC (39.20), foaming stability (17.94) and viscosity (23.31) of whole egg from DL were higher (P<0.05) than those from BC. The highest FC was recorded in eggs from hens fed VmP 3 (40.18). However, the highest foaming stability (25.13) and viscosity (26.03) were observed in eggs from hens on diets VmP 4 and 1, respectively which differed (P<0.05) from others. Foaming capacity (56.94), foaming stability (35.30) and viscosity (45.84) of whole egg decreased significantly (P<0.05) to 20.40, 9.65 and 12.34, respectively in DOS.

Functional properties and oxidative stability of whole egg

Effect of HS, VmP and DOS on functional properties and oxidative stability of whole egg is shown in Table 8. Emulsion capacity of eggs was not affected (P>0.05) by HS. Emulsion stability, least gelation concentration and TBARS in DL (0.35, 7.32 and 0.16, respectively) were significantly higher (P<0.05) compared to those from BC. Eggs from hens on VmP 1 had higher emulsion capacity compared with those on diets containing VmP 3, 4 and 5. However, DOS had significant effect on emulsion capacity (P<0.05) which was highest at day 0 (0.56) and lowest on day 28 (0.20). Emulsion stability differed significantly (P<0.05) with VmP and DOS. Emulsion stability decreased from 19.70 in eggs from hens on dietary VmP1 to 16.23 in VmP 5 also, from 32.24 on day 0 to 10.5 at day 28.

Eggs from hens on VmP 5 had highest least gelation concentration (8.50) which was significantly different (P<0.05) from those on VmP 1 (4.80), 2 (6.00), 3 (7.10) and 4 (7.10). Effect of DOS on least gelation concentration was also significant (P<0.05) which increased from 3.40 at day zero to 9.80 on 28 DOS.

Table 7: Effect of housing systems, vitamin-mineral premixes and duration of storage on specific gravity and functional properties of whole egg

	Factors	Specific gravity (g/cm^3)	Foaming capacity (%)	Foaming stability (%)	Viscosity (CentiStokes)
Housing System	Battery cage	1.13[a]	25.06[b]	16.56[b]	22.55[b]
	Deep litter	1.11[b]	39.20[a]	17.94[a]	23.31[a]
	SEM	0.001	0.03	0.03	0.03
Vitamin-Mineral Premix	1	1.12[a]	25.15[e]	13.75[a]	26.03[a]
	2	1.12[a]	39.37[b]	11.23[e]	23.06[b]
	3	1.11[a,b]	40.18[a]	23.47[b]	22.79[c]
	4	1.11[b]	30.18[c]	25.13[c]	21.60[d]
	5	1.12[a,b]	25.79[d]	12.67[d]	20.88[d]
	SEM	0.002	0.05	0.04	0.04
Duration of Storage	0	1.17[a]	56.94[a]	35.30[a]	45.84[a]
	7	1.11[b]	38.49[b]	17.70[b]	22.01[b]
	14	1.11[b]	24.66[c]	12.57[c]	19.18[c]
	21	1.10[c]	20.18[d]	11.03[d]	15.29[d]
	28	1.10[c]	20.40[e]	9.65[e]	12.34[e]
	SEM	0.002	0.05	0.04	0.04
	Source of variation				
	HS	<0.001	<0.001	<0.001	<0.001
	Treatment	0.004	<0.001	<0.001	<0.001
	DOS	<0.001	<0.001	<0.001	<0.001
	HS*Treatment	0.004	<0.001	<0.001	<0.001
	HS*DOS	<0.001	<0.001	<0.001	<0.001
	Treatment* DOS	0.473	<0.001	<0.001	<0.001
	HS*Treatment*DOS	0.367	<0.001	<0.001	<0.001

[a-e]Means in the same column with different superscripts differs significantly ($P<0.05$). SEM- standard error of mean. 1 cSt (centistoke) = $1mm^2/s$, HS= Housing system, DOS=Duration of storage

Table 8: Effect of housing systems, vitamin-mineral premixes and duration of storage on functional properties and oxidative stability of whole egg

