Journal of Innovative Agriculture: 9(2) : 1-11, 2022
DOI: 10.37446/jinagri/rsa/9.2.2022.1-11
Research paper

The quality of white and brown chicken eggs kept under different storage length and storage temperatures

Francis Kruenti[1*], Julius Kofi Hagan[2], Maxwell Okai Ansong[3], Vida Korkor Lamptey[4]

[1, 3, 4] Farm Animal Technology Development Division, Council for Scientific and Industrial Research – Animal Research Institute, Katamanso, P.o. Box AH 20, Achimota, Accra, Ghana.
[2] Department of Animal Science, University of Cape Coast, Cape Coast, Ghana.

Received: 30 December 2021
Accepted: 07 June 2022
Published: 30 June 2022

***Correspondence**
Francis Kruenti
kruentifrancis@yahoo.com

The work evaluated the effects of egg colour and storage conditions on quality traits of chicken eggs. Methods: 336 eggs were randomly picked from a flock of white and brown hens and classified into 4 groups of storage length (0, 7, 14 and 21 days) and 2 temperature groups (ambient and refrigeration). Data was analysed with the two-way Analysis of Variance embedded in the General Linear Model procedure of Minitab (version 18). Differences in means were separated using the Tukey Pairwise Comparisons Method at 5% significance level. Significantly, the white eggs (58.5g) were heavier than the brown eggs (55.3g). Storage length did not affect egg weight, but eggs stored at room temperature were 1.4g lighter. Shell quality traits were approximately unchanged by egg colour and storage conditions. Egg colour x storage length and egg colour x storage temperature interactions significantly affected egg weight loss but the interactions did not affect the weight of the eggs and the shell quality traits. Egg colour did not affect the albumen height and Haugh unit significantly but the variables decreased as the storage length was increased. Albumen height under refrigeration was higher (8.0mm) than at room temperature (6.1mm). Egg colour and storage conditions significantly influenced yolk height and yolk weight. Albumen weight decreased as the storage was prolonged but was higher under refrigeration (27.3g) than room temperature (25.6g). Egg yolk was deeper in the brown (5.9) than white (3.4) eggs, deeper in the refrigerated eggs but varied irregularly with storage length. The interactions of egg colour and the storage conditions did not affect albumen height, Haugh unit, albumen weight, yolk weight and yolk colour significantly but yolk height was significantly influenced except for the egg colour x storage length interaction. The storage length x storage temperature interaction significantly affected Yolk pH. Eggs should be kept cold, but not more than 7 days because their quality can be affected under inadequate storage conditions.

Key words: *egg quality, storage length, storage temperature, egg colour*

INTRODUCTION

Eggs, when consumed, supply the body with nutrients fit for healthy lives (International Egg Foundation (IEF, 2014), reproduction and child growth (Abanikannda et al., 2007) and mental development (FAO, 2012; IEF, 2014; Miranda et al., 2015). Nonetheless, the nutrients can only be supplied fully in quantity and quality if they are well maintained in the eggs through the value chain until they are finally consumed. Egg quality whether exterior or interior can be influenced by the duration of storage and storage temperature. Egg quality and its stability during storage are dependent on the physical structure and biochemical content of the product (Seidler, 2003), as well as the storage environment – controlled by temperature, humidity and the amount of carbon dioxide (Khan et al., 2013; Ryu et al., 2011; Zhang et al., 2011). Therefore, these must be considered (Ewonetu & Negassi, 2016; Grashorn et al., 2016) and controlled during egg storage to maintain its quality. In a study, Tilki & Saatci (2004) identified different places where farmers store eggs and the devices used but the common methods use in our market places and homes are open room storage and refrigeration. These methods however appear to be appropriate up to certain temperatures and number of storage days (Feddern et al., 2017). De Oliveira & De Oliveira (2013) indicated that the longer eggs are stored, the more their internal quality depletes to make the albumen thin and the yolk flat – due to loss of carbon dioxide, and changes in temperature and humidity. Several authors have reported on the effects of storage length and storage temperature on egg quality, but such information under the Ghanaian conditions are either scanty or not readily available. Therefore, this work assessed the effects of egg colour, storage length, storage temperature and their interactions on egg quality traits within the Ghanaian environment.

MATERIALS AND METHODS

Study areas and research design

The eggs used were collected from a poultry farm in Abokobi within the Greater Accra Region of Ghana. Abokobi is located on latitude 5º 44´ north and longitude 0º 12´ west. The experiment was conducted at the Nutrition Laboratory at the Technology Village of the University of Cape Coast. The university is found in the Central region which has minimum and maximum temperatures of 21-25ºC and 26-32ºC, and an annual precipitation of 1300mm.

The experiment was completely randomised in a 2 x 4 x 2 factorial experiment that comprised of two egg colours (white and brown), four storage lengths (0, 7, 14 and 21 days) and two storage temperatures (room: 21-32ºC and cold: 5ºC) (Hagan & Eichie, 2019; Perić et al., 2017). A total of 336 eggs, 168 each of white and brown eggs were randomly chosen and examined. 48 out the total eggs (24 in each egg colour group) were analysed as fresh (day 0) eggs. The remaining 144 eggs in each egg colour group were stored at 48 eggs per storage length of 7, 14 and 21 days. 8 eggs each were stored under the two storage temperatures making 16 eggs per storage day. The eggs in all treatments were collected from the white and brown Lohmann chickens. They were housed together in a deep litter house and fed a chicken layer diet composed of 3200 kilocalories of metabolisable energy and 18% crude protein. All essential vaccines and drugs were appropriately given.

Data collection Instruments and procedure

The eggs were collected from the flock between 8:00 and 8:30 am Greenwich Meridian Time. A clean dry cloth was used to clean them after which they were placed in a carton on paper crates, and transported to the laboratory for four hours with their broad ends up. On arrival, a permanent marker was used to number them for proof of identity, and then they were separated into the four storage days and two storage temperatures per egg colour. Each of the eggs was weighed for its fresh weight and then the fresh (day 0) eggs were examined within 24 hours from the time they collected from the flock. Eggs in the other two groups were respectively stored at room temperature (21-32ºC) and in a LOGIK CB BC-90 Fridge at 5ºC (Hagan & Eichie, 2019; Perić et al., 2017) on paper crates in both cases and analysed on the respective storage days. Eggs in both storage groups were weighed individually on each experimental day to determine their respective egg weight loss. Each egg was carefully broken onto a glass prism after which a matchstick/ toothpick was dipped into the thick albumen to touch the bottom of the prism, and the albumen's height (AH) immediately measured on a plastic ruler according to Eyesus (2018). Yolk colour was measured with a 14-blade Roche Colour Fan (Markos et al., 2017). Egg yolk was separated from the albumen with a yolk separator onto the glass prism and the yolk height was measured using the method used for the albumen's height. Egg yolk weight was measured on a clean dry petri dish that was scaled to zero after removing the attached chalaza with forceps. Each yolk and albumen was kept separately in an air-tight container that was identified by the colour, storage group and the number. A NISSO pH Meter was used to measure the yolk and albumen pH accordingly. After each egg was examined, the tools were washed with distilled water dispensed from a wash bottle and dried with tissue paper. The wet shells were weighed and washed under tap water to remove residual albumen (Hanusova et al., 2015), and then dried for 72 hours at room temperature (21-32ºC). The dry shells were weighed for the shell weight then its thickness without the vet line membrane, was measured from the three (narrow, middle and broad) ends with a micrometre screw gauge at a precision of 0.01mm and averaged (Blanco et al., 2014; Hanusová et al., 2015; Sinha et al., 2017). All weights in this experiment were taken with a SHS Inside Super Hybrid Sensor (HR-250A2-252g/0.1mg) electronic balance manufactured by the H & D Company Limited, Korea. The following derived external and internal egg quality traits were computed from the physical measurements using the Mathematical expressions below.

