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PHYSICAL AND MECHANICAL PROPERTIES OF HRVATICA HEN EGGS FROM FREE-RANGE RAISING AND THEIR COMPARISON WITH EGGS FROM CAGE HOUSING

FIZIKALNA I MEHANIČKA SVOJSTVA JAJA SLOBODNO DRŽANIH KOKOŠI HRVATICA I NJIHOVA USPOREDBA S JAJIMA IZ KAVEZNOG UZGOJA

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Izvorni znanstveni članak – Original scientific paper
Primljeno – Received: 25. travanj - April 2016.

SUMMARY

The aim of this study was to determine physical and mechanical properties of Hrvatica hen eggs from free-range raising and their comparison with properties of Hy-Line hybrid hen eggs from cage housing. The average values of Hrvatica hen eggs length, width, geometric mean diameter, surface area and volume were found to be 55.82 mm, 40.43 mm, 45.01 mm, 6366.42 mm^2 and 47835.20 mm^3, respectively. According to average mass of 51.01 g, Hrvatica hen eggs can be classified as small, and according to average shape index of 72.52%, can be characterised as normal or standard. In comparison with eggs from cage housing system, Hrvatica hen eggs had stronger shell, their average firmness was 20.1% higher and required in average 9.3% greater force to rupture egg.

Keywords: egg dimensions, shape index, shell strength, rupture force, egg firmness

INTRODUCTION

The physical and mechanical properties of animal and plant materials are necessary considerations in the design and effective utilization of the equipment used in the transportation, processing, packaging and storage of agricultural products, including eggs (Mohsenin, 1970.; Altuntaş and Şekeroğlu, 2010.). A chicken egg is a packaged food and an important quality aspect of the packaged egg material is the mechanical strength of the eggshell (Altuntaş and Şekeroğlu, 2008.). The eggshell is a natural packing material which can block the direct invasion of extraneous bacteria, viruses, and pathogens, reducing the likelihood of diseases caused by contaminated eggs (Nys et al., 2011.). Shell breakage for any reason during the production chain will result in downgrade of eggs as well as economic losses to commercial companies (Hunton, 2005.). For this reason, egg production, processing and packaging systems must be designed taking into consideration physical properties of eggs and their resistance to damage through mechanical shock (Altuntaş and Şekeroğlu, 2010.). Eggshell strength was been described using various variables such as eggshell thickness, stiffness and rupture force (De Ketelaere et al., 2002.). The rupture force of hen eggs depends on various factors such as breeding conditions (Lichovníková and Zeman, 2008.), the breed of hen (Máchal and Simeonovová, 2002.), diet (Lichovníková et al., 2008.),

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egg shape (Nedomová et al., 2009.) and other parameters. The physical and mechanical properties of chicken eggs have been comprehensively studied by many researches, but there are no technical information and data on the physical and mechanical properties of Hrvatica hen eggs.

Chicken breed called Hrvatica, was created in the first half of the twentieth century in the area along the river Drava in north-west Croatia by crossing domestic hens with Leghorn roosters, while the final characteristics of Hrvatica hens were obtained by crossing with the breed Wellsummer. Hrvatica hens breed are characterized by good egg production (200-220 eggs per year) and tasty meat, hens mass is 1.6-1.8 kg (Janjecic et al., 2013.). Although it was almost eradicated after World War II, now its number is increasing and Hrvatica hens are bred on small farms in almost the whole. Many consumers are prepared to pay an increased price for such a product in spite of the higher cost of production associated with the greater land area required, increased labour output per bird, higher feed consumption and poor economies of scale in grading, packaging and distribution as compared to the cage industry (Miao et al., 2005.). It is a well-known trend that some consumers prefer free-range poultry products because they think that free-range products are healthier than others (Şekeroğlu et al., 2010.). The aim of this study was to determine various physical and mechanical properties of Hrvatica hen eggs from free-range raising and compare them with the properties of commercial hybrid hen eggs from cage housing.

