THE LEVEL OF DEFECTIVE EGGS AMONG THREE STRAINS OF COMMERCIAL EGG-TYPE CHICKENS AND ITS ECONOMIC IMPLICATIONS

Adomako, K., Asiedu, E., Hamidu, J. A. and Olympio, O. S.
Department of Animal Science,
Faculty of Agriculture,
Kwame Nkrumah University of Science and Technology, Kumasi

ABSTRACT
The study was conducted to determine the number of rejected eggs, causes and economic implications among three egg-type strains in a commercial poultry farm. A total of eight thousand layers were used for the on-farm study. Total eggs for each strain were determined by recording and counting each day's production. The defective eggs were sorted out and the totals were recorded. Percentage for the defective eggs were then calculated. Data were taken four times a day at particular time intervals. Strains 1 and 2 were 47 weeks and strain 3 was 82 weeks old at the start of the study. Data collected were analysed using one-way analysis of variance (ANOVA) with the aid of Genstat, Fifteenth Edition (2012) and the treatment means were separated using the Tukey's Studentized Range Test. Strain 2 produced the highest number of eggs (p<0.05) but recorded the lowest percentage of defective eggs (p<0.05). Strain 3 produced the lowest number of eggs (p<0.05) and yet recorded the highest percentage of defective eggs (p<0.05). The number of eggs collected and the percentage of defective eggs were significantly different (p<0.0) among the strains. The total economic loss as a result of defective was GH¢17, 106.43 with strain 3 recording the highest economic loss (GH¢8, 304. 77) followed by strain 1 (GH¢6, 022.76) which also recorded a higher economic than strain 2 (GH¢2, 778.90). It can be concluded that all other factors being equal, strain and age influence the percentage of defective eggs with the type of strain used either increasing or decreasing the number of defective eggs; and with older birds producing more defective eggs than younger ones irrespective of the strain. Eggs with defect result in huge economic losses which would eventually affects profitability.

Keywords: *Chickens, egg-type, defective eggs, economic loss*

INTRODUCTION
Globally, people keep domestic birds purposely for their eggs and meat. The main revenue that the poultry industry generates is from the sales of either eggs or meat and/or both. In the United States, the proportion of rejected eggs constitutes over 30% of the total production, (The International Egg Foundation, 2007).

Eggs colliding in the shell gland region of the oviduct when an ovum (yolk) is released too soon after the previous one is one of the main causes of defective eggs. Necropsy examinations have demonstrated that two full-sized eggs can be found in the shell gland pouch. As the second egg comes in contact with the first, pressure is exerted, disrupting the pattern of mineralization. The first egg acquires a white band and chalky appearance, while the second egg is flattened on its contiguous surface (ie, slab-sided), (Espinosa, 2019). Pimpled or rough eggs may have been retained too long in the shell gland. Blood spots result when a follicle vessel along the stigma ruptures as the ovum is being released. Meat spots occur when a piece of follicle membrane or residual albumen from the previous day is incorporated into the developing egg (Espinosa, 2019).

According to Espinosa (2019), many abnormalities appear to have no specific cause, but the incidence is much higher in hens subjected to stressful management conditions or rough handling (catching or vaccination) during production. A significant increase in the number of soft-shelled eggs is also common as a result of viral diseases such as infectious bronchitis, egg drop syndrome, Newcastle disease, avian pneumovirus, and avian influenza. He also indicated that small eggs with no yolk form around a nidus of material (residual albumen) in the magnum of the oviduct are laid occasionally. Small eggs with reduced albumen and eggs with defective shells may be the result of damage to the epithelium of the magnum or shell gland. He further stated that, foreign material that enters the oviduct through the vagina (eg, a roundworm) may rarely be incorporated into an egg. Cracked and broken eggs are caused by poor nest condition, delays in egg collection from the laying nest, poor handling of eggs during collection, loading, off-loading and transportation.