1. Egg Weight Loss = Initial (Fresh) egg weight – Final egg weight (egg weight at the respective storage days) (Perić et al., 2017).

2. Shell thickness (ST) = $\frac{\text{Thickness (Broad+middle+narrow (ends))}}{3}$ (Blanco et al., 2014; Hanusová et al., 2015; Sinha et al., 2017).

3. Haugh unit (HU) = 100 log (H + 7.57 - $1.7W^{0.37}$) where H and W represent albumen height and egg weight accordingly (Haugh, 1937).

4. Albumen weight (AW) = Egg weight - (Wet shell weight + yolk weight) (Tůmová et al., 2017).

Data analysis

Data on the external and internal egg quality parameters were subjected to the two-way Analysis of Variance with egg colour, storage length and storage temperature as the fixed factors. The General Linear Model procedure of Minitab (version 18) was used to analyse the data. Differences in means were separated using the Tukey Pairwise Comparisons Method at a significance level of 5%. The model used was:

$Y_{ij} = \mu + C_i + L_i + T_j + CLT_i + \varepsilon_{ij}$

Where: Y_{ij} = the dependent variable; μ = the general or population mean; C_i = ith observation for egg colour; L_i = ith observation for storage length; T_i = ith observation for storage temperature; CLT_i = ith observation for egg colour x storage length x storage temperature interaction and ε_{ij} = the random error associated with the dependent variable.

RESULTS AND DISCUSSION

The colour of the eggs and storage temperatures significantly affected egg weight. The white coloured eggs were heavier (58.5g) compared to the brown eggs (55.3g).

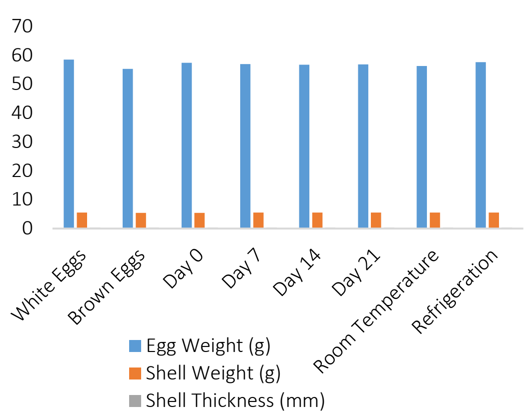

Figure 1. The effects of egg colour, storage length and storage temperature on external quality traits of eggs

Eggs stored at room temperature recorded a lower weight (56.2g) than their refrigerated counterparts (57.6g). Storage length did not show any significant effect on the weight of the eggs, but the variable declined from 57.3-56.9-56.8-56.6g as the storage length was increased from 0-21 days correspondently. Approximately, shell weight and shell thickness were not different between the white and brown eggs, storage days and storage temperatures (Figure 1).

The results presented in Table 1 show that the interactions of egg colour, storage length and storage temperature did not affect the eggs' weight significantly, but the brown coloured eggs were marginally heavier (55.0-59.3g) than the white eggs (54.3-57.8g) across the storage conditions. The egg colour x storage length and the egg colour x storage temperature interactions significantly affected egg weight loss. The white coloured eggs generally lost more weight from 0 to 0.7 to 1.6 to 2.4g and from 0 to 0.2 to 0.6 to 1.0g than the brown eggs that lost weight from 0 to 0.6 to 1.2 to 1.7g and from 0 to 0.3 to 0.6 to 0.7g respectively for eggs stored under ambient and cold temperatures. The interactions of egg colour, storage length and storage temperature had no significant effect on shell weight and shell thickness but shell weight varied intermittently from 5.3-5.6g in both the brown and white eggs across the storage conditions (Table 1).

Effect of egg colour, storage length, storage temperature and their interactions on external egg quality parameters

Egg weight and egg weight loss

Egg weight is the price-determining factor in the egg industry and so the most important parameter to farmers and consumers (Genchev, 2012) including egg sellers. Information about egg weight loss during storage is vital to egg sellers and consumers because eggs graded at lay may reach consumers at a lower weight than recorded on egg packs (Grashorn et al. (2016) – to reduce economic gains in the market. The current results show that white eggs are heavier than brown eggs (Alsobayel & Albadry, 2011; Anderson et al., 2004; Kruenti, 2020; Shafey et al., 2002) but maintaining the weight of eggs during storage would be better in brown than white coloured eggs. The result however, is against Aygun & Narinc (2016) who found heavier eggs in brown than white shelled eggs. However, for heavier eggs in storage, brown eggs are a better choice. The ability of the brown eggs to maintain their weight in storage could mean that they have better shells that protect their content or to control the loss of gases and water – the process that cause weight loss in eggs under storage (Alsobayel & Albadry, 2011; Dudusola, 2009; Jin et al., 2011; Tabidi, 2011). Notwithstanding these, differences in egg weight and its loss could also depend largely on storage length (Khan et al., 2014; Olugbenga et al., 2015) and storage temperature (Grashorn *et al*., 2016) under which white eggs will possibly lose more weight than brown eggs. Per the current findings, as storage length increases, egg weight loss will increase (Addo et al., 2018; Sogunle et al., 2017; Tilki & Saatci, 2004) to decrease egg weight. Olugbenga et al. (2015) put egg weight loss at 0, 0.9, 1.7, 2.5 and 3.2% for 0, 7, 14, 21 and 28 days of storage accordingly. However, in an earlier reportage, egg weight did not vary during a 10-day storage period, but the observation could not be explained (Silversides & Scott, 2000). At large, refrigerated eggs will lose less weight during storage compared to eggs stored under room or ambient temperature. This could mean that water

Table 1. The effects of egg colour x storage length x storage temperature interaction on external quality traits of eggs