MATERIALS AND METHODS

In this study, eggs of Hrvatica hen and commercial hybrid Hy-Line hen were analyzed. Hrvatica hens were 38 weeks old and free range raised. In this raising method hens spent the night in a closed object, while during the day they were on the fenced meadow with 10 m^2 area per hen. Hrvatica hens were fed only maize grits, free of chemical products and medicines. The Hy-Line hybrid hens were also 38 weeks old, kept in enriched cages and fed feed mixture composition presented in Table 1. The eggs were collected during April 2015 and average air temperature and relative humidity during the egg collection period were 12.1 °C and 57%. In this study, a total sample of 150 eggs from both breeding unit was used.

Table 1. Feed mixture composition for cage housed Hy-Line hens

Tablica 1. Sastav smjese za Hy-Line kokoši iz kaveznog uzgoja

Ingredients Sastojci	Percentage (%)	Chemical composition Kemijski sastav	Percentage (%)
Maize - Kukuruz	60.17	Dry matter - Suha tvar	91.60
Soybean meal - Sojina sačma	20.48	Crude protein - Sirovi protein	17.92
Sunflower meal - Suncokret. sačma	5.00	Crude fat - Sirova mast	4.80
Wheat bran - Pšenično stoč. brašno	2.21	Crude fiber - Sirova vlakna	2.70
Shell meal - Mljevene školjke	2.00	Crude ash - Pepeo	13.30
Vegetable oil - Biljno ulje	0.50	Calcium - Kalcij	3.93
Limestone - Vapnenac	7.93	Phosphorus - Fosfor	0.46
Salt - Sol	0.24	Sodium - Natrij	0.16
Sodium chloride - Soda bikarbona	0.15		
Methionine - Metionin	0.11	ME (MJ/kg)	11.68
Monocalcium phosphate - Monokalcij fosfat	0.66		
Vitamin-mineral premix - Vitaminsko-mineralni dodatak	0.55		

ME = Metabolizable energy - Metabolička energija

Physical properties

Length (L) and width (W) of eggs were measured using an electronic digital calliper with accuracy of 0.01 mm. Eggshell thickness was measured using an electronic digital micrometer with accuracy of 0.001 mm. To evaluate the mass, eggs were separately weighed on a precision electronic balance reading to 0.01 g. The geometric mean diameter (D_g), sphericity (ϕ), surface area (S), volume (V) and shape index (SI) were calculated using the following equations:

$$D_g = (LW^2)^{1/3} \quad (1)$$

$$f = [(LW^2)^{1/3}/L] \times 100 \quad (2)$$

$$S = \varpi D_g^2 \quad (3)$$

$$V = P/6\ (LW^2) \quad (4)$$

$$SI = (W/L) \times 100 \quad (5)$$

where: L is length in mm, W is width in mm, D_g is geometric mean diameter in mm, ϕ is sphericity in %, S is surface area in mm^2, V is volume in mm^3 and SI is shape index in % (Mohsenin, 1970; Anderson et al., 2004.; Polat et al., 2007.; Altuntaş and Şekeroğlu, 2008.). For determining egg physical properties, a total sample of 150 eggs from both breeding systems was used.

Mechanical properties

A commonly used technique for the measurement of the shell strength is the compression of an egg between two plates. To measure the forces required to rupture egg, a universal testing machine schematic aisle presented in Fig. 1. was used to compress the egg. The egg sample was placed on the fixed plate, loaded at the compression speed of 0.33 mm s^{-1} and pressed with a moving plate connected to the load cell until the egg ruptured (Altuntaş and Şekeroğlu, 2008.; Nedomová et al., 2009.). The forces were measured by the data acquisition system, which included dynamometer HBM (Hottinger Baldwin Messtechnik, Darmstadt, Germany), amplifier HBM DMC 9012 A and personal computer.

Two compression axes (X and Z) of an egg were used to determine the rupture force, specific deformation, absorbed energy, firmness and toughness. The X-axis was the loading axis through the length dimension in two directions, front (force F_{xa}) and back (force F_{xb}), while the Z-axis (force F_z) was the transverse axis containing the width dimension (Fig. 2). The series of fifteen eggs was tested for each orientation and breeding unit.

