The Influence of Two Housing Systems on the Physical and Mechanical Properties of ISA Brown Hen Eggs

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Summary

The aim of this study was to compare various physical and mechanical characteristics of eggs laid by ISA Brown hens kept in two different housing systems: aviary housing and free-range system. Aviary housed laying hens laid eggs of statistically significantly higher ($P<0.05$) weight than laying hens kept in free range system (68.03 g vs. 62.38 g). Eggs from laying hens kept in aviaries had higher shape index and shell thickness (78.17% and 0.436 mm) than eggs obtained from free range laying hens (74.57% and 0.396 mm). Eggs from free range laying hens had significantly higher yolk percentage and yolk to albumen ratio (26.80% and 0.446) than eggs from aviary system (24.89% and 0.399). In comparison to eggs from free range system, eggs from aviary housing had higher shell strength and required greater force to rupture egg. The average force required to rupture eggs from aviary housing and free-range system in all three axes was 38.11 N and 36.28 N, respectively.

Key words

egg composition, dimensions, weight, shape index, rupture force

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Introduction

Eggs are a high quality, easily available and favourable food product present in the diet of people all around the world. Egg products are also functional ingredients of primary importance for many food formulations. The physical and morphological characteristics such as dimensions, weight, shape and composition influence egg quality and grading. The major egg components are yolk, albumen and shell, and the most important trait of egg composition, linked to egg dry matter, is the yolk to albumen ratio (Harms and Hussein, 1993; Gutierrez et al., 1996; Hartman et al., 2003). The results of some studies showed that eggs with the heaviest yolks and the highest yolk to albumen (Y:A) ratios contain the higher amount of cholesterol (Hussein et al., 1993; Campo, 1995). Considering that possibility, eggs containing a small proportion of yolk and a large proportion of albumen would appear to be suitable for egg consumers. On the contrary, eggs containing a large proportion of yolk should be more desirable for processed foods such as mayonnaise, which utilize the yolk as a major ingredient (Suk and Park, 2001). The yolk proportion is important for egg processing industry as it is linked to higher dry matter content and to a higher content of essential fatty acids (Benabdeljelil and Merat, 1995).

The various physical characteristics such as dimensions, volume, sphericity and others affect the mechanical characteristics of eggs. Egg shell strength is necessary to prevent damage from handling and to preserve eggs during transport from farm to market (Altuntas and Sekeroglu, 2010). Broken eggs cause economic damage in two ways: they cannot be sold as first-quality eggs, and the occurrence of hair cracks raises the risk for bacterial contamination of the broken egg and of other eggs when leaking, creating problems with internal and external quality and food safety (Mertens et al., 2006). Egg resistance to damage through mechanical shock can be characterized by measures such as rupture force, specific deformation, absorbed energy and firmness (Abdallah et al., 1993; Altuntas and Sekeroglu, 2008). The rupture force of hen eggs depends on various factors such as breeding conditions (Lichovnikova and Zeman, 2008), the breed of hen (Machal and Simenonova, 2002), diet (Lichovnikova et al., 2008), egg shape (Nedomova et al., 2009), and other parameters. The physical and mechanical characteristics of chicken eggs have been studied in the literature by several researches and the strongest correlation was found between these characteristics (De Ketelaere et al., 2002; Narushin et al., 2004).

The housing of laying hens is permitted only in enriched cages or in alternative systems, such as litter housings, aviary or free range, to improve the welfare of the hens (Englmaierova et al., 2014) and reasons for this were mainly focused on animal welfare issues (Fiks-Van Niekerk, 2005). These systems influence, directly and indirectly, not only the behaviour, productivity and health of hens, but also the quality of their eggs (Tauson, 2005). Consumers are becoming more and more aware of farmed animal welfare, considering it as a major factor affecting food quality and safety (Alamprese et al., 2011). Consumers believe that eggs laid by hens keeping in one of alternative housing systems were bigger and better if compared with eggs of laying hens kept in cages (Kralik et al., 2013).

Because alternative systems have become more important, the effect of these systems on egg quality characteristics needs to be determined. Thus, the objective of this study was to determine the influence of two alternative housing systems, aviary housing and free-range system on the physical and mechanical characteristics of ISA Brown hen eggs.