Egg Colour	Storage Length (Days)	Storage Temperature (^{o}C)	Egg Weight (g)	Egg Weight Loss (g)	Shell Weight (g)	Shell Thickness (mm)
White	7	Room Temp.	57.8^{ab}	0.7^{d}	5.3^{a}	0.3^{a}
White	14	Room Temp.	57.3^{abc}	1.6^{a}	5.4^{a}	0.3^{a}
White	21	Room Temp.	57.2^{abc}	2.4^{a}	5.6^{c}	0.3^{a}
White	7	Refrigeration	55.0^{bc}	0.2^{e}	5.6^{a}	0.3^{a}
White	14	Refrigeration	55.0^{bc}	0.6^{bc}	5.6^{a}	0.3^{a}
white	21	Refrigeration	54.3^{c}	1.0^{c}	5.4^{a}	0.3^{a}
Brown	7	Room Temp.	58.1^{ab}	0.6^{bc}	5.5^{a}	0.3^{a}
Brown	14	Room Temp.	59.3^{a}	1.2^{a}	5.6^{a}	0.3^{a}
Brown	21	Room Temp.	59.0^{a}	1.7^{b}	5.6^{a}	0.3^{a}
Brown	7	Refrigeration	56.7^{abc}	0.3^{e}	5.5^{a}	0.3^{a}
Brown	14	Refrigeration	55.0^{bc}	0.6^{bc}	5.3^{a}	0.3^{a}
Brown	21	Refrigeration	56.9^{abc}	0.7^{d}	5.6^{a}	0.3^{a}
White	0 (Fresh Eggs)		59.1^{a}	-	5.5^{a}	0.3^{a}
Brown	0 (Fresh Eggs)		54.2^{b}	-	5.4^{a}	0.3^{a}
Sources of Variation				**p-value**		
Egg Colour			0.001	0.001	0.862	0.001
Storage Length			0.886	0.003	0.712	0.782
Storage Temperature			0.001	0.001	0.819	0.907
Egg Colour x Storage Length			0.491	0.038	0.290	0.289
Egg Colour x Storage Temperature			0.991	0.004	0.094	0.258
Storage Length x Storage Temperature			0.415	0.060	0.619	0.857
Egg Colour x Storage Length x Storage Temperature			0.236	0.091	0.070	0.816

Means that carry different superscripts are significantly different; **Temp.:** temperature, **g:** grams; **mm:** millimetre; **^{o}C:** degree Celsius; **p-value:** probability value ($p < 0.05$)

formed on the surface of refrigerated eggs seals egg pores to slow the processes that cause gases and water to escape from the products. In regards, it is prudent to keep eggs under cold conditions to maintain their weight if higher market prices are needed for the products in store.

Shell weight and shell thickness

Agreeing to Ledvinka et al. (2012), weight, thickness and breaking strength are the parameters mostly use to describe the quality of eggshell. Prime among them is the thickness – the determinant of eggs' capacity to hatch (Narushin & Romanov, 2002; Kruenti et al., 2022), break or keep their constituents. Approximately, this work reveals that shell weight and shell thickness cannot be changed significantly by egg colour, storage length and storage temperature or their interactions. Statistically, there may be more shells in white than brown eggs (Ledvinka et al., 2000) but thicker shells in brown than white eggs as observed in the current experiment. According to Kgwatalala et al. (2016), bigger/ heavier eggs have thin shells because of their extensive surface area for shell deposition. Therefore, the high shell content of the white eggs despite their heavy size/ weight means white hens are better at mineralising eggs while the thicker shells noted in the brown eggs could be ascribed to their smaller sizes (weight). The results contradict Leyendecker et al. (2001) who found white-egg-laying hybrid birds to lay eggs with higher shell quality compared to their brown counterparts. Samli et al. (2005) proposed that, due to the direct contact of shells with the external environment, they lose more water as storage duration increases, to become lighter in weight; so, shell weight could slightly decrease as storage time increases. The estimated shell thickness (0.3mm) of eggs in all the treatments of this study is medium according to the classification of Yamak et al. (2016). Differences found in the quality of the shell traits between the white and brown eggs in the current work can be credited to genetics (Clunies et al., 1992 as cited by Jones, 2006) rather than the storage conditions (Silversides & Scott, 2000; Tilki & Inal, 2004a; Tilki & Inal, 2004b). However, because the shell membrane or the shell cuticle can shrink when eggs are stored for an extended time (Grashorn et al., 2016), storage duration had had a decreasing effect on eggshell thickness in other experiments (Alsobayel & Albadry, 2011; Grashorn et al., 2016; Monira et al., 2003).

There was no significant effect of egg colour on albumen height and Haugh unit, but the storage conditions significantly affected the traits. They were higher in the brown (7.1mm; 83.2) than white (7.0mm; 82.7) coloured eggs accordingly. The albumen height and Haugh unit decreased as the storage was prolonged from 9.3-6.8-6.1-5.9mm and from 98.6-81.7-76.6-74.7 according to the traits and the storage length of 0, 7, 14 and 21 days. The refrigerated eggs had a higher albumen height (8.0mm) compared to those kept at room temperature (6.1mm). Egg colour, storage time and storage temperature significantly influenced yolk height. Yolk height was higher in the white (11.9mm) than brown (11.2mm) eggs; it decreased from 14.1-11.4,-10.5-10.2mm according to the storage days, and was higher in the refrigerated eggs (13.3mm) than those kept under room temperature (9.8). Albumen weight significantly decreased from 28.0-26.4-25.8-25.5g as the

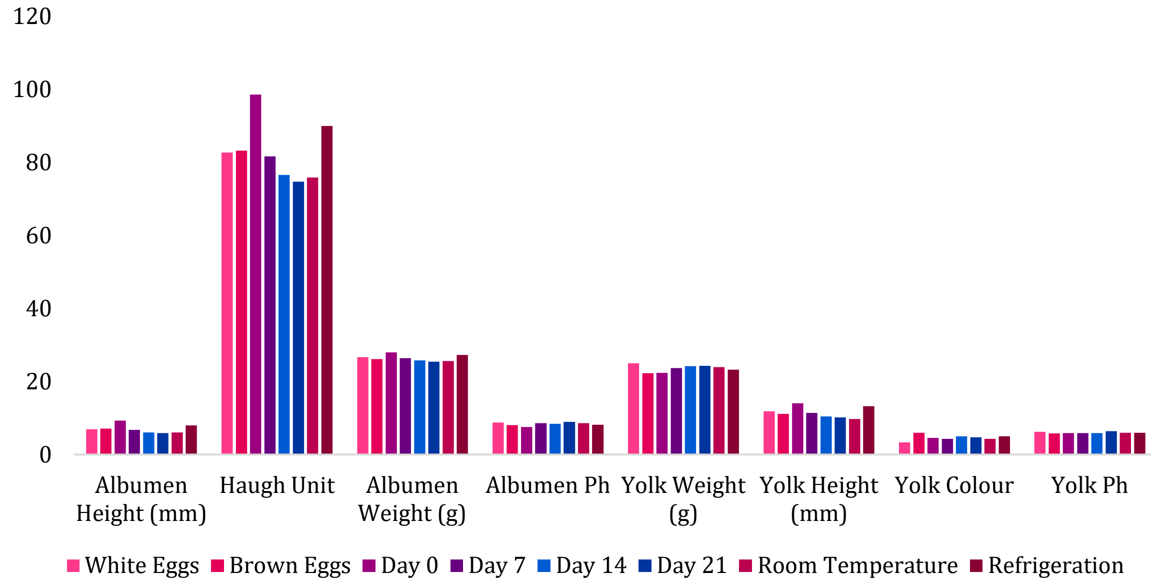

Figure 2. The effects of egg colour, storage length and storage temperature on internal quality traits of eggs