The incidence of downgraded eggs represents an important source of economic loss for the egg industry due to the products damage and the need for further processing (Mazzuco and Bertechini, 2014). According to Coutts and Graham (2007), the incidence of eggshell defects could reach one percent in young and nine percent in older birds. Most egg producers usually lose revenue because of the poor patronage of deformed or poor shelled eggs thereby reducing productivity. Early Transition in countries such as Georgia, and Mongolia, and the western Balkan example, Serbia, and Macedonia, import not - in-shell eggs and egg yolks. The Early Transition countries imported 50.6 and 44.5 tons of not in-shell eggs and yolk that was worth 83.5 (US dollars) and 85.5 (US dollars) respectively within 2006 and 2007 while the Western Balkan countries also imported 2766.8 and 358 tons worth 1212 (US dollars) and 1943 (US dollars) respectively within the same period (FAOSTAT, 2010). In Ghana, there are few or no industries that are into the purchase of not in-shell or liquid eggs therefore rejected eggs from commercial farms are either sold at a cheaper price or are left to go waste. The breeder industry also incurs huge economic losses due to reduced chicken embryo liveability and hatchability since the successful development of a chick embryo depends on a robust eggshell for mechanical resistance, protection from infection, prevention of water loss and as the main source of calcium for the embryonic skeleton (Yang *et al*., 2012). Therefore, the investigation of the causes and economic implications of defective eggs is imperative. The objective of this study were to compare the number of rejected eggs among three layer strains and also establish the economic implications of the rejected eggs among these layer strains.

MATERIALS AND METHODS

Experimental Site and Duration

The study was done at Rockland Farm Limited located at Ankamadoa within the Sekyere Central District in the Ashanti Region of Ghana. It lies within longitudes, 0.05 and 1.30 degrees West and latitudes, 6.55 degrees and 7.30 North. The study lasted for ten weeks.

Experimental Birds and Design

Three commercial strains, Bovan Brown (n = 2454) and Dekalb White (n = 2930) which were 47 weeks old and Lohman Brown (n = 2605) which were 82 weeks old were used for the study. A total of seven thousand, nine hundred and eighty-nine birds involved in this on-farm study. Each strain was reared in a 50m x 50m (2500m^2) deep litter pens in an intensive system. Wooden laying nests were provided in the pens. Feed and water were offered *ad libitum.* Routine vaccination and other management practices were carried out. All strains were fed with layer mash containing 17% CP and 2550 kcal ME/kg. The completely randomized design was employed for the study with the strains as treatments and the number of weeks as the replicates.

Data Collection

The focus of the study was on the total number of eggs laid per day per strain, the number of defective eggs collected per day per strain and the time within the day where high numbers of defective eggs were recorded among the strains. Data was taken four times within a day (8:00 am, 10:00 am, 1:00 pm and 4:00 pm) and eggs were sorted to separate the defective ones from the whole ones. The totals were calculated by adding all the daily defects and all the daily productions. The percentages were calculated by dividing a particular total defect by total rejected/defective eggs for the whole ten weeks. The time within the day with the highest defects among the strains were also recorded.

The main factors were the physical defects of eggshells which included: Pimple (P-R), Calcium Coated (Cal.-C), White Band (W-B), Calcium Sparkles (Cal.-SP) Calcium Deposits (Cal.-Dep), Lilac (Lil), Shell Less (SHL), Wrinkled (WRINK), Brown Sparkles (BR.-SP), Body Checked (B.-CH), Slab Sided (S.-S), Broken and Mended (B & MEN), Dirty (D), Soft Shelled (SO.-H), Cracked (C), Jumbo (J), Pee Wee (PEE), Broken (BROK) and Corrugated (COR).

Data Analysis

Data collected were analysed using one-way analysis of variance (ANOVA) with the aid of Genstat, Fifteenth Edition (2012) and the treatment means were separated using the Tukey's Studentized Range Test.

RESULTS AND DISCUSSION

The number of rejected eggs in three different laying strains

Broken and mended (Fig. 1) eggs in strain 1 was not significantly different from that of strain 2 ($p>0.05$) but it was lower in strains 1 and 2 compared to strain 3 ($p<0.05$), (Table 1). This could be as a result of the differences in age, heredity and/or poor pen management.

Figure 1: Broken and Mended eggs

A diagonal break occurs during egg formation and it is mended before lay (Fig.1). This defect often occurs when the bird is stressed during the calcification period. (Roberts, 2019).

Brown sparkles (Fig. 2) were higher in strain 1 than strain 2 ($p<0.05$) with strain 3 not recording any (Table 1). However, calcium sparkles (Fig. 2) were higher in eggs laid by strain 3 than strain 1 ($p<0.05$) but there were no differences between eggs laid by strains 1 and 2 and also between strains 2 and 3 ($p>0.05$).