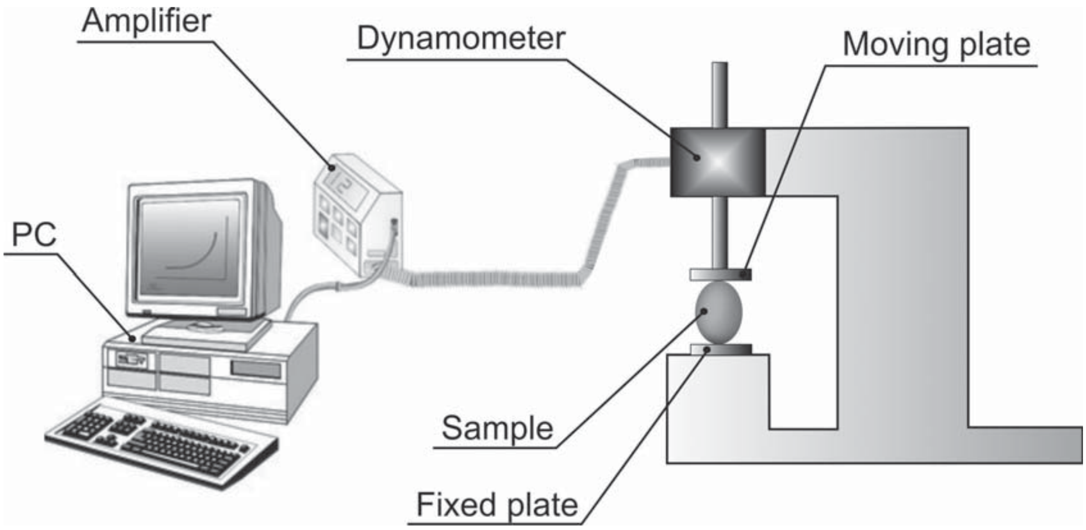

Figure 1. Schematic presentation of universal testing machine used to measure the egg rupture forces

Slika 1. Shematski prikaz uređaja za određivanje sile loma jaja

The specific deformation was obtained using the following equation:

$$\varepsilon = (1 - L_f/L) \times 100 \qquad (6)$$

where: ε is the specific deformation in %, L_f is the deformed egg length measured in the direction of the compression axis in mm and L is the undeformed egg length measured in the direction of the compression axis in mm (Braga et al., 1999.; Altuntaş and Şekeroğlu, 2008.).

Energy absorbed (E_a) by an egg at the moment of rupture was calculated using the following equation:

$$E_a = (F_r D_r)/2 \qquad (7)$$

where: E_a is the absorbed energy in Nmm, F_r is the rupture force in N and D_r is the deformation at rupture point in mm (Braga et al., 1999; Altuntaş and Şekeroğlu, 2008.).

Firmness (Q) is regarded as a ratio of compressive force to deformation at the rupture point of egg and was obtained using the following equation:

$$Q = F_r/D_r \qquad (8)$$

where: Q is the firmness in N mm^{-1}, F_r is the rupture force in N and D_r is the deformation at rupture point in mm (Olaniyan and Oje, 2002; Altuntaş and Şekeroğlu, 2008.).

The obtained data were analysed applying the analysis of variance and the LSD test was used to compare the mean results. The differences were considered as significant if $P<0.05$.