Table 2. The effects of egg colour x storage length x storage temperature interaction on internal quality traits of eggs

Egg Colour	Storage Length (Days)	Storage Temperature (°C)	Albumen Height (mm)	Haugh Unit	Albumen Weight (g)	Yolk Weight (g)	Yolk Height (mm)	Yolk Colour	Yolk pH	Albumen pH
White	**7**	**Room Temp.**	6.0^{bcd}	76.4^{bcd}	26.2^{abc}	25.0^{a}	10.5^{d}	2.7^{d}	6.4^{abc}	9.3^{ab}
White	**14**	**Room Temp.**	5.0^{d}	69.0^{d}	24.7^{abc}	26.2^{a}	8.8^{fg}	3.6^{cd}	6.2^{abcd}	9.2^{abc}
White	**21**	**Room Temp.**	4.8^{d}	65.8^{d}	24.0^{c}	26.4^{a}	7.8^{g}	3.1^{cd}	6.7^{ab}	9.6^{a}
White	**7**	**Refrigeration**	8.0^{a}	89.1^{a}	26.4^{abc}	24.9^{a}	12.9^{ab}	3.3^{cd}	6.0^{cdef}	8.8^{cde}
White	**14**	**Refrigeration**	6.7^{abc}	81.1^{abc}	27.6^{a}	24.9^{a}	12.8^{abc}	4.3^{bc}	6.4^{abc}	8.7^{de}
white	**21**	**Refrigeration**	6.8^{abc}	82.1^{ab}	26.6^{abc}	25.2^{a}	13.2^{a}	4.0^{bcd}	6.7^{a}	9.1^{bcd}
Brown	**7**	**Room Temp.**	5.6^{cd}	74.8^{bcd}	25.8^{abc}	22.6^{b}	9.7^{ef}	5.0^{ab}	5.7^{def}	8.3^{fg}
Brown	**14**	**Room Temp.**	5.0^{d}	69.8^{cd}	25.3^{abc}	23.0^{b}	8.9^{fg}	5.9^{a}	5.5^{ef}	8.2^{fg}
Brown	**21**	**Room Temp.**	5.0^{d}	68.0^{d}	24.4^{bc}	23.2^{b}	8.0^{g}	5.6^{a}	6.2^{bcd}	8.8^{cde}
Brown	**7**	**Refrigeration**	7.6^{ab}	86.5^{ab}	27.4^{ab}	22.4^{b}	12.4^{abc}	6.3^{a}	5.5^{ef}	7.9^{g}
Brown	**14**	**Refrigeration**	7.5^{ab}	86.5^{ab}	25.7^{abc}	22.5^{b}	11.5^{cd}	6.2^{a}	5.5^{ef}	8.0^{g}
Brown	**21**	**Refrigeration**	7.0^{abc}	83.1^{ab}	27.1^{abc}	22.7^{b}	11.7^{bc}	6.3^{a}	6.2^{bcd}	8.5^{ef}
Sources of Variation						**p-value**				
Egg Colour			0.527	0.569	0.913	0.001	0.001	0.001	0.001	0.001
Storage Length			0.001	0.001	0.151	0.030	0.001	0.004	0.001	0.001
Storage Temperature			0.001	0.001	0.001	0.001	0.001	0.001	0.601	0.001
Egg Colour x Storage Length			0.221	0.338	0.441	0.673	0.943	0.365	0.374	0.106
Egg Colour x Storage Temperature			0.527	0.0768	0.661	0.230	0.007	0.836	0.747	0.122
Storage Length x Storage Temperature			0.941	0.619	0.202	0.239	0.001	0.507	0.018	0.660
Egg Colour x Storage Length x Storage Temperature			0.531	0.662	0.123	0.661	0.026	0.434	0.442	0.934

Means that carry different superscripts are significantly different; **g**: grams; **mm:** millimetre; **°C:** degree Celsius; **p-value:** probability value ($p < 0.05$)

storage length was increased and was significantly higher in the eggs stored under refrigeration (27.3g) than those kept at room temperature (25.6g). Egg colour however did not change albumen weight significantly. Yolk weight was significantly higher in the white (25.0g) than brown (22.3g) eggs. Yolk weight did not change significantly in the stored eggs, but showed a decreasing trend from 23.7-24.2-24.4g respectively for day 7 to day 21. Yolk weight was significantly lower in the refrigerated eggs (23.3g) compare to the eggs kept at room temperature (24.0g). Albumen pH was significantly lower in the brown eggs (8.1) compared to the white eggs (8.8). Storage length and storage temperature also had significant influence on the albumen pH that varied intermittently with the storage days at 7.6, 8.6, 8.5 and 9.0 accordingly. Albumen pH was lower in the refrigerated eggs (8.2) than the eggs kept at ambient temperature (8.6). Yolk pH did change largely with egg colour, and stood at 6.3 in the white eggs and 5.8 in the brown eggs. Though yolk pH did not vary significantly among the first three storage days at 5.9, it deferred largely on the 21st day (6.4) of storage. Meanwhile, the egg trait did not change significantly with storage temperature. Egg colour and the storage conditions significantly influenced the yolks' colour. The brown eggs' yolks were deeper in colour (5.9) than those from the white (3.4) eggs. While yolk colour was higher in the refrigerated eggs (5.0) than those stored under room temperature (4.3), it varied irregularly according to the storage days at 4.6, 4.3, 5.0 and 4.8 correspondently.