Figure 2: Calcium/Brown sparkles eggs

With the exception of sparkles being smaller, they are similar to deposits. These eggs are laid down before or after the cuticle is formed and are pigmented white or brown (Fig. 2). This is caused by a defective shell gland, disturbances during calcification and excess calcium in the diet. (Roberts, 2019).

Corrugated rejected eggs (Fig. 3) were very few, and were not different among eggs laid by the 3 strains just like pee wee (Fig. 4) eggs ($p>0.05$), (Table 1).

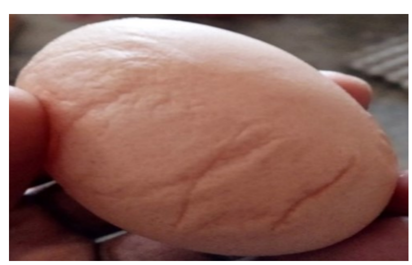


Figure 3: Corrugated eggs

Corrugated eggs (Fig. 3) have rough and irregular ribbed appearance. These eggs are produced when plumping is not controlled and is terminated. Their production can also be as a result of infectious diseases, heat stress, saline water, old age and poor nutrition. (Roberts, 2019).

Figure 4: Jumbo and Pee Wee eggs

All hens cannot produce the same egg size. The size of an egg is of great importance to a farmer since larger eggs have good market value than the smaller ones, but, small and medium eggs do not crack easily as compared with jumbo eggs. Based on the normal classifications of eggs, a jumbo egg weighs 70g and above while a pee wee egg weighs below 42g per unit. The factors that cause a hen to lay a jumbo or pee wee eggs (Fig. 4) are their age, genetics/strain, nutrition, stress, temperature, disease, lighting system and water consumption.

Strains 2 and 3 recorded significantly higher body checked (Fig. 5) eggs ($p<0.05$) than strain 1 but the differences were not significant between strains 2 and 3 ($p>0.05$), (Table 1).

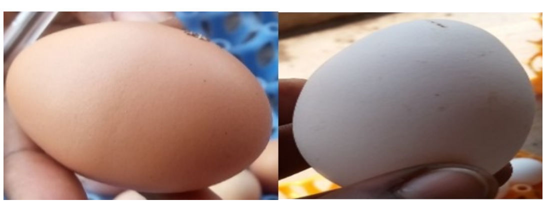


Figure 5: Body checked eggs

As shown in Figure 5, body-checked egg has a shell with a pronounced belt or extra shell layer around the middle and it occurs when eggs crack in the shell gland pouch and it is repaired before it is lay. This occurs 10 – 14 hours before lay (Abanikannda *et al*., 2007). This incidence increases with age from about 1% of production to 9% in the very late stages of lay. It is mostly caused by incorrect lighting, disturbances and overcrowding in pens (Mack, 2019; Roberts, 2019). Jones (2006) stated that this defect can be managed by proper handling.

Strain 3 laid eggs which had more calcium coated (Fig. 6), calcium deposits (7), jumbo (Fig. 4), soft-shelled and shell less (Fig. 8) than strains 1 and 2 ($p<0.05$) but strains 1 and 2 did not differ in the number of these rejected eggs ($p>0.05$). Strains 1 and 2 did not lay any shell less eggs at all (Table 1).

Figure 6: Calcium Coated eggs

An extra layer of calcium can be noticed all over or just one part of the eggshell (Figure 6). Incidence ranges from 5% to 20% and it is caused by defective shell gland, disturbances during calcification and excess calcium in diet (Roberts, 2019).

Figure 7: Calcium Depots Eggs

This is classified by white irregular shaped spots on an eggshell (Fig. 7). This may be caused by defective shell gland, disturbances during calcification, poor nutrition and retention of egg within the shell gland (Roberts, 2019). According to Khan *et. al*. (2004), this defect is thought to be hereditary.

Soft Shell **Shell less**

Figure 8: Shell Less and Soft-Shell eggs

A shell-less egg (Fig. 8) is laid without a shell layer and is protected by only the shell membrane whiles a soft-shelled egg is laid with an incomplete shell. Eggs may be protected by only the shell membrane and a thin layer of calcium. These incidences range from 0.5% to 6% of production. This problem is commonly caused by an immature shell gland, inadequate nutrition, saline water, disease and stress (Roberts, 2019).

