DETERMINATION OF HEN EGGSHELL STRESS BY THE PUNCTURE METHOD

ODREĐIVANJE ČVRSTOĆE KOKOŠIJIH JAJA METODOM PROBIJANJA LJUSKE

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ABSTRACT

The aim of this study was to design and apply the measuring acquisition system, or a device for determining the limit values of eggshell stress using the puncture method. This study focused on class "L" eggs produced on a laying hen farm in the vicinity of Čačak and determined the external physical properties of egg quality: length, width, shape index and mass. In addition, the following eggshell properties were determined: mass, proportion, thickness, and puncture force. The average egg length was 58.05 mm, width 45.46 mm, and shape index 78.25%. The average egg mass was 65.89 g, and the eggshell ratio 12.76% (8.44 g). The average eggshell thickness was 0.48 mm with a 4.69% coefficient of variation. Results showed that the tested eggs had uniform stress, with an average value of the minimum shell puncture force 26.34 N, with a 0.95% coefficient of variation.

Keywords: eggshell breaking stress*, puncture method*

REZIME

U procesu proizvodnje i distribucije jaja zbog lošeg kvaliteta ljuske, svakodnevno se polomi 6-10% od ukupnog broja proizvedenih jaja, što je značajan ekonomski gubitak. Cilj ovog rada je bio projektovanje i primena merno akvizacionog uređaja za utvrđivanje graničnih vrednosti čvrstoće ljuske jaja korišćenjem direktne metode probijanja ljuske. U postavljenom eksperimentu su korišćena jaja "L" klase proizvedena na farmi kokoši nosilja u okolini Čačka. U istraživanjima su određene osnovne spoljašnje fizičke osobine kvaliteta kokošijih jaja: dužina, širina, indeks oblika i masa jaja. Pored toga, utvrđene su i osobine ljuske: masa, udeo, debljina i sila probijanja. U ovom istraživanju, prosečna dužina jaja je bila 58,05 mm, širina 45,46 mm, a indeks oblika 78,25%. Od prosečne mase jaja (65,89 g), udeo ljuske je iznosio 12,76% (8,44 g). Prosečna debljina ljuske sa opnom je bila 0,48 mm, sa koeficijentom varijacije 4,69%. Rezultati istraživanja pokazuju da su ispitivana jaja imala ujednačenu čvrstoću, prosečna vrednost minimalne sile probijanja ljuske iznosila je 26,34 N, sa koeficijentom varijacije 0,95%. Prednost metode probijanja u odnosu na metod pritiska je u tome što je vrlo precizna i daje konkretne podatke o vrednostima čvrstoće, odnosno sile probijanja, a da pri tome ne dolazi do razbijanja jaja. Na istom uzorku, testiranja se mogu ponoviti više puta na bilo kom mestu ljuske jaja. Rezultati ovih istraživanja mogu dati značajne podatke za konstrukciju kaveza, projektovanje opreme za prikupljanje i pakovanje jaja, dizajniranje ambalaže za jaja, važni su pri selekciji novih linija i hibrida kokoši koje imaju veću otpornost ljuske na lomljenje.

Ključne reči: čvrstoća pucanja ljuske, metod probijanja

INTRODUCTION

One of the major daily financial losses in egg production and distribution stems from the low mechanical stress of the eggshell. Consequently, eggshell stress is the key contributing factor in the economic result of egg farming, since about 6-10% of the total hatched eggs may break. Considerable effort is therefore devoted to decreasing the impact of external forces and possible egg damages during handling and transporting from farms to consumers. Experts from research and practice have tried to lower the number of cracked and broken eggs in different ways: new cage construction, decreased angle of egg rolling on the cage bottom, increased number of times eggs are collected daily, automated egg collection and packaging, and new design of egg carton. Although these attempts have played a significant role in decreasing the number of damaged eggs in the production chain, eggshell stress remains the main reason for egg damages.

Many studies have aimed at improved eggshell stress using different techniques, devices and measuring methods. All such methods for determining the eggshell quality can be divided into two basic groups: indirect and direct. Indirect methods include specific egg mass and non-destructive shell deformation. The advantage of these methods is that the eggs do not break during the experiment, but a disadvantage is that the data on eggshell stress is not completely reliable. On the other hand, direct methods include measurement of puncture force, quasi-static compression force, impact force, and free fall on a known surface force.

Comparative testing of eggshell stress used quasi-static compression and puncture methods and found that the average breaking force measured by compression was 32.41 N, and 14.63 N measured by puncture test. The maximum breaking stress of eggshells calculated on the puncture force was 35.43 N/cm^2 (*Hunt et al., 1977*).