Material and methods

Eggs were collected from two farms with different housing systems located near Bjelovar, small town 80 km north-east from Zagreb, Croatia (latitude 45° 54’ N, longitude 16° 50’ E) during April 2017. Pullets of ISA Brown breed were reared to 16 weeks of age in the litter confinement system according to the technological recommendations. At 16 weeks, 600 hens were divided into two experimental groups (300 per group) and placed in different housing systems. Hens from first experimental group were kept in aviary housing system that was equipped with three central tiers. The hens had no access to the floor under the lowest tier. Family nest boxes in one tier with an artificial turf floor were attached on the walls of the room opposite the aviary tiers. The floor was covered with litter (chopped straw) which removal was not carried out before the hens were removed from the aviary. The lighting schedule in aviary housing matched the duration of daylight for the hens in the outdoor free-range system. Installed power density of lighting system (neon tubes) in aviary housing was 3.0 W/m^2. Hens from second experimental group were kept in free range system and spend the night in a closed object, while during the day they are on the fenced meadow with 10 m^2 area per hen. Nests were located in a relatively dark area and covering with chopped straw. Hens from both experimental groups were fed *ad libitum* with a same commercial feed for laying hens. The composition of feed mixture is presented in Table 1. Hens from free range system were able to supplement their diets using vegetation (various grasses and herbs) and small fauna (grubs, larvae, etc.).

Table 1. Feed mixture composition for ISA Brown laying hens, nutrient values and metabolizable energy (ME)

Ingredients	Percentage (%)	Calculated nutrients	Percentage (%)
Maize	60.17	Dry matter	91.60
Soybean meal	20.48	Crude protein	17.92
Sunflower meal	5.00	Crude fat	4.80
Wheat bran	2.21	Crude fibre	2.70
Shell meal	2.00	Crude ash	13.30
Vegetable oil	0.50	Calcium	3.93
Limestone	7.93	Phosphorus	0.46
Salt	0.24	Natrium	0.16
Sodium chloride	0.15	ME (MJ/kg)	11.68
Monocalcium phosphate	0.66		
Methionine	0.11		
Vitamin-mineral premix	0.55		

Seventy-five eggs were randomly chosen from each experimental group during the 36th week of age. The eggs were gathered between 10 and 11 a.m. and were kept at room temperature overnight for the next day evaluation.

Physical characteristics

Firstly, a total sample of 150 eggs, 75 from each housing system, was used for the determination of following physical characteristics. Length (L) and width (W) of eggs were measured using an electronic digital calliper with accuracy of 0.01 mm. The geometric mean diameter (D_g), sphericity (ϕ), surface area (S), volume (V) and shape index (SI) were calculated using the following equations:

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

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

$S = \pi D^2_g$ (3)

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

$SI = (W/L) \times 100$ (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; Altuntas and Sekeroglu, 2008).

To evaluate the egg weight, eggs were weighed on a precision electronic balance reading to 0.01 g. After measuring the rupture forces, the egg yolks were separated from the albumen. The chalazae were carefully removed from the yolk using forceps and all yolks were rolled several times on a paper towel to remove adhering albumen before weighing. The shells were carefully washed to remove albumen and dried at 21°C for 48 h before weighing. Albumen weight was determined by subtracting yolk and dry shell weights from the total egg weight. Using the individual weight of each egg and its components, yolk percentage (yolk weight/egg weight x 100), albumen percentage (albumen weight/egg weight x 100), shell percentage (shell weight/egg weight x 100) and yolk to albumen ratio (yolk weight/albumen weight) were calculated. Egg shell thickness was measured after removing the internal membranes of the shell using an electronic digital micrometer with accuracy of 0.001 mm. Measurements were taken at three egg regions (middle and two ends) and then averaged.

Mechanical characteristics

A commonly used technique for the measurement of the shell strength is the compression of an egg between two parallel steel plates (De Ketelaere et al., 2002; Altuntas and Sekeroglu, 2010). To measure the forces required to rupture egg, a universal testing machine was used to compress the egg (Fig. 1). 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 (Altuntas and Sekeroglu, 2008). 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.

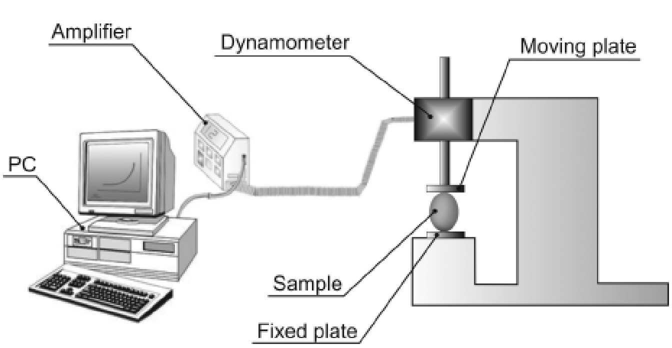

Figure 1. Schematic presentation of universal testing machine used to measure the rupture forces