	Factors	Emulsion capacity (%)	Emulsion stability (%)	Least Gelation Concentration	TBARS (mg/MA/100g)
Housing system	Battery cage	0.33[a]	19.17[a]	6.40[a]	0.15[b]
	Deep litter	0.35[a]	16.09[b]	7.32[b]	0.16[a]
	SEM	0.01	0.05	0.01	0.000
Vitamin-mineral premix	1	0.40[a]	19.70[a]	4.80[e]	0.155[b]
	2	0.38[a,b]	18.22[b]	6.00[d]	0.156[a]
	3	0.33[bc]	16.89[d]	7.10[c]	0.156[a]
	4	0.30[c]	17.11[c]	7.90[b]	0.153[b]
	5	0.29[c]	16.23[e]	8.50[a]	0.151[c]
	SEM	0.02	0.08	0.01	0.000
Duration of storage	0	0.56[a]	32.24[a]	3.40[e]	0.010[e]
	7	0.38[b]	16.27[b]	5.50[d]	0.125[d]
	14	0.30[c]	15.50[c]	7.40[c]	0.162[c]
	21	0.26[c]	13.29[d]	8.50[b]	0.216[b]
	28	0.20[d]	10.85[e]	9.80[a]	0.256[a]
	SEM	0.02	0.08	0.01	0.000
	Source of variation				
	HS	0.095[NS]	<0.001	<0.001	<0.001
	Treatment	<0.001	<0.001	<0.001	<0.001
	DOS	<0.001	<0.001	<0.001	<0.001
	HS*Treatment	0.009[NS]	<0.001	<0.001	<0.001
	HS*DOS	<0.001	<0.001	<0.001	<0.001
	Treatment*DOS	0.414[NS]	<0.001	<0.001	<0.001
	HS*Treatment*DOS	0.099[NS]	<0.001	<0.001	<0.001

[a-e] Means in the same column with different superscripts differs significantly ($P<0.05$). SEM- Standard Error of Mean. NS- not significant, HS= Housing system, DOS=Duration of storage

The TBARS in eggs from hens on VmP 1 (0.155) and 4 (0.153) were similar (P>0.05) but lower significantly (P<0.05) from those on VmP 2 (0.156) and 3 (0.156) and least (0.151) in eggs of those on VmP 5. The TBARS were higher (P<0.05) on 28 (0.256) DOS compared to other days and least at day 0 (0.010).

Effect of housing system and vitamin-mineral premix on whole egg attributes

Effect of interaction of HS and VmP on whole egg attributes is shown in Table 9. Interaction of HS and VmP on specific gravity of whole eggs from hens on VmP 1(1.13) was similar (P>0.05) to those on VmP 2 (1.124), 3 (1.124), 4 (1.121) and 5 (1.128) in BC which however differed (P<0.05) from those in DL. Specific gravity of eggs from hens on VmP 1(1.110) in DL was similar to those on VmP3 (1.105) and 4 (1.105) but higher (P<0.05) compared with those on VmP5 (1.102).

The FC, foaming stability, viscosity, emulsion capacity, least gelation concentration and TBARS of egg from hens on different VmP were higher in DL than in BC except for those from hens VmP 3 where foaming capacity (29.58) and foaming stability (28.627) of eggs in BC were higher compared with those on VmP 3 in DL (26.740 and 18.307, respectively) Also, FC (23.77) and viscosity (21.13) of eggs from hens on VmP 5 in BC were higher than those on VmP 5 (19.053 and 20.631, respectively) in DL. Foaming capacity (%) across all VmP in both HS differed significantly (P<0.05). Interaction of DL and VmP 2 resulted in higher FC (40.92%) which was least (17.99) in eggs of hens on VmP 1 in BC.