Trying to determine eggshell stress, *Voisey et al. (1978)* were among the first ones to apply the puncture method. The average puncture force was 15.70 N, with a coefficient of variation

ranging from 14.6% to 15.2%. The same authors reported in a different study that the average puncture force in hen eggshells was 17.06 N, ranging from 16.81 N to 17.05 N (*Voisey et al., 1979*). The mean value of maximum breaking stress was 40.42 N/cm² in eggs with an eggshell thickness of 0.334 mm. Puncture force was 20.57 N in organically reared hens, 26.51 N in hens reared in a facility with an outlet, 30.17 N in hens kept in cages, with respective eggshell thickness values of 0.308 mm, 0.320 mm, and 0.338 mm (*Krawczyk, 2009*).

Hen breed Hisex Brown showed average egg-breaking force measured by quasi-static compression method to be 36.43 N on the short axis of symmetry, and 34.92 N on the long axis of symmetry, ranging from 10.03 N to 58.96 N (*Nedomova et al., 2009*).

Using the same method, *Pavlovski and Vitorović (1996)* determined the eggshell breaking force (stress) of the Hisex hybrid (42.28 N and 46.21 N) and Isa Brown (39.24 N and 39.04 N) in eggs collected in the intervals 5-7 am and 9-11 am.

Cage-reared hens produced eggshell strength of 37.40 N/cm² in eggs with the thinnest shell (0.28-0.30 mm), 45.97 N/cm² in eggs with the medium-thick shell (0.33-0.36 mm), and 50.89 N/cm² in eggs with the thickest eggshell (0.39-0.41 mm). Egg strength correlates with the shell thickness, weight and ratio of the shell in total egg mass (*Keta and Tumova, 2018*).

Depending on the farming method, hens that were 21-40 weeks old produced eggshell stress of 38.16 N/cm² in an aviary system, 30.61 N/cm² in a barn system, and 28.94 N/cm² in a conventional cage system, with a shell thickness of 0.39 mm, 0.40 mm and 0.38 mm, respectively (*Ahammed et al., 2014*).

Maximum eggshell breaking stress in hen hybrid Czech Hen was 40.58 N/cm², and in Lohmann, it was 42.74 N/cm² (*Tumova et al., 2016*). Since eggshell stress decreases with the age of laying hens, the eggshell breaking stress is lower in older hens (32.67 N/cm²) than in the younger ones (35.32 N/cm²) (*Tumova et al., 2014*).

Three egg farmers produced eggs with shell stress and thickness of 29.23 N/cm² and 0.39 mm; 29.72 N/cm² and 0.41 mm, 37.28 N/cm² and 0.43 mm. Eggshell stress ranged between 38.26-40.22 N/cm² for white eggs and 37.77 -40.22 N/cm² for brown eggs (*Kralik et al., 2012).*

The mean value of maximum eggshell breaking stress in the Lohmann Brown breed was 40.61 N/cm², ranging from 35.51 N/cm² to 47.68 N/cm² *(Yan et al., 2014). Turker and Alkan (2019)* reported there were no significant differences in egg mass (61.907 g and 61.358 g), breaking stress (28.04 N/cm² and 27.59 N/cm²)*,* shell thickness (0.377 mm and 0.378 mm), and shape index (78.79% and 78.42%) between free-range and deep-litter housed hens. Studying hens reared in conventional cages, *Dikmen et al. (2017)* reported average egg mass 58.35 g, eggshell mass 5.68 g, the eggshell ratio in total egg mass 9.83%, shape index 78.31%, shell thickness 0.397 mm, and shell breaking stress 21.88 N /cm².

The aim of this study was to design and apply the device for the determination of minimum values of puncture force and maximum eggshell stress by using the direct method of eggshell puncture.

MATERIAL AND METHOD

This study used 10 "L" class eggs in three repetitions, from hen breed Isa Brown aged 34 weeks, produced at the farm "Grbović" in the vicinity of Čačak. The study determined the main external physical properties of hen eggs: length, width, shape index, and egg mass. The shape index is given as a relative ratio of egg width and length. Additionally, the following eggshell properties were determined: mass, thickness, puncture force and the ratio of shell in total egg mass. Egg mass and shell mass with membrane were measured by analytical scales Kern EMS 3000-2 with the precision of 0.01 g. Physical properties (length and width) of the eggs and shell thickness with membrane were measured by electronic pocket vernier calipers with a display Fowler-Pro-max Sylvyc system with the precision of 0.01 mm.