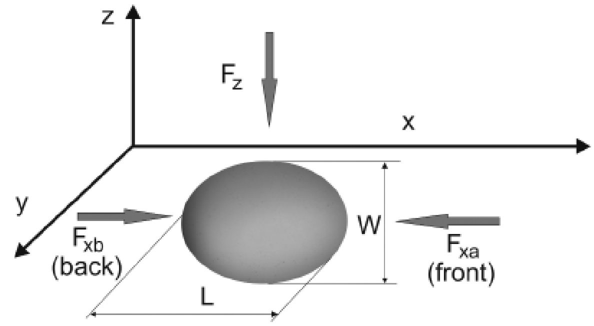

Figure 2. Characteristic dimensions of eggs and compression directions; length (L), width (W) and forces applied in three directions (F_{xa}, F_{xb}, F_z)

Two compression axes (X and Z) of an egg were used to determine the rupture force, specific deformation, absorbed energy and firmness. The X-axis was the loading axis through the length dimension in two directions, front (eggs loaded at the sharp end - force F_{xa}) and back (eggs loaded at the blunt end - force F_{xb}), while the Z-axis (force F_z) was the transverse axis containing the width dimension (Fig. 2). After determining the external physical properties 75 eggs from each housing system were divided into three subgroups and in each subgroup of 25 eggs mechanical properties in particular direction (F_{xa}, F_{xb}, F_z) were determined.

The specific deformation was obtained using the following equation:

$\mathcal{E} = (1 - L_f/L) \times 100$ (6)

where: $\mathcal{E}$ 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 (Polat et al., 2007; Altuntas and Sekeroglu, 2008).

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

$E_a = (F_r\, D_r)/2$ (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 (Polat et al., 2007; Altuntas and Sekeroglu, 2008). Deformation of the egg shell at rupture point was measured by displacement sensor HBM WA/100. The rupture point is indicated by the maximum load force before the crack of the shell.

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:

$Q = F_r/D_r$ (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 (Altuntas and Sekeroglu, 2008).

Statistical analysis

Statistical data analysis was done with the SAS software (SAS Institute, 2004). The results were expressed as mean value ± standard deviation (SD) of seventy-five measurements for physical and mechanical egg characteristics from two housing systems and twenty-five measurements for each egg compression direction and housing system. The significance of differences between the values of observed parameters was assessed by analysis of variance (ANOVA). The Fisher's least significant difference (LSD) test was used to compare the means and differences were considered as significant at the level of probability $p < 0.05$.

Results and discussion

Physical characteristics

The physical characteristics of the ISA Brown hen eggs from two different housing systems are presented in Table 2. According to average egg dimensions, no statistically significant differences (p<0.05) were observed in length, width and geometric mean diameter of eggs from aviary housing and free-range system, while significant higher values for egg surface area and volume were observed on the eggs from aviary housing. Eggs from aviary housing were shorter and wider which had the most impact on egg shape index. According to egg sphericity, there was no significant difference between eggs from aviary housing and free-range system, but higher sphericity was observed in eggs from aviary 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 shown in the Table 2, there was statistically significant difference (P<0.05) in egg shape index of the ISA Brown hen eggs from two housing system. Eggs from aviary housing had SI 78.69% and its shape can be characterised as round, while eggs from free range system according to SI 73.92% can be characterised as normal or standard. The shape index of eggs from aviary housing was higher than shape index of eggs from ISA Brown laying hens kept in cages (75.29%) and two free range systems (74.90%) reported by Djukic-Stojcic et al. (2009). Egg shape is an important indicator in egg evaluation from an economic point of view, because the more regular elliptical shape the egg has, the less loss is expected in transport (Kralik et al., 2013).

Statistically significant difference (P<0.05) between eggs from aviary housing and free-range system was also observed in egg shell thickness. The shell of eggs from aviary housing was in average 8.2% thicker than shall of free ranged hen eggs. The contrasting results can be found in literature according to influence of housing system on shell thickness. Comparing aviary (barn), free range and cage systems, Pavlovski et al. (2001) detected thicker shells in aviary eggs and thinner shells in free range eggs, while Leyendecker et al. (2001) observed thicker shells in free range. According to Harms et al. (1990) and Casiraghi et al. (2005), the egg size and egg shell thickness are strongly related to each other, which is corresponding to results observed in this study. The average shell thickness of eggs from both housing systems observed in this study were thicker than cage housed hen eggs shell thickness reported to range 0.310-0.350 mm (Monira et al., 2003) and 0.344-0.351 mm (Altuntas and Sekeroglu, 2008), but thinner than average egg shell thickness of ISA Brown hens from free range system (0.468 mm) reported by Angelovicova et al. (2014). According to Altuntas and Sekeroglu (2010), egg properties such as shape index and shell thickness affect the proportion of damaged eggs during handling and transport.