Strain 2 laid more cracked (Fig. 9) and dirty (Fig. 10) eggs than strains 1 and 3 ($p<0.05$) but the difference was not significant between eggs laid by strains 1 and 3 for these rejected eggs ($p>0.05$), (Table 1).

Figure 9: Cracked eggs

There are many different types of cracks in eggshells (Fig.9). Examples include hair line cracks, star cracks or large cracks that results in a hole in the shell. Incidence of cracks can range from 1% to 5% of production. Cracks are caused by different factors including heat stress, saline water, old age and poor nutrition (Roberts, 2019).

As shown in Fig. 10, the egg shell is stained when laid. It is important to avoid feed ingredients that will cause wet droppings. This may also be caused by adding large amounts of indi-

Figure 10: Dirty eggs

gestible compounds in feed, poor gut health, and imbalance electrolyte/saline water (Roberts, 2019).

Lilac eggs (Fig. 11) were higher among eggs laid by strain 1 compared to those laid by strain 3 ($p<0.05$) but strain 2 did not record any lilac eggs at all (Table 1).

Figure 11: Lilac egg

This egg (Fig. 11) appears to be pink or lilac due to the association between the cuticle and an extra calcium layer. Lilac eggs as with other eggs with extra calcium deposits such as sparkled egg, often results from stress or excess calcium in the feed (Roberts, 2019).

Strain 3 laid more pimple eggs (Fig. 12) than strain 2 which also laid more pimple eggs than strain 1 ($p<0.05$), (Table 1).

Figure 12: Pimple eggs

As shown in Figure 12, small lumps of calcified materials appear on the eggshell. Some can be removed easily by simply rubbing while others are formed from the internal membrane layers of the shell and may leave tiny holes in the shell when an attempt is made to remove them. The severity of the occurrence of pimples depends on the foreign materials present during the calcification process in relation to birds' age, strain and nutritional status. (Roberts, 2019).

Wrinkled (Fig. 13) and slab sided (Fig. 14) eggs were higher in strain 3 than strain 1 ($p<0.05$) but the differences were not significant between strains 1 and 2 and also between strains 2 and 3 (Table 1).

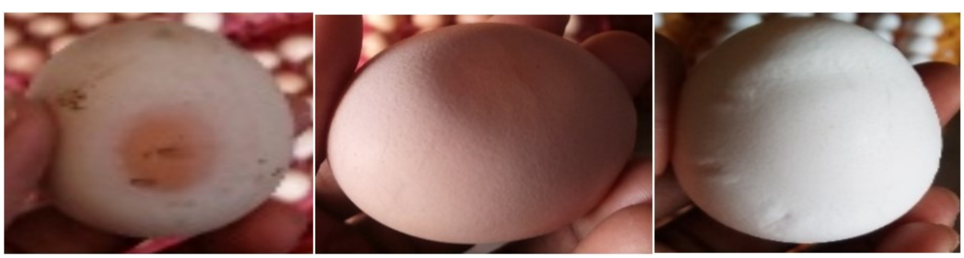
Figure 13: Wrinkled Eggs

Tiny creases and wrinkles (Fig. 13) are found on the surfaces of the egg when the egg's albumen is under developed and watery, and the shell is not able to develop normally. This may occur anywhere and at any direction. Wrinkles may occur as a result of stress, disease, defective shell gland and overcrowding of birds. (Mack, 2019; Roberts, 2019).

White Band and Slab-sided eggs (Fig. 14) occur when normal calcification is interrupted as a result of two eggs coming into contact with each other in the shell gland pouch. The first egg that was in the pouch will only have an extra calcium layer which is seen as the white band marking and the second egg that enters the shell gland pouch is not as complete as the first egg, and the point of contact becomes flattened, hence the term Slab Sided. This may be caused by stress from disturbances, change in the lighting pattern or the presence of an infection. (Roberts, 2019).

Strains 1 and 3 laid more white band eggs than strains 2 ($p<0.05$), however the number of white band eggs were not different between strains 1 and 3 ($p>0.05$).