Eggshell puncture force was measured by the measuring acquisition system which is also used for testing mechanical properties of agricultural crop products. This device for measuring egg stress by determining the shell puncture force was designed at the Laboratory for Mechatronics of the Faculty of Technical Sciences in Čačak, and it was applied at the Faculty of Agronomy in Čačak. A more detailed account of this measuring acquisition device for determining mechanical properties is given in *Božić et al. (2014)*.

The device for testing the mechanical properties of eggs consists of a stable stand, support plate, movable pressing equipment (presser), pressure probe with a diameter of 2 mm, measuring cell (force transducer) and LabVIEW software application on a computer. Egg stress is determined by measuring the eggshell puncture force by first placing the egg on the supporting plate in a horizontal position along the longer axis (along the length) perpendicular to the direction of the force.

The pusher with the probe moves slowly towards the egg and acts, on it at the short axis until the shell cracks, whereby the maximum puncture force is registered. The maximum breaking strength was measured by placing a whole, undamaged piece of eggshell between two carriers on the plate. A probe of 2 mm thickness acts on the shell until it punctures, whereby puncture force, or maximum breaking stress, is registered.

The device registers and gives data on the measured values of maximum puncture force in an Excel table and graph (Figure 1). The table also gives statistical data on the puncture force, such as minimum, maximum, mean value, coefficient of variation, and standard deviation.
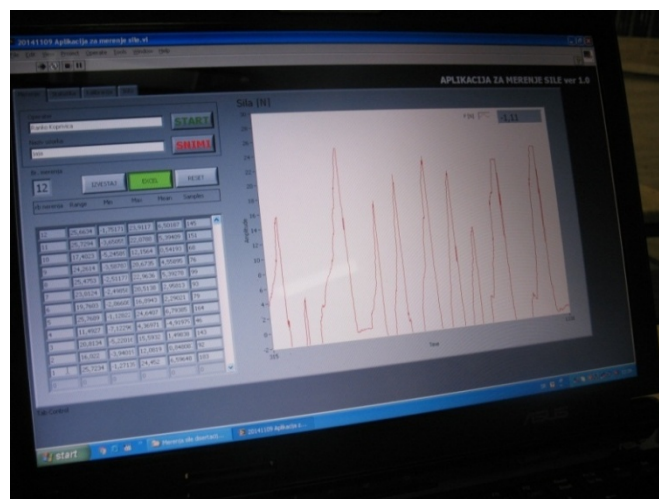

Fig. 1. The report on measuring eggshell puncture force

RESULTS AND DISCUSSION

Eggshell quality is significantly affected by laying hen rearing system, genotype, hen age, time of laying eggs and nutritive value of feed, especially the levels of protein, Ca, Mg and P in feed. Farm "Grbović" uses a complete feed mixture, the composition of which is given in Table 1. The adequate feed used at the farm provides uniform eggshell stress and fewer egg cracks, which achieves better financial results.

Main quality indicators refer to the external and internal properties of hen eggs. Table 2 shows basic external physical properties of eggs: length, width, shape index, and egg mass. The average egg length was 58.05 mm, ranging between 56.79 mm and 59.65 mm, while the average egg width was 45.46 mm, ranging between 44.88 mm and 46.89 mm. The shape index is one of the most important properties of the external egg quality because it is used to classify eggs and design the egg packaging. The optimal shape index of hen eggs is 74% since this value minimizes the possibility of eggshell cracking and egg breaking during handling. Eggs with a shape index below 72% are considered too elongated, and those above 76% are too round. According to the results, the eggs in this study are round-shaped since the average shape index was 78.25%. The study results are in agreement with *Kralik et al. (2012), Ahammed et al, (2014), Turker and Alkan (2019), Dikmen et al. (2017), Rakita et al. (2016),* and *Nedomova et al. (2009).*

Table 1. Quality of concentrated feed mix for laying hens

Chemical composition	Ratio (%)
Total protein	17.00
Moisture max	13.50
Cellulose	8.00
Ash	13.00
Calcium	3.60-4.00
Phosphorus %	0.37-0.60
Sodium %	0.15-0.20
Lysine %	0.83
Methionine + cystine %	0.60
Metabolic energy MJ	11.50

Table 2. External physical properties of eggs

Egg properties	Mean	Stan. Dev.	Min.	Max.	CV in %
Lenght (mm)	58.05	1.12	56.79	59.65	1.93
Width (mm)	45.46	0.65	44.88	46.89	1.42
Shape index (%)	78.25	1.81	75.3	79.86	2.31
Egg mass (g)	65.89	2.11	63.05	69.15	3.2