The current data show an insignificant effect of the interactions of egg colour, storage length and storage temperature on albumen height and Haugh unit of the eggs. However, the parameters decreased as storage length increased with higher reductions in the eggs that were stored under room temperature than those stored under refrigeration (Table 2). The interactions of egg colour and storage conditions significantly affected yolk height except for the egg colour x storage length interaction. Yolk height decreased with storage length in the brown (12.0-9.7-8.9-8.0mm) and white (12.7-10.5-8.8-7.8mm) eggs stored under room temperature, but the variable changed unevenly in the refrigerated eggs in both brown and white eggs. Results in Table 2 show no significant interaction effect of egg colour, storage length and storage temperature on albumen and yolk weights. Albumen weight decreased regularly under room temperature as storage length increased from 28.0-26.2-24.7-24.0g in the white eggs and from 26.2-25.8-25.3-24.4g in the brown eggs, but changed unevenly in the refrigerated eggs in both white and brown eggs. Yolk weight showed an increasing order with storage length irrespective of storage temperature, but it was lower in the refrigerated eggs (Table 2). The interactions of egg colour, storage length and storage temperature did not significantly affect albumen pH, but the storage length x storage temperature interaction affected yolk pH significantly (Table 2). Both albumen pH and yolk pH showed an increasing trend with storage length irrespective of the storage temperature in both egg colour groups. Data in Table 2 show that the interactions of egg colour and the storage conditions had no significant influence on yolk colour, but the parameter was deeper in the brown than white eggs under each storage condition. However, the refrigerated eggs had yolks that were deeper in colour than those from the eggs kept under ambient temperature across the storage periods in both white and brown eggs.

Effect of egg colour, storage length, storage temperature and their interactions on internal egg quality parameters

Albumen height, haugh unit and yolk height

Eggs' internal quality is mostly a function of their albumen's quality (Nonga et al., 2010) traits which include but not limited to the albumen weight, albumen height, Haugh unit, yolk weight, yolk height, yolk and albumen pH and yolk colour. Even though the albumen height and Haugh unit did not change largely with egg colour in the current work, the higher albumen height observed in the brown eggs (Kruenti, 2020) suggests that they are of higher quality (freshness) compared with the white eggs (Zeidler, 2002). In opposition, Aygün and Narinç (2017) reported a higher albumen height for some white eggs (7.73mm) over brown eggs (7.01mm). Leyendecker et al. (2001b) had earlier reported a higher Haugh unit in white than brown eggs which is not supported by the current findings. The current results however, agree to the notion that brown layers produced eggs with higher Haugh unit (Curtis et al., 1986). The current data is also in support of several other scientists who have indicated that, the duration (Olugbenga et al., 2015; Silversides and Scott, 2000) and the temperature (Ewonetu & Negassi, 2016; Van Niekerk, 2014) of storing eggs can significantly influence their internal quality – which is mostly dependent on the height of the albumen and Haugh unit (Grashorn et al., 2016). Chemical and physical modifications take place within eggs including thinning of the albumen during storage (Sogunle et al., 2017). These may account for the lower albumen height recorded as the storage day was increased because while these alterations occur, the formation of the bioactive egg white glycoprotein (ovomucin), and lysozyme deteriorates to reduce the height of the egg white (Grashorn et al., 2016). Similar to the current findings, a past investigation has also shown that eggs' internal quality deteriorates more rapidly at room temperature (USDA, 2000) than at cold temperature (Jones, 2006). Under cold temperature, the degeneration of albumen protein is lowered so that its' quality (freshness) is maintained as was found in the current work for Haugh unit. The decreasing trend in yolk height as storage is prolonged irrespective of storage temperature confirms the reduction in the parameter from 15.52 to 5.41mm with increasing storage length from 0-28 days according to Olugbenga et al. (2015), and Sogunle et al. (2017) who named flattening of the yolk as an alteration that occurs in eggs during storage. The decrease in yolk height had been attributed to the fact that during storage the yolk vitelline membrane disintegrates to imbibe fluids from the albumen (Okoli and Udedibie, 2000 as cited in Kumari et al., 2020). The variations found in yolk height could also largely be due to differences in genotype (egg colour), storage length or storage temperature. However, eggs should be stored cold if albumen and yolk quality must be maintained as evidenced in this work – cold storage slowed their rate of deterioration.

Albumen and yolk weight

Albumen (egg white) forms more than 50% of eggs from every domesticated bird (Chepkemoi et al., 2017), but its content can be affected by egg weight (Suk & Park, 2001) and storage (Addo et al., 2018). The findings of this investigation show that albumen content of eggs in storage will not differ significantly either in white or brown eggs irrespective of their storage length and storage temperature. Nonetheless, the egg component can decrease regularly as storage is prolonged under room temperature but intermittently under refrigeration – perhaps due to irregularities that occur during storage regarding temperature and humidity. Therefore, it is important to consider and regularise these climatic factors when keeping eggs in cooling devices if maintaining their quality is the hallmark. Low albumen weight could also result from the loss of albumen fluid into the yolk (Addo et al., 2018) during storage. The slight increase in albumen weight of the white eggs means they have more albumen over the brown eggs, which could be ascribed to genetic differences (Hanusová et al., 2015) or higher egg productivity in brown layers according to Jones (2006) who related low albumen content to layers that lay more eggs. The current data show that yolk weight would increase slightly as storage day increases – confirming the results of previous investigators (Olugbenga et al., 2015; Samli et al., 2005; Silversides and Scott, 2000; Tilki & Saatci, 2004). They too did not find significant differences in yolk weight at different storage lengths even though the variable differed largely between the stored and fresh eggs in the current work. Yolk weight may consistently increase with storage day though it was unevenly distributed across 0-35 days in an experiment (Tilki & Saatci, 2004). Yolk weight was significantly lower in the refrigerated eggs which means under warm condition (room temperature), yolk quality is quickly destroyed because more water will move from the albumen into it. Notwithstanding these, the significantly high yolk weight detected in the white eggs against the brown ones renders them more suitable for consumers or food processors who need egg yolk (Padhi *et al.,* 2013). The present results agree to Leyendecker et al. (2001b) who also documented significant and higher yolk weight in Lohmann white chicken eggs in comparison with their brown tradition though Hagan et al*.* (2013) have reported the reverse at 14.9 and 15.7g for eggs collected from the same strains correspondently.

Albumen and yolk pH

Yolk pH and albumen pH were lower in the brown eggs than the white eggs regardless of the storage conditions, and this means brown eggs are more acidic compared to white eggs – which would make brown eggs more defensive against microorganisms, even though the significance of the variation observed for albumen pH between the white and brown eggs disagrees to Aygün & Narinç (2017). The rise in albumen pH as the storage time was increased under both storage temperatures does not deviate from the findings of Feddern et al. (2017), and Samli et al. (2005) who reported an increase in albumen pH from 7.47 to 9.11 during a 10-day storage period. Despite these assertions, Olugbenga et al. (2015) did not find much difference in albumen pH between eggs stored for 21 and 28 days as was found in the present work from day 7 to day 14. The low albumen pH of eggs kept under refrigeration could mean that the formation of carbonic acid (H_2CO_3) – the compound which controls egg acidity; or diffusion of carbon dioxide (CO_2) from the eggs is slowed under cold temperature. According to Reijrink et al. (2008) the pH of the yolk of a fresh egg is between 6.0-6.3 which increases gradually and stabilizes at around 6.5-6.8. These values are somewhat close to the yolk pH of 5.8 and 6.3 respectively realised in the eggs used in this work. However, the significance of variation in yolk pH between the brown (5.8) and white (6.3) eggs opposes the results of Aygün & Narinç (2017) and the significantly higher yolk pH reported for brown-shelled eggs (7.88) over white-shelled eggs (7.35) according to Begli et al. (2010). Nonetheless, the irregularity of yolk pH with storage time in this work partly agrees to Samli et al. (2005) for their significant increase in yolk pH for eggs stored on different days.