Strain 3 recorded the highest number of defects from calcium coated. This result disagrees with those of Coutts and Graham (2007) who reported that, calcium coated shells is often found in younger birds which are coming into production (pullets). This could be due to the fact that additional calcium was given since they are older and the fear of losing much eggs to breakages meanwhile, cracked and broken shell-eggs are regarded as a great economic loss to producers (Kemps *et.al*., 2006). According to Hincke *et. al.* (2000) despite the numerous calcium metabolism and eggshell formation researches, week/ poor eggshell formation still is a problem for the industry due to the fact that these defects are presumed to come as a result of disease infection. Meanwhile, aside genetic factors, any condition that disturbs the laying bird ten to fourteen hours to lay doubles the chances/incidence of producing defected egg (Coutts and Graham, 2007). High egg weight and body weight are as a result of increased number of double yolks and this tends to have more shell defects (Wolc, *et. al*., 2012).



White Band **Slab Sided** **Slab Sided**

Figure 14: White Band and Slab-Sided eggs

According to Coutts and Graham (2007), the incidence of slab sided and white band is estimated to be less than 1% and it varies among strains and this study agrees with their findings. An obvious reason for egg shell cracks is mechanical damage and it is caused by either the birds themselves or due to poor management practices like poor handling, delay in egg collection or poor housing and/or coop design.

The total number of eggs collected (production) at the various times within the day

Eggs were collected at different times within the day. The number of eggs collected at 8:00am and 10.00am among the three strains was significantly higher ($p<0.05$) in strain 2 than in strain 3 which was also higher than in strain 1 but there was no difference ($p>0.05$) between strains 1 and 3 for the number of eggs collected at 10.00am (Table 2). Eggs collected at 4.00pm was higher ($p>0.05$) in strains 1 than 3 but there was no difference ($p>0.05$) between strains 1 and 2 as well as 2 and 3 (Table 2). There was no difference ($p>0.05$) in the number of eggs produced among the three strains at 1:00pm (Table 2).

Percentage of rejected eggs within the total eggs produced at various times within the day

The percentage of eggs that was counted as rejected within the four times as shown in Table 3. Rejected eggs collected at 8.00am, 1pm and 4pm were higher ($p<0.05$) in strain 3 compared to strain 1 which was also higher ($p<0.05$) than that of strain 2. The quantity of rejected eggs among eggs collected at 10am was higher $p<0.05$) in

Table 1: **Percentage (%) of defective eggs in three laying strains**

Parameter/ Strain	Strain 1	Strain 2	Strain 3	SED	P-Value
Broken eggs	1.43^{b}	2.41^{b}	6.48^{a}	1.312	0.002
Brown Sparkles	22.1^{a}	0.0^{c}	7.4^{b}	2.720	<.001
Body checked	3.10^{b}	7.78^{a}	9.56^{a}	0.981	<.001
Broken & Mended	0.24^{b}	0.40^{b}	1.09^{a}	0.293	0.017
Calcium coated	1.67^{a}	0.25^{b}	2.89^{a}	0.593	<.001
Calcium Deposits	4.80^{b}	4.46^{b}	12.3^{a}	1.003	<.001
Calcium Sparkles	8.40^{b}	10.6^{ab}	11.7^{a}	1.504	<.001
Corrugated	0.07	0.14	0.17	0.071	0.378
Cracked	13.1^{b}	30.8^{a}	6.8^{b}	3.040	<.001
Dirty	2.45^{b}	4.79^{a}	1.09^{b}	0.781	<.001
Jumbo	6.03^{b}	5.76^{b}	9.27^{a}	1.179	0.010
Lilac	16.6^{a}	0.0^{c}	8.48^{b}	1.538	<.001
Pee Wee	8.8	7.5	12.5	2.490	0.133
Pimple	0.26^{c}	2.17^{b}	4.12^{a}	0.412	<.001
Soft Shelled	0.40^{b}	0.25^{b}	0.96^{a}	0.138	<.001
Slab Sided	0.41^{b}	0.69^{ab}	1.05^{a}	0.191	0.008
Shell Less	0.00^{b}	0.00^{b}	0.05^{a}	0.017	0.010
White band	2.09^{a}	0.29^{b}	2.53^{a}	0.426	<.001
Wrinkled	8.71^{b}	12.8^{ab}	14.3^{a}	1.471	0.002

$^{a-c}$Different superscripts within the same row are significantly different at $p < 0.05$; SED = Standard Errors of Difference.