Table 9: Effect of housing system and vitamin-mineral premix on whole egg

Housing system	VMP	SG (g/cm^3)	FC (%)	FS (%)	VS (centistokes)	EC (%)	ES (%)	LGC	TBARS (mg/MA/100g)
Battery Cage	T1	1.13^{a}	17.987^{i}	7.960^{i}	25.464^{b}	0.353^{bc}	20.933^{a}	4.200^{d}	0.147^{f}
	T2	1.124^{a}	30.880^{b}	7.493^{j}	22.047^{f}	0.400^{ab}	19.213^{b}	5.400^{cd}	0.146^{f}
	T3	1.124^{a}	29.580^{c}	28.627^{a}	22.313^{e}	0.307^{c}	18.107^{d}	6.800^{bc}	0.142^{g}
	T4	1.121^{ab}	23.100^{g}	26.813^{b}	21.801^{g}	0.287^{c}	19.027^{b}	7.200^{ab}	0.153^{de}
	T5	1.128a	23.773^{f}	11.927^{h}	21.133^{i}	0.300^{c}	18.587^{c}	8.400^{a}	0.147^{f}
Deep Litter	T1	1.110^{cd}	27.867^{d}	19.540^{d}	26.604^{a}	0.447^{a}	18.467^{c}	5.400^{b}	0.161^{c}
	T2	1.114^{bc}	40.920^{a}	14.967^{f}	24.075^{c}	0.353^{bc}	17.220^{e}	6.600^{ab}	0.167^{b}
	T3	1.105^{cd}	26.740^{e}	18.307^{e}	23.820^{d}	0.347^{bc}	15.680^{f}	7.400^{ab}	0.170^{a}
	T4	1.105^{cd}	30.967^{b}	23.447^{c}	21.401^{h}	0.320^{bc}	15.193^{g}	8.600^{a}	0.152^{e}
	T5	1.102^{d}	19.053^{h}	13.420^{g}	20.631^{j}	0.287^{c}	13.873^{a}	8.600^{a}	0.155^{d}
	SEM	0.00	1.18	1.08	1.00	0.01	0.66	0.23	0.01

$^{a-i}$ Means in the same column with different superscripts differs significantly (P<0.05). SEM- standard error of mean. VMP = Vitamin -mineral premix. SG = Specific gravity, FC = Foaming capacity, FS= Foaming stability, VS = Viscosity, EC = Emulsion capacity, ES = Emulsion stability, LGC = Least gelation concentration, TBARS = Thiobarbituric acid reactive substance. 1 cSt (centistoke) = 1mm^2/s

Effect of housing system and duration of storage on whole egg attributes

Interaction of HS and DOS on attributes of whole egg is shown in Table 10. Specific gravity of eggs from BC at day 0 (1.213) was significantly higher (P<0.05) than those from BC (1.123) at zero DOS. However, specific gravity of corresponding eggs from hens in BC (1.106 and 1.095) and DL (1.107 and 1.095) at 14 and 28 DOS, respectively were similar (P>0.05). Foaming capacity across all DOS in both HS were significantly different (P<0.05). Interaction of DL X zero DOS on FC (%) was higher (49.620) and least in (13.847) BC X 28 DOS. Foaming stability differed significantly (P<0.95) across all DOS in both HS. Interaction of DL X zero DOS on foaming stability (%) was higher (38.48) but lowest (8.347) for BC X 28 DOS.

The viscosity of egg white from hens in BC at zero DOS (46.346) was significantly higher ($P<0.05$) than for corresponding eggs from DL (45.332) and all other days in both HS. The lowest viscosity (9.673) was in eggs from BC at 28 DOS. However, emulsion capacity (%) in egg white from BC (0.620) at zero DOS was significantly higher ($P<0.05$) than corresponding ones from DL (0.507) and others across both HS and DOS. Emulsion capacity of eggs from BC at 14 DOS (0.313) was similar to those from DL at 21 DOS (0.340). Least emulsion capacity (0.140) was observed in eggs from BC at 28 DOS.

Emulsion stability differed significantly ($P<0.05$) in eggs from BC at zero DOS and others. However, there was similarity in observed values for eggs in BC on 14 DOS (15.647) and corresponding value in DL (15.353). Similar trends were observed in whole eggs from DL and BC on 21 (13.273 and 13.313) and 28 (11.007 and 10.700) DOS. Emulsion stability of BC eggs at 7 DOS (19.967) was also significantly different from others. Least gelation capacity was highest (10.400) in DL at 28 DOS which was similar ($P>0.05$) to corresponding values for eggs from BC (9.200). This trend was observed across all other DOS in both HS. The TBARS (mg/MA/100g) was highest ($P<0.05$) (0.276) in DL whole eggs at 28 DOS compared to corresponding 0.236 in BC and all others. However, similar ($P>0.05$) TBARS of 0.125 was obtained in whole eggs from BC and DL at 7 DOS. The lowest TBARS ($P<0.05$) of 0.008 was observed in BC at zero DOS.