Yolk colour

The innermost egg trait a consumer sights first when an egg is broken is the yolk colour (Feddern et al., 2017). Its preference differs from one person to another, but many consumers like the darkest coloured yolk (Beardsworth, 2007). In regards, brown eggs should be the best choice for consumers because they would contain deeper yolk (Kruenti, 2020) than white eggs as observed in the current work between the fresh and stored eggs. Similarly, the yolks of eggs from some brown layers were found to be insignificant but deeper in colour (10.4) than the yolks contained in eggs from their white counterparts (10.3) (Hagan et al., 2013). Contradictory to these was the lighter yolk colour declared for brown-shelled eggs (Alsobayel & Albadry, 2011) who also reported a non-significant effect of storage period on yolk colour, though the present work shows that significant changes occurred in yolk colour at the different storage length and storage temperatures. In a past study, yolk colour at room temperature declined from 8.0 to 7.5, and declined from 7.4 to 7.1 at a lower temperature (Feddern et al., 2017), but the current data shows an irregular pattern for yolk colour with the storage conditions. Internal egg quality largely would depend on where, when and how eggs are stored. Irrespective of storage place, duration or method, climatic elements such as humidity, temperature and CO_2 must be considered and regularised when keeping eggs (Ewonetu & Negassi, 2016) to maintain their quality because prolonged storage can influence eggs' internal quality if these conditions are inadequate (Van Niekerk, 2014). Also, storing eggs to increase or maintain their interior properties irrespective of the number of days or temperature, may cause some differences in their nutritional composition (Dudusola, 2009; Mackie, 1993; Marwa, 2015; Rizzi & Marangon, 2012). Hence, these conditions must be given much attention as proposed by Grashorn et al. (2016) and Keener et al. (2001) to maintain the nutritional veracity of the products even if they are kept in cooling devices. This is because, frozen storage had caused deviations in protein and lipid structures of fish (Shenouda, 1980) while increasing eggs' internal temperature above 7°C was perceived to have caused the protein structures of their thick albumen to break down faster (Jones, 2006).

CONCLUSION

The findings of this work reveal that, the quality of an egg is mostly dependent on its colour but also its storage duration and temperature. Eggs from the white Lohmann strain are heavier than their brown counterparts, but the brown ones could maintain their weight better during storage. Shell quality of both white and brown eggs may not change with storage. Egg colour would not affect albumen quality significantly except its pH, but albumen traits could change significantly under different storage conditions. Yolk weight and yolk height could be significantly higher in white than brown eggs. Yolk pH would not vary significantly with egg colour. Brown eggs could have deeper yolks than white eggs. Albumen quality except the pH would decrease with increasing storage time. Albumen traits except the pH can be higher in refrigerated eggs. Yolk height would be significantly higher in eggs stored for shorter days and under cold temperatures. Yolk weight would be significantly higher in eggs stored cold but decrease marginally as storage is prolonged. Yolk pH may not change with storage temperature but could be irregular with storage length. Eggs kept under refrigeration would have deeper yolks than under room temperature, but the trait would change irregularly with storage length. Generally, cold storage up to 7 days is the best for maintaining egg quality. However, brown eggs can maintain their internal quality better than white eggs under both room temperature and refrigeration.

ACKNOWLEDGEMENT

The writers wish to thank Miss Francisca Kruenti of Ernest Chemist Limited, Accra, Ghana, and Mr. Stephen Adu of the Nutrition Laboratory at the Technology Village of the University of Cape Coast, Ghana, for their respective financial and technical supports.

AUTHOR CONTRIBUTIONS

Francis Kruenti and Julius Kofi Hagan conceived the research idea. Francis Kruenti developed the work proposal and supervised the experiment with procedural advice from Julius Kofi Hagan. Francis Kruenti analysed the data and wrote the manuscript. Maxwell Okai Ansong and Vida Korkor Lamptey proofread the manuscript. Francis Kruenti prepared the final manuscript.

COMPETING INTERESTS

The author declares that there is no competing interest.

ETHICS APPROVAL

Not applicable

REFERENCES

Abanikannda, O. T. F., Olutogun, O., Leigh, A. O., & Ajayi, L. A. (2007). Statistical modelling of egg weight and egg dimension in commercial layers. *International Journal of Poultry Science*, *6*(1), 59-63.

Addo, A., Hamidu, J. A., Ansah, A. Y., & Adomako, K. (2018). Impact of egg storage duration and temperature on egg quality, fertility, hatchability and chick quality in naked neck chickens. *International Journal of Poultry Science*, *17*(4) 175-183.

Alsobayel, A. A., & Albadry, M. A. (2011). Effect of storage period and strain of layer on internal and external quality characteristics of eggs marketed in Riyadh area. *Journal of the Saudi Society of Agricultural Sciences*, *10*(1), 41-45.

Anderson, K. E., Tharrington, J. B., Curtis, P. A., & Jones, F. T. (2004). Shell characteristics of eggs from historic strains of Single Comb White Leghorn chickens and the relationship of egg shape to shell strength. *International Journal of Poultry Science*, *3*(1), 17-19.

Aygun, A., & Narinc, D. (2016). Effect of egg shell colour on some egg quality in table eggs during storage at refrigerator temperature. *AIP Conference Proceedings*. 1726(1), 020012. https://doi.org/10.1063/1.4945838

Aygün, A., & Narinç, D. (2017). Differences in internal egg quality characteristics between white and brown shell eggs. *AIP Conference Proceedings*. 1833, 020058. https://doi.org/10.1063/1.4981706

Beardsworth, P. M. (2007). Yolk colour – an important egg quality attribute. *International poultry production*, *12*(5), 17-18.

Begli, H. E., Zerehdaran, S., Hassani, S., Abbasi, M. A., & Khan Ahmadi, A. R. (2010). Heritability, genetic and phenotypic correlations of egg quality traits in Iranian native fowl. *British Poultry Science*, *51*(6), 740-744.

Blanco, A. E., Icken, W., Ould-Ali, D., Cavero, D., & Schmutz, M. (2014). Genetic parameters of egg quality traits on different pedigree layers with special focus on dynamic stiffness. *Poultry Science*, *93*(10), 2457-2463.