RESULTS AND DISCUSSION

The physical properties of the Hrvatica hen eggs from free range raising and Hy-Line hen eggs from cage housing are presented in Table 2. According to mean dimensional properties, Hrvatica hen eggs were 8.8% shorter, 12.7% narrower and had 11.4% lower geometric mean diameter, 24.0% lower surface area and 38.0% lower volume than Hy-Line hen eggs from cage housing. According to mean mass value, Hrvatica hen eggs were 37.4% lighter than Hy-Line hen eggs from cage housing. Hrvatica hen eggs from free range raising were also smaller and lighter than Barred Plymouth Rock, White Leghorn, Rhode Island Red, White Rock (Monira et al., 2003.), Lohmann (Altuntaş and Şekeroğlu, 2008.) and Hisex Brown (Trnka et al., 2012.) hen eggs from cage housing. As the average mass of Hrvatica hen eggs was below 53 g, these eggs can be classified as small, according to EU classification (European Union, 2008). The average mass of Hy-Line hen eggs was between 63 and 73 g, and these eggs can be classified as large. One reason for such a differ-

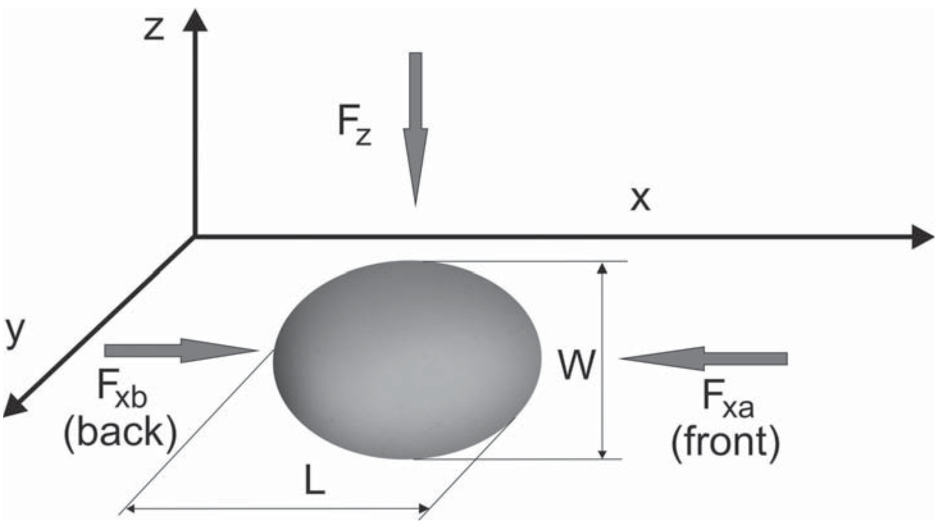

Figure 2. Characteristic dimensions of eggs and compression directions; length (L), width (W) and forces applied in three directions (F_{xa}, F_{xb}, F_z)

Slika 2. Karakteristične dimenzije jaja; duljina (L), širina (W) i smjerovi djelovanja sila (F_{xa}, F_{xb}, F_z)

ence in egg mass was for sure that Hy-Line hens were fed commercial feed mixture presented in Table 2, while Hrvatica hens were fed only with maize grits. Although organic eggs from free-range raising are much lighter in comparison with eggs from cage housing, they achieve higher price and many consumers are prepared to pay this price. According to egg sphericity, there was no significant difference between eggs from free range raising and cage housing.

Eggs are available in different shapes and can be characterised using a shape index (SI) as sharp, normal (standard) and round if they have an SI value of <72, between 72 and 76, and >76, respectively (Sarica and Erensayin, 2004.). As the Hrvatica hen eggs from free-range raising have SI 72.52%, their shape can be characterised as normal or standard, just like the Hy-Line hen eggs from cage housing with SI 75.06% and at this difference was not significant. According to Harms et al. (1990.), egg size and the eggshell thickness are strongly positively correlated to each other and this is confirmed by the results in this study. Mean shell thickness of Hrvatica hen eggs was 12.4% lower than Hy-Line hen eggs. De Ketelaere et al. (2002.), Monira et al. (2003.) and Altuntaş and Şekeroğlu (2008.) observed egg shell thickness of cage housed hen eggs in range from 0.310 mm to 0.363 mm. Hy-Line hen eggs, despite the difference in size and weight are selected for comparison because of the similarity in other physical parameters such as sphericity and shape index. Egg properties such as shape index and shell thickness affect the proportion of damaged eggs during handling and transport (Altuntaş and Şekeroğlu, 2010.).