Table 10: Effect of housing system and vitamin-mineral premix on attributes of whole egg

Housing System	Duration of storage	SG (g/cm^3)	FC (%)	FS (%)	VS (centistokes)	EC (%)	ES (%)	LGC	TBARS (mg/MA/ 100g)
Battery Cage	Day 0	1.213^{a}	44.840^{b}	32.113^{b}	46.346^{a}	0.620^{a}	36.240^{a}	3.600^{e}	0.008^{i}
	Day 7	1.110^{cd}	27.360^{d}	17.767^{c}	23.707^{c}	0.400^{c}	19.967^{c}	5.200^{d}	0.125^{g}
	Day 14	1.106^{cde}	21.653^{g}	13.760^{d}	19.447^{e}	0.313^{cde}	15.647^{d}	6.400^{c}	0.166^{e}
	Day 21	1.102^{def}	17.620^{i}	10.833^{f}	13.587^{i}	0.173^{fg}	13.313^{e}	7.600^{b}	0.199^{d}
	Day 28	1.095^{f}	13.847^{h}	8.347^{g}	9.673^{e}	0.140^{g}	10.700^{g}	9.200^{a}	0.236^{b}
Deep Litter	Day 0	1.123^{b}	49.620^{a}	38.480^{a}	45.332^{b}	0.507^{b}	28.233^{b}	3.200^{e}	0.012^{h}
	Day 7	1.112^{c}	27.673^{c}	17.627^{c}	20.307^{d}	0.353^{cd}	12.567^{f}	5.200^{d}	0.125^{g}
	Day 14	1.107^{cde}	26.947^{e}	11.387^{e}	18.907^{f}	0.293^{de}	15.353^{d}	8.400^{c}	0.159^{f}
	Day 21	1.098^{ef}	22.733^{f}	11.227^{e}	16.987^{g}	0.340^{cde}	13.273^{e}	9.400^{b}	0.234^{c}
	Day 28	1.095^{f}	18.573^{j}	10.960^{f}	15.000^{h}	0.260^{ef}	11.007^{g}	10.400^{a}	0.276^{a}

$^{a-i}$Means in the same column with different superscripts differs significantly ($P<0.05$). SEM- standard error of mean. VMP = Vitamin-mineral premix. SG = Specific gravity, FC = Foaming capacity, FS= Foaming stability, VS = Viscosity, EC = Emulsion capacity, ES = Emulsion st ability, LGC = Least gelation concentration, TBARS = Thiobarbituric acid reactive substance. 1 cSt (centistoke) = $1 mm^2/s$.

Discussion

Properties of egg white

Specific gravity

There was lowered specific gravity of egg white from hens in the DL compared with those from BC. This could be because eggs from BC were not in contact with droppings of hens. This conforms to the report of Sekeroglu *et al*. (2008) on observed differences in the eggs from DL, free-range and cage systems. Though, specific gravity decreased as DOS increased which corresponds to the report of Sekeroglu *et al*. (2008) that extension in DOS decreases egg specific gravity. However, effect of storage on specific gravity of egg white in this study was not significantly different. This contrasted the findings of Hasan and Aylin (2009) of clear negative effect of storage durations and temperature at week 50 on the specific gravity of eggs and that DOS and temperature were found to be important in keeping eggs fresh. In this study, interaction effect of HS and DOS on specific gravity of eggs was not significant as earlier documented (Sekeroglu *et al*., 2008) that the interaction of HS and DOS was not significantly different for observed attributes of eggs except yolk colour. However, Sekeroglu *et al*. (2008) surmised that storage length affected egg albumen quality more compared with yolk. Additionally, increased DOS decreased overall egg quality characteristics.

Foaming and emulsifying properties

Higher FC and foaming stability observed in eggs from BC agreed with the findings of Alamprese *et al.* (2012) that better foaming properties were obtained in eggs from cage and organic poultry. The foam consistency index, overrun and hen age seemed to be affected by HS. As reported (Jones *et al*., 2014), barn eggs showed slightly lower foaming performance, but had similar foam instability as cage eggs. Wang and Narsimhan (2004) further posited that other than the differences in egg weight at wk 4 of cold storage, no significant differences were observed in rate of quality decline among the HS. Earlier studies (Jones *et al.,* 2014) surmised that increased dietary protein concentration resulted in increase foaming capacity because of higher rate of protein adsorption at the air–water interface and subsequent reduction in surface tension. However, differences observed in this study could not be ascribed to variations in protein content of the diets fed to hens in both HS which were isonitrogenous. Foaming properties of proteins are also influenced by environmental factors like ionic strength or pH. Kuropatwa *et al*. (2009) demonstrated that large variations in pH affect egg white foaming performances: the best foam characteristics were obtained at pH 5 than at pH 7 and 9. It should be noted however, that differences in foaming properties on the basis of HS, even if statistically significant, were small and unlikely to have real effects when the eggs were used in food preparations. Hammershøj and Qvist (2001) in a study on eggs from white Leghorn hens in cages, observed a slight decrease in foam overrun as a function of hen age in the thin albumen. It was therefore concluded that hen strains are important in determining albumen foaming properties during the laying cycle. In this study, the foaming capacity of egg white decreased as DOS increased which contrasted report of Silversides *et al.* (2004) that stale egg white has maximum foaming ability compared to fresh egg white