Chepkemoi, M., Macharia, J. W., Sila, D., Oyier, P., Malaki, P., Ndiema, E., Agwanda, B., Obanda, V., Ngeiywa, K. J., Lichoti, J., & Ommeh, S. C. (2017). Physical characteristics and nutritional composition of meat and eggs of five poultry species in Kenya. *Livestock Research for Rural Development*, *29*(8), 153.

Curtis, P. A., Gardner, F. A., & Mellor, D. B. (1986). A comparison of selected quality and compositional characteristics of brown and white shell eggs. I. Shell quality. *Poultry Science*, *65*(3), 297-301.

De Oliveira, B. L., & De Oliveira, D. D. (2013). Egg quality and technology. (Ed. 1) (pp. 223). Lavras, MG: UFLA.

Dudusola, I. O. (2009). Effects of storage methods and length of storage on some quality parameters of Japanese quail eggs. *Tropicultura*, *27*(1), 45-48.

Ewonetu, K. S., & Negassi, A. Z. (2016). Evaluation of External and Internal Quality of Chicken Table Eggs at Retailers in Eastern Ethiopia. *Journal of Animal Science Advances*, *6*(5), 1642-1649

Eyesus, T. W. (2018). *Performance of farmer managed Bovans brown layers fed on different locally available rations*. (Master's thesis). Mekelle University, Ethiopia. https://cgspace.cgiar.org/bitstream/handle/10568/97029/thesis_eyesus_2018. df?sequence=1&isAllowed=y

FAO (2012). *World Egg Day*. http://www.fao.org/ag/againfo/home/en/news_archive/2012_World_Egg_Day_2012.html

Feddern, V., Celant De Prá, M., Mores, R., Rodrigo, S. N., Coldebella, A., & Abreu, P. G. (2017). Egg quality assessment at different storage conditions, seasons and laying hen strains. *Ciência e Agrotecnologia*, *41*(3), 322-333.

Genchev, A. (2012). Quality and composition of Japanese quail eggs (*Coturnix japonica*). *Trakia Journal of Sciences*, 10(2), 91-101.

Grashorn, M., Juergens, A., & Bessei, W. (2016). Effects of storage conditions on egg quality. *Lohmann Information*, *50*(1), 26-27.

Hagan, J. K., & Eichie, F. O. (2019). Egg quality of two-layer strains as influenced by extended storage periods and storage temperatures. *Livestock Research for Rural Development*, 31 (9), 145.

Hagan, J. K., Adjei, I. A., & Baah, A. (2013). Effects of extended period of storage and strain of layer on quality of chicken eggs. *Journal of Science and Technology*, *33*(2), 1-11.

Halaj, M., & Golian, J. (2011). Table eggs characteristics (pp. 37-62). Nitra, Slovak: Garmond.

Hanusová, E., Hrnčár, C., Hanus, A., & Oravcová, M. (2015). Effect of breed on some parameters of egg quality in laying hens. *Acta fytotechnology. zootechnology*, *18*(1), 20-24.

Haugh, H. (1937). The Haugh unit for measuring egg quality. *The U.S. Egg &Poultry Magazine*, *43*(1), 552-555, 572-573.

International Egg Foundation (2014). *New International Egg Foundation Launched to help combat malnutrition in developing countries*. https://www.internationalegg.com/corporate/news/details.asp?nid=924

Jin Y. H, Lee, K. T., Lee, W. I., & Han, Y. K. (2011). Effects of Storage Temperature and Time on the Quality of Eggs from Laying Hens at Peak Production. *Asian Australian Journal of Animal Science*, *24*(2), 279-284.

Jones, D. R., Tharrington, J. B., Curtis, P. A., Anderson, K. E., Keener, K. M., & Jones, F. T. (2002). Effect of cryogenic cooling of shell eggs on egg quality. *Poultry Science*, *81(*5), 727-733.

Keener, K. M., LaCrosse, J. D., & Babson, J. K. (2001). Chemical method for determination of carbon dioxide content in egg yolk and egg albumen. *Poultry Science*, *80*(7), 983-987.

Kgwatalala, P. M., Molapisi, M., Thutwa, K., Sekgopi, B., Selemoge, T. P., & Nsoso, S. J. (2016). Egg quality characteristics and phenotypic correlations among egg quality traits in the naked neck, normal and dwarf strains of Tswana chickens raised under intensive management system. *International Journal of Environmental & Agriculture Research*, *2*(8), 96-105.

Khan, A. J. A., Khan, S. H., Bukhsh, A., Abbass, M. I., & Javed, M. (2013). Effect of different storage period on egg weight internal egg quality and hatchability characteristics of Fayumi eggs. *Italian Journal of Animal Science*, *12*(2), 51.

Khan, M. J. A., Khan, S. H., Bukhsh, A., & Amin, M. (2014). The effect of storage time on egg quality and hatchability characteristics of Rhode Island Red (RIR) hens. *Veterinary Archives*, *84*(3), 291-303.

Kruenti, F. (2020). *Relationship between external and internal egg quality traits of chicken layers as influenced by genetic and non-genetic factors*. (Unpublished master's thesis). University of Cape Coast, Cape Coast, Ghana. https://ir.ucc.edu.gh/xmlui/bitstream/handle/123456789/7264/KRUENTI%2c%202020.pdf?sequence=1&isAllowed=y

Kruenti, F., Lamptey, V.K., Okai, M.A., Adu-Aboagye, G., Oduro-Owuso, A.D., Bebanaayele, F., & Suurbessig, B. (2022). The influence of flock age and egg size on egg shape index, hatchability and growth of japanese quail chicks. *Journal of Innovative Agriculture*, *9*(1), 8-16.

Kumari, A., Tripathi, U. K., Maurya, V., & Kumar, M. (2020). Internal quality changes in eggs during storage. *International Journal of Science, Environment and Technology*, *9*(4), 615-624.

Ledvinka, Z., Tůmová, E., Arent, E., Holoubek. J., Klesalová, L. (2000). Egg shell quality in some white-egg and brown-egg cross combinations of dominant hens. *Czech Journal of Animal Science*, *45*(6), 285-288.

Ledvinka, Z., Zita, L., & Klesalová, L. (2012). Egg quality and some factors influencing it: a review. *Scientia Agriculturae Boichemica*, *43*(1), 46-52.

Leyendecker, M., Hamann, H., Hartung, J., Kamphues, J., Ring, C., Gluender, G., Ahlers, C., Sander, I., Neumann, U., & Distl, O. (2001b). Analysis of genotype-environment interactions between layer lines and housing systems for performance traits, egg quality and bone breaking strength. 2nd communication: Egg quality traits. *Zuchtungskunde*, *73*(4), 308-323.