Table 2: The total number of eggs collected (production) at various times within the day

Time/ Strains	Strain 1	Strain 2	Strain 3	SED	P-Values
8:00 am	4055.0^{c}	6220.0^{a}	5078.0^{b}	282.3	<.001
10:00 am	5122.0^{b}	8686.0^{a}	4794.0^{b}	421.9	<.001
1:00 pm	2563.0	2491.0	1497.0	366.6	0.012
4:00pm	1201.0^{a}	833.0^{ab}	722.0^{b}	92.4	<.001

$^{a-c}$Different superscripts within the same row are significantly different at $p < 0.05$.
SED = Standard Errors of Difference

Table 3: The times of egg collection within the day and the percentage number of rejections

Time/ Strains	Strain 1	Strain 2	Strain 3	SED	P-Values
8:00 am	10.41^{b}	3.38^{c}	15.34^{a}	0.956	<.001
10:00 am	9.59^{a}	2.51^{b}	12.46^{a}	1.623	<.001
1:00 pm	9.92^{b}	4.78^{c}	17.70^{a}	1.554	<.001
4:00pm	16.44^{b}	10.92^{c}	21.44^{a}	2.240	<.001

Different superscripts within the same row are significantly different at $P < 0.05$.
SED= Standard Errors of Difference.

strains 2 and 3 than in strain 1, but the differences were not significant p>0.05) between strains 2 and 3 (Table 3). The finding results of this study disagrees with the findings of Wolc *et. al*. (2012), who reported that high producing hens have a lower genetic frequency rate to lay rejected eggs.

In summary, strain 2 produced the highest number of eggs within the weeks yet produced the least percentage of defective eggs while strain 3 produced the lowest number of eggs but had the highest percentage of defective eggs (Table 4). This was because strain 3 was an older flock compared to strains 1 and 2. These results agree with that of Mazzuco and Hester (2005), who stated that a decline in eggshell quality is detected as hens approach the end of their laying period. As hens age, their egg shell colour generally becomes lighter, there is decreased shell strength, high chances of egg deformation and the metabolic processes as well as dietary requirements also change slightly. Strains 1 and 2 which were below 50 weeks of age produced the highest number of eggs and gave the lowest percentage of defects while strain 3 which was above 50 weeks produced the least number of eggs and recorded the highest percentage of defective eggs.

The economic implications of the defective eggs

Table 5 shows that, 430.6 (GH¢6022.76) crates were lost from Strain 1 out of the total defective eggs collected from this strain while 198.15 and 593.6 crates at the cost of GH¢2778.90 and GH¢ 8304.76 respectively were lost from strains 2 and 3 respectively (Table 4.5). If after a huge sum of production costs, a farmer had to lose these huge amounts to rejected eggs, then this can be regarded as a great economic loss to the farmer and the country as a whole. The findings of this research agree with the report of Mazzuco and Bertechini (2014), who stated that the incidence of downgraded/defective egg (shells)

Table 4: Summary of results

Result/strain	Strain 1	Strain 2	Strain 3	SED	P-Value
Total eggs collected within the 10 weeks	13360.0	18024.0	11922.0	288.5	<.001
Total number of rejected eggs within the 10 weeks	1291.0	596.0	1780.0	104.4	<.001
Total rejected percentage within the 10 weeks	9.67	3.29	14.88	0.692	<.001

Table 5: The economic value of defective eggs

Strain	Defective eggs (pieces)	Defective eggs (Crates)	Price per crate (GH¢)	Total economic value of defective eggs (GHC)
1	12,906	430.6	14.00	6,022.76
2	5,955	198.15	14.00	2,778.90
3	17,796	593.6	14.00	8,304.76

represents an important source of economic loss for the egg industry.

In Ghana, loses incurred as a result of defective eggs is quite moderate compared to the loses realized in this study. This is because Ghana Poultry Farmers are able to sell defective eggs at a reduced price to “kyebom” sellers and pastries producers. Some poultry farmers also give some of the defective eggs to their workers, family and friends as gratis.

CONCLUSION

It can be concluded that strain, age and egg collection time had a huge influence on the percentage of defective eggs. Understanding the factors that cause defects in eggshells is key since defective/ low quality shells/eggs can lead to great economic losses to the producer. The rate of shell damages varied among strains and birds at different ages. The type of strain used can either increase or decrease the number of defected eggs; and older birds produce more defective eggs than younger ones irrespective of the strain. Defective eggs result in a huge economic loss which eventually affects profitability.