Main properties which determine the eggshell quality include shell weight, the ratio of shell in total egg mass, shell thickness and stress. The data shown in Table 3 show that the average egg mass was 65.89 g, shell mass 12.76 g, and shell thickness with membrane 0.48 mm. The ratio of shell in total egg weight found in this study (12.76%) is in agreement with *Rakonjac et al. (2017), Tumova et al. (2016),* and *Ketta and Tumova (2018).*

Table 3. Eggshell properties

Eggshell properties	Mean	Stan. Dev.	Min.	Max.	Cv in %
Shell mass (g)	8.44	0.39	7.79	8.92	4.62
Shell ratio in total egg mass (%)	12.76	0.48	12.13	13.48	3.77
Thickness with membrane (mm)	0.48	0.02	0.44	0.51	4.69
Puncture force (N)	26.34	0.25	25.82	26.55	0.95
Max. stress (N/cm²)	37.18	0.41	31.59	44.93	10.77

Eggshell stress is one of the most important indicators of egg quality. The shell has to be strong enough to resist external forces acting on it during carrying, collecting, storing, packing, and transporting table eggs to prevent cracks. Hatching eggs, however, have to have a shell of such stress that handling does not cause cracking but weak enough for the chick to easily break it with its beak while hatching. According to *Hamilton and Thompson (1986),* the stress of hatching eggshells can be determined on multiple spots using the puncture method before placing the eggs into an incubator, without any effects on the percentage of hatched eggs. The same authors reported the eggshell puncture force in the Leghorn breed to be 13.8-14.3 N, and 16.1-16.9 N in the Broiler breed.

The tested eggs showed uniform quality and shell stress since the average puncture force was found to be 26.34 N for the eggshell thickness of 0.48 mm. The low coefficient of variation (0.95%) testifies to the uniformity of the shell puncture force (25.82 N to 26.55 N). Such values of puncture force are in agreement with *Krawczyk (2009),* but lower than those reported by *Hunt et al. (1977), Voisey et al. (1978), Voisey et al. (1979),* and *Hamilton and Thompson (1986).* On the other hand, the values of breaking force by using quasi-static compression reported by *Nedomova et al. (2009)* and *Pavlovski and Vitorović (1996)* are higher than the ones given in this paper.

Breaking stress implies the ability of the eggshell to resist external forces acting on it to break it. The minimum force needed to break the eggshell arises when eggshell stress is lower than the pressure force acting on it. The results of this study showed that the average breaking stress was 37.18 N/cm², ranging from 31.59 N/cm² to 44.93 N/cm² with a 10.77% coefficient of variation. These results are in agreement with *Kralik et al. (2012), Ahamed et al. (2014),* and *Keta and Tumova (2018).* Somewhat lower values of eggshell breaking stress were reported by *Rakita et al. (2016), Dikmen et al. (2017), Turker and Alkan (2019),* and higher results were reported by *Yan et al. (2014)* and *Tumova et al. (2016).*

It can be assumed that the difference in the values of eggshell stress shown in this study and results in other studies comes from different genotypes, rearing systems, rearing conditions, hen age and feed, which is supported by *Nedomova et al. (2009)* and *Ketta and Tumova (2018)* who reported that eggshell stress is impacted by many factors, such as genotype, hen age, rearing system, feed, microstructure, thickness and ratio of eggshell, specific mass, mass, volume, surface area, and shape index.

The results of this study are important not only for constructing cages, designing the equipment for collecting and packing eggs, and designing egg packaging but also for breeding new hybrids with increased eggshell resistance to breaking.

CONCLUSION

The device for determining eggshell stress which employs the direct puncture method is very precise and provides specific data on the values of eggshell breaking force and breaking stress. The puncture method is non-invasive and does not imply cracking but only puncturing the shell, leaving the eggs usable after the test. Moreover, this method allows for repeated punctures at any position along both egg axes in order to measure the stress, which is not the case with the direct method of quasi-static compression. Additionally, the same sample can combine tests to reveal two indicators of eggshell stress: puncture force and breaking stress. The device is portable and can be utilized both in a laboratory and on farms. Finally, it can be concluded that the device is fairly easy to operate and very efficient. The results of puncture force and eggshell stress from this study are comparable with the results found in other studies. The first results of testing eggshell puncture force on this device

indicate that the research will continue on a larger scale and include different factors.

Results of this study are important for constructing cages, designing the equipment for collecting and packing eggs, as well for designing egg packaging. Finally, understanding eggshell puncture force is important in the selection of new hen breeds and hybrids with higher resistance to eggshell breaking.

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