Average values of mechanical properties measured in this study are presented in Table 3. The highest forces required to rupture eggs from both breeding systems were determined in loading along the *X*-front axis and the lowest forces were determined along the *Z*-axis. The average force required to rupture Hrvatica hen eggs in all three axes was 38.76 N, which was 9.3% higher than average force required to rupture Hy-Line hen eggs in all three axes. The average rupture force for cage housed hen eggs has been reported to range 30.9-37.8 N (De Ketelaere et al., 2002.), 33.4-35.3 N (Pavlovski et al., 2003.), 30.4-36.3 N (Trnka et al., 2012.) and 27.3-29.4 N (Altuntaş and Şekeroğlu, 2008.). So, in comparison to cage housed hen eggs, Hrvatica hen eggs from free range raising tested in this study had higher shell strength and required greater force to rupture on egg. This result might be explained by the low average size observed for the Hrvatica hen eggs in comparison with cage housed hen eggs. Indirect correlation between egg weight and shell breaking strength was also reported by Casiraghi et al. (2005.).

Table 2 Physical properties of hrvatica hen eggs from free-range raising and eggs from cage housing

Tablica 2. Fizikalna svojstva jaja slobodno držanih kokoši hrvatica i jaja kokoši iz kaveznog uzgoja

Physical properties Fizikalna svojstva	Hrvatica hen eggs		Hy-Line hen eggs	
	Mean	S_d	Mean	S_d
Length - Duljina (mm)	55.82^a	2.35	60.74^b	2.01
Width - Širina (mm)	40.43^a	1.23	45.56^b	1.02
G.m. diameter - S.g. promjer (mm)	45.01^a	1.29	50.13^b	1.05
Mass - Masa (g)	51.01^a	3.99	70.06^b	4.49
Sphericity - Sferičnost (%)	80.71^a	2.27	82.58^a	1.85
Surface area - Površina (mm^2)	6366.42^a	363.33	7895.50^b	329.39
Volume - Volumen (mm^3)	47835.20^a	4080.35	66028.44^b	4132.88
Shape index - Indeks oblika (%)	72.52^a	3.08	75.06^a	2.52
Shell thickness - Debljina ljuske (mm)	0.331^a	0.024	0.372^b	0.025

Mean = mean value; S_d = standard deviation; G.m. = geometric mean; S.g. = srednji geometrijski
Mean values followed by the different letter are significantly different ($P < 0.05$)
Srednje vrijednosti označene različitim slovima su signifikantno različite ($P < 0.05$)

The deformation values expressed in mm and specific deformation values expressed in percentage for Hrvatica hen eggs from free range raising as well as for eggs from cage housing were significantly higher when eggs were compressed along the *Z*-axis than if compressed along both *X*-axes. The same relation was also observed by Altuntaş and Şekeroğlu (2008.). The average deformation in all three axes during the compression of Hrvatica hen eggs was 10.0% lower than average deformation of Hy-Line hen eggs, while the average specific deformation was 5.0% lower on Hrvatica hen eggs.

The absorbed energy was determined as a function of rupture force and deformation on the surface of egg. The highest absorbed energy was determined in loading along the *Z*-axis, while the least energy was determined along the *X*-front in both breeding systems. So, loading along the *X*-front axis required the least amount of absorbed energy to rupture the egg shell. The differences in absorbed energy between tested eggs from two systems were not significant. Similar values of absorbed energy were observed by Altuntaş and Şekeroğlu (2008.) for Lohmann hen eggs, while greater values were observed by Nedomová et al. (2009.) for Hisex Brown hen eggs and Polat et al. (2007.) for Japanese quail eggs.

The average firmness of Hrvatica hen eggs in all three axes was 20.1% higher than average firmness of Hy-Line hen eggs.Thereby, the firmness values determined along the *Z*-axis were significantly lower than those determined along both *X*-axes of eggs from both breeding systems. This indicated that the lowest force was required to rupture eggs along the *Z*-axis. The firmness values for eggs compressed along *X*-front axis were significantly higher than along *X*-back axis of eggs from both breeding systems. Same relation, but with lower values, was observed by Altuntaş and Şekeroğlu (2008.) for Lohmann hen eggs from cage housing, while higher values were observed by Nedomová et al. (2009.) for Hisex Brown hen eggs.