Albumen viscosity

The viscosity of eggs across both HS decreased with increasing DOS. This could be due to gradual evaporation of water through the shell which causes a decrease in density as the air cells enlarge. This agrees with the report of Caner and Yusser (2015) that the viscosity of egg albumen decreased during storage which also confirms earlier submissions (Kemps, *et al*., 2010; Kannan, *et al*., 2013).

Effect of HS, DOS and VmP on TBARS of egg white

The observed higher MDA of egg albumen from hens fed VmP 5 could be attributed to the noted relatively higher levels of vitamin E and B6 as well as the minerals zinc, iron, manganese and selenium content in the VmP. Vitamin E has been reported by Halliwell *et al*. (1995) to protect cells from reactive oxygen species *in vivo*. Cherian *et al*. (1996) posited that vitamin E maintains oxidative stability and vitamin B6 improves egg quality. Organic trace minerals such as iron, selenium, manganese and zinc increased the shelf life of eggs which all agreed with the observations in this study. Highest MDA due to interactive effect of DL and 28 DOS was because deterioration in eggs begins as soon as the egg is laid and continues until the egg is consumed.

Properties of whole egg

Specific gravity

The specific gravity of whole egg was lowered in DL compared to BC. This could be due to relatively neater eggs from BC as earlier observed (Sekeroglu *et al*., 2008) that advancing DOS decreased egg specific gravity. Increased DOS lowers overall egg quality characteristics because eggs lose their quality rapidly between the period of collection and consumption. Highest specific gravity recorded at zero DOS due to interactive effect of HS and DOS in both DL and BC could be because freshly laid eggs have all their properties intact and the deterioration was slower until after it has stayed for over 24 hours (Blokhuis *et al*., 2007; Ogunwole *et al*., 2015b)

Foaming and emulsifying properties

Foaming capacity and stability for whole egg in this study were than those of egg white. This could be because egg yolk was also mixed. This agrees with the report of Kim and Setser (1982) as cited by Lomakina and Mikova (2006) that the presence of even small quantities of yolk decreases albumen foaming ability. Aro *et al*. (2011) earlier reported that fish oil supplementation in feed influences foaming properties of fresh eggs and eggs stored for 21 days lost part of their foaming properties in fish oil supplemented group. This conforms to the result of this study that composition of the diet in terms of the different VmP may affect foaming properties. The interactive effect of HS and treatment on foaming capacity and stability of whole egg could be attributed to the fact that BC and DL HS influenced foaming properties of eggs. The emulsifying properties of eggs in fish oil and fish supplemented groups differed compared to control group. This could be because eggs also undergo a sequence of interior (functional) quality changes and microbial contamination during storage (Jones *et al*., 2004).

Viscosity of whole egg

As was observed for egg white, viscosity of whole egg reduced with different VmP and DOS. However, whole egg had lower viscosity than egg white which could be due to the presence of yolk.

Effect of HS, DOS and vitamin-mineral premix on TBARS of whole egg

The MDA of whole egg was also highest on 28 DOS and was significantly different from values observed at 0 DOS. This could be because rate of deterioration of egg increases as DOS increased. Sekeroglu *et al*. (2008) earlier stated that eggs may lose their quality rapidly between the period of collection and consumption. The TBARS of whole egg in this study were observed to be higher in all the factors considered (HS, VmP and DOS) compared with the corresponding egg white. This could be attributed to the fact that egg yolks contain more fat than the albumen portion and are perhaps more prone to deterioration by reactive oxygen species.

Conclusion

The study showed that egg functional properties were affected by the different dietary VmP. The synergistic effect of HS and VmP did not affect overall acceptability. Therefore, the duration of storage facilitated deterioration of eggs and affected properties of egg in spite of HS and dietary supplement of VmP.

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