RECOMMENDATIONS

Strain 2 is recommended for higher egg production and low percentage of defective eggs. Further studies should be conducted on different strains at the same age and/or the same strain at different ages.

REFERENCES

Abanikannda, O. T. F., Leigh, O. A., Ojedapo, L. O., and Kpossu, O. D. (2007). Interspecific variation in shell thickness of commercial poultry eggs. Proceedings of the 12th Annual Conference of Animal Science Association of Nigeria, Sept. 10-13, Nigeria, pp: 9-9.

Coutts, J. A. and Graham, C.W. (2007). Optimum Egg Quality-A Practical Approach. 5M Publishing, Sheffield, Great Britain, 65p.

Espinosa, R. A. (2019). Defective or Abnormal Eggs in Poultry. MSD Veterinary Manual. Merck Sharp & Dohme Corp., a subsidiary of Merck & Co., Inc., Kenilworth, NJ, USA. https://www.msdvetmanual.com/poultry/disorders-of-the-reproductive-system/defective-or-abnormal-eggs-in-poultry

FAOSTAT (2010). Poultry Meat and Eggs, Agribusiness Handbook, Investment Centre Division Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, pp 39-69. pdfcoffee.com_fao-agribusiness-handbook-poultry-meat-amp-eggspdf-pdf -free.pdf

Genstat, Fifteenth Edition (2012). VSN International Software for Biosciences, Oxford, United Kingdom.

Hincke, M.T.; St. Maurice, M.; Nys, Y.; Gautron, J.; Panheleux, M.; Tsang, C. P.W.; Bain, M.M.; Solomon, S.E.; McKee, M. D. (2000). Eggshell proteins and shell strength: molecular biology of eggshell matrix proteins and industry applications. In: Sim; Nakai; Guenter (Eds). Egg Nutrition and Biotechnology. CABI Publishing, Wallingford, UK, 2000, 495p.

International Egg Foundation (IEF) (2007). New International Egg Foundation Launched to Help Combat Malnutrition in Developing Countries. https://www.internationalegg. com /corporate/news/details.asp?nid=924

Kemps, B.J., Govaerts, T., De Ketelaere, B., Mertens, K., Bamelis, F.R. Bain, M.M., Decuypere, E.M and De Baerdemaeker, J.G. (2006). The influence of line and laying period on the relationship between different eggshell and membrane strength parameters. Poultry Science, 85 (7): 1309 - 1317.

Khan, M.K.I., Khantun, M.J. and Kibria, A.K.M.G. (2004). Study of the quality of eggs of different genotypes of chicken under semi-scavenging system at Bangladesh. Pak. J. Biol. Sci.,7: 2163-216.

Mack, E. D., (2019). Eggshell Problems: Causes and Cures. https://www.Community chickens.com.

Mazzuco, H and Bertechini, A.G. (2014). Critical points on egg production: causes, importance and incidence of eggshell breakage and defects. Cienc. Agrotec. (online), 38: (1): 7-14. https://doi.org/10.1590/S1413-705 42014000100001

Mazzuco, H. and Hester, P.Y. (2005). The effect of an induced molt and a second cycle of lay on skeletal integrity of white leghorns. Poultry Science, 84 (5):771-781.

Roberts, J.R. (2019). Egg Quality Reference Manual – First Edition: a resource to further inform producers about egg and eggshell quality. Australian Eggs Limited, pp12-16. All rights reserved. 978-1-920835-23-1

Wolc, A.,J., Arango, P. Settar, N.P.O., Sullivan, V.E., Olori, I.M., White, W.G. H. and Dekkers, J.C.M. (2012). Genetic parameters of egg defects and egg quality in layer chickens. Poultry Science, 91(6):1292-1298.

Yang, X., Lelun, Z., Xiaofang, A., Nan, Z., Zhang, L., Han, J. Junhu, Y., Charron C., Yajing, S. (2012). Effects of diets supplemented with zinc and manganese on performance and related parameters in laying hens. Animal Science Journal, 83(6):474-481.

Yang, H.M., Z. Yang, W. Wang, Z.Y. Wang, H.N. Sun, X.J. Ju, X.M., Q.I, (2014). Effects of different housing systems on visceral organs, serum biochemical proportions, immune performance and egg quality of laying hens. European Poultry Science, 78: 1-9.