Table 3 Mechanical properties of Hrvatica hen eggs from free-range raising and eggs from cage housing

Tablica 3. Mehanička svojstva jaja slobodno držanih kokoši hrvatica i jaja kokoši iz kaveznog uzgoja

Mechanical properties Mehanička svojstva	Direction Smjer	Hrvatica hen eggs		Hy-Line hen eggs	
		Mean	S_d	Mean	S_d
Rupture force	*X*-front	42.02[a]	6.24	38.83[b]	3.71
Sila razbijanja	*X*-back	38.97[a]	4.75	35.31[b]	6.31
(N)	*Z*	35.29[a]	4.63	32.28[b]	6.41
Deformation	*X*-front	0.16[a]	0.03	0.18[b]	0.04
Deformacija	*X*-back	0.19[a]	0.04	0.21[b]	0.04
(mm)	*Z*	0.25[a]	0.04	0.28[b]	0.03
Spec. deformation	*X*-front	0.28[a]	0.05	0.29[a]	0.06
Spec. deformacija	*X*-back	0.34[a]	0.07	0.35[a]	0.07
(%)	*Z*	0.57[a]	0.09	0.61[b]	0.08
Absorbed energy	*X*-front	3.34[a]	0.65	3.44[a]	0.94
Absorbirana energija	*X*-back	3.69[a]	0.55	3.77[a]	1.08
(Nmm)	*Z*	4.36[a]	1.11	4.49[a]	1.17
Firmness	*X*-front	270.48[a]	58.11	231.08[b]	54.55
Čvrstoća	*X*-back	211.20[a]	52.34	170.90[b]	39.10
($N\ mm^{-1}$)	*Z*	146.52[a]	24.98	117.42[b]	24.28

Mean = mean value; S_d = standard deviation
Mean values followed by the different letter are significantly different ($P < 0.05$)
Srednje vrijednosti označene različitim slovima su signifikantno različite ($P < 0.05$)

CONCLUSION

Hy-Line hen eggs, despite the difference in size and weight are selected for comparison because of the similarity in other physical parameters such as sphericity and shape index, which have a significant effect on the mechanical properties of eggs, ie. the behaviour under the influence of external forces. Based on the obtained mechanical properties, Hrvatica hen eggs had stronger shell, higher firmness and required greater force to rupture egg than eggs from cage housing. Results also suggest that the values of rupture force and other mechanical properties (deformation, absorbed energy and firmness) depend on the direction of the loading force during egg compression.

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SAŽETAK

Cilj ovog istraživanja bio je utvrditi fizikalna i mehanička svojstva jaja slobodno držanih kokoši hrvatica i njihova usporedba sa svojstvima jaja Hy-Line hibrida iz kaveznog uzgoja. Jaja kokoši hrvatica su bila u prosjeku 8,8% kraća, 12,7% uža i imala su 11,4% manji srednji geometrijski promjer, 24,0% manju površinu, 38,0% manji volumen i 12,4% manju debljinu ljuske u odnosu na jaja iz kaveznog uzgoja. Prosječna masa jaja kokoši hrvatica bila je 51,01 gr, što je 37,4% manje nego masa jaja iz kaveznog uzgoja. S obzirom na utvrđeni indeks oblika od 72,52%, oblik jaja kokoši hrvatica može se okarakterizirati kao normalan odnosno standardan. U odnosu na jaja iz kaveza stambenih sustava, jaja kokoši hrvatica su imala jaču ljusku, njihova prosječna čvrstoća bila je 20,1% veća i potrebna je u prosjeku 9,3% veća sila za razbijanje jaja.

Ključne riječi: dimenzije jaja, indeks oblika, čvrstoća ljuske, sila razbijanja, čvrstoća jaja