Leyendecker, M., Hamann, H., Hartung, J., Kamphues, J., Ring, C., Gluender, G., Ahlers, C., Sander, I., Neumann, U., & Distl, O. (2001a). Analysis of genotype-environment interactions between layer lines and housing systems for performance traits, egg quality and bone breaking strength - 1st communication: Performance traits. *Züchtungskunde*, *73*(3), 290-307.

Mackie, I. M. (1993). The effects of freezing on flesh proteins. *Food Reviews International*, *9*(4), 575-610.

Markos, S., Belay, B., & Astatkie, T. (2017). Evaluation of egg quality traits of three indigenous chicken ecotypes kept under farmers' management conditions. *International Journal of Poultry Science*, *16*(5), 180-188.

Marwa, M. M. (2015). Effects of freezing storage on the biochemical composition in muscles of Saurida undosquamis (Richardson, 1848) comparing with imported frozen. *International Journal of Fisheries and Aquatic Studies*, *3*(2), 295-299.

Miranda, J. M., Anton, X., Redondo-Valbuena, C., Roca-Saavedra, P., Rodriguez, J. A., Lamas, A., Franco, C. M., & Cepeda, A. (2015). Egg and egg derived foods. Effects on human health and use as functional foods. *Nutrients*, *7*(1), 706-729.

Monira, K. N., Salahuddin, M., & Gous, G. (2003). Effects of breed and holding period on egg quality characteristics of chicken. *International Journal of Poultry Science*, *2*(4), 261-263.

Narushin, V. G., & Romanov, M. N. (2002). Egg physical characteristics and hatchability. *World's Poultry Science Journal*, *58*(3), 297-303.

Nonga, H. E., Kanjuna, F. F., Ngomi, H. A., & Karimuribo, E. D. (2010). Physical egg quality characteristics of free-range local chickens in Mogorogoro Municipality, *Tanzania. Livestock Research for Rural Development*, *22*(12). http://www.lrrd.org/lrrd22/12/nong22218.htm

Olugbenga A. O., Akinola, Y. P. O., Mutiu, O. O., & Emem, A. E. **(**2015). **P**roximate composition and physical characteristics of eggs from laying chickens fed different proprietary vitamin-mineral premixes under two rearing systems during storage. *International Journal of Food Science and Nutrition Engineering*, *5*(1), 59-67.

Padhi, M. K., Chatterjee, R. N., Haunshi, S., & Rajkumar, U. (2013). Effect of age on egg quality in chicken. *Indian Journal of Poultry Science*, *48*(1), 122-125.

Perić, L., Stojčić, M. Đ., & Bjedov. S. (2017). The effect of storage and age of hens on the quality of table eggs. *Advanced Research in Life Sciences*, *1*(1), 64-67.

Reijrink, I., Meijerhof, R., Kemp, B., & Van den Brand, H. (2008). The chicken embryo and its micro-environment during egg storage and early incubation. *World's Poultry Science Journal*, *64*(4), 581-598.

Rizzi, C., & Marangon, A. (2012). Quality of organic eggs of hybrid and Italian breed hens. *Poultry Science*, *91*(9), 2330-2340.

Ryu, K. N., No, H. K., & Prinyawiwatkul, W. (2011). Internal quality and shelf life of eggs coated with oils from different sources. *Journal of Food Science*, *76*(5), 325-329.

Samli, H. E., Agma, A., & Senkoylu, N. (2005). Effects of storage time and temperature on egg quality in old laying hens. *Journal of Applied Poultry Research*, *14*(3), 548-553.

Seidler, E. (2003). FAO, egg marketing. A guide for the production and sale of eggs. Agricultural Services Bullet. 150, Rome, Italy.

Shafey, A. A., Alsobayel, A. A., Al-Mohsen, T. H., & Al-Batshan, H. A. (2002). Effects of eggshell pigmentation and egg size on the spectral properties and characteristics of egg shell of meat and layer breeder eggs. *Asian-Australian Journal of Animal Science*, *15*(2), 297-302.

Shenouda, S. Y. K. (1980). Theories of protein denaturation during frozen storage of fish flesh. *Advances in Food Research*, *26*(1), 275-311.

Silversides, F. G., & Scott, T. A. (2000). Effect of storage and layer age on quality of eggs from two lines of hens. *Poultry Science*, *80*(8), 1240-1245.

Sinha, B., Mandal, K. G., & Kumari, R. (2017). Effect of egg weight on egg quality traits of laying hens. *International Journal Pure and Applied. Bioscience*, *5*(3), 293-300.

Sogunle, O. M., Ayoade, A. A., Fafiolu, A. O., Bello, K. O., Ekunseitan, D. A., Safiyu, K. K., & Odutayo, O. J. (2017). Evaluation of external and internal traits of eggs from three poultry species at different storage durations in tropical environment. *Nigerian Journal of Animal Science*, *19*(2), 177-189.

Suk, Y. O., & Park, C. (2001). Effect of breed and age of hens on the yolk to albumen ratio in two different genetic stocks. *Poultry Science*, *80*(7), 855-858

Tabidi, M. H. (2011). Impact of storage period and quality on composition of Table egg. *Advances in Environmental Biology*, *5*(5), 856-861.

Tilki, M., & Inal, S. (2004a). Quality traits of goose eggs. 1. Effects of goose age and storage time of eggs. *Archives Für Geflugelk.*, *68*(4), 182-186.

Tilki, M., & Inal, S. (2004b). Quality traits of goose eggs. 2. Effects of goose origin and storage time of eggs. *Archives Für Geflugelk.*, *68*(5), 230-234.

Tilki, M., & Saatci, M. (2004). Effects of storage time on external and internal characteristics in partridge (*Alectoris graeca*) eggs. *Revue de Médecine Vétérinaire*, *155*(11), 561-564.

Tůmová, E., Vlčková, J., & Chodová, D. (2017). Differences in oviposition and egg quality of various genotypes of laying hens. *Czech Journal of Animal Science*, *62*(9), 377-383.

United States Department of Agriculture (2000). United States standards, grades, and weight classes for shell eggs (Agricultural Research Note RN 23 12/99). Washington, D.C., USA: United States Department of Agriculture.

Van Niekerk, T. (2014): Egg quality. Low Input Breeds technical note. www.lowinputbreeds.org

Yamak, U. S., Sarica, M., Boz, M. A., & Ucar, A. (2016). The effect of eggshell thickness on hatching traits of partridges. *Brazilian Journal of Poultry Science*, *8*(Special Issue, Quails), 13-18.

Zeidler, G. (2002). *Shell quality and preservation*. In D. D. Bell & W. D. Jr. Weaver (Ed.), Commercial chicken meat and egg production 5th Review (pp. 1199-1217). Norwell, MA: Kluwer Academic Publishers.

Zhang, W., Zheng, J. X., & Xu, G. Y. (2011). Toward better control of salmonella contamination by taking advantage of the egg's self-defence system: a review. *Journal of Food Science*, *76*(3), 76-81.