The total weight and composition of the ISA Brown hen eggs from two different housing systems are presented in Table 3. According to EU classification, eggs are classified into four weight classes: XL eggs weighing 73 g and more, L eggs weighing from 63 g to 73 g, M eggs weighing from 53 g to 63 g and S eggs weighing less than 53 g (European Union, 2008). In this study, significantly heavier eggs were from aviary housing system (68.03 g) and these eggs belong to weight class L, while eggs from free range system (62.38 g) belong to weight class M. The average weight values of eggs from both housing systems observed in this study were higher than average weight of eggs laid by ISA Brown hens kept in cages 60.63 g and deep litter 62.02 g reported by Pistekova et al. (2006). The average weight of eggs from free range system observed in this study was lower in comparison to average weight of 64.75 g and 65.25 g of eggs laid by ISA Brown hens kept in two free range systems reported by Djukic-Stojcic et al. (2009). It is difficult to compare the characteristics of eggs from different experiments, even if the same commercial laying strain was used in these experiments. In addition to the genotype of the hens, many other factors, such as the age of hens, nutrition, microclimate, lighting program and weight of hens influence the weight of an egg.

Table 2. Physical characteristics of eggs from two different housing systems

	Aviary	Free range
Length (mm)*	58.38±1.75a	59.18±1.57a
Width (mm)	45.79±1.07a	43.71±1.44a
Geometric mean diameter (mm)	49.65±1.04a	48.34±1.03a
Surface area (mm^2)	7,743.49±325.82a	7,341.36±316.39b
Volume (mm^3)	64,131.44±4,055.67a	59,202.78±3,886.42b
Sphericity (%)	85.08±1.80a	81.73±2.55a
Shape index (%)	78.69±2.57a	73.92±3.51b
Shell thickness (mm)	0.38±0.02a	0.35±0.02b

*Mean ± standard deviation; means followed by the different letter within the same row are statistically different (p<0.05).

Table 3. Total weight and composition of eggs from two different housing systems

	Aviary	Free range
Egg weight (g) *	68.03±3.63a	62.38±1.72b
Albumen weight (g)	42.66±3.52a	37.70±2.53b
Albumen percentage (%)	62.64±2.35a	60.39±2.94a
Yolk weight (g)	16.89±1.22a	16.70±1.53a
Yolk percentage (%)	24.89±2.04b	26.80±2.56a
Shell weight (g)	8.58±0.63a	7.98±0.93b
Shell percentage (%)	12.62±0.91a	12.81±1.57a
Y:A ratio	0.40±0.05b	0.45±0.06a

*Mean ± standard deviation; means followed by the different letter within the same row are statistically different (p<0.05).

In accordance with the results obtained in this study on total egg weight, albumen weights were also significantly higher (42.66 g vs 37.70 g) on eggs from aviary housing. The positive correlation between total egg weight and albumen weight has been also reported by Hartmann et al. (2003), Suk and Park (2001) and Laxmi (2006).

No statistical difference of yolk weight was observed between the eggs from aviary housing (16.89 g) and from free range system (16.70 g). The significantly heavier egg shell was observed on eggs laid by aviary housed hens (8.58 g) then free-range hens (7.98 g). These results show positive correlation between shell weight and total egg weight and this is in accordance with the results of Suk

Table 4. Mechanical characteristics of eggs from two different housing systems

	Direction	Aviary	Free range
Rupture force (N) *	*X*-front	42.17±4.42a	40.46±4.87a
	X-back	38.35±4.60a	36.74±3.81a
	Z	33.81±3.65a	31.65±3.01b
Spec. deformation (%)	*X*-front	0.31±0.08a	0.29±0.05b
	X-back	0.34±0.07a	0.31±0.07b
	Z	0.46±0.09a	0.43±0.08b
Absorbed energy (N mm)	*X*-front	3.95±1.17a	3.48±0.73b
	X-back	3.85±1.22a	3.32±0.81b
	Z	3.50±0.56a	2.90±0.49b
Firmness (N mm^{-1})	*X*-front	242.03±74.36a	243.50±61.40a
	X-back	200.84±43.17b	215.30±69.46a
	Z	166.59±36.74b	178.68±43.63a

*Mean ± standard deviation; means followed by the different letter within the same row are statistically different (p<0.05).

and Park (2001) who reported higher total weight and heavier shells on eggs from ISA Brown breed compared to Korean local breed. On the contrary, Harms and Hussein (1993) observed no relation existed between shell weight and total egg weight. In this study there were no significant differences in albumen and shell percentage of total egg weight between two housing systems, but the significant difference was observed at yolk percentage. The yolk percentage was significantly higher on eggs from free range system (26.80%) than on eggs from aviary housing (24.89%).

The yolk to albumen (Y:A) ratio was also significantly higher on eggs from free range system, which is in average 11.8% higher in comparison to eggs from aviary housing. This is in accordance with Ahn et al. (1997) and Dottavio et al. (2005), who found that smaller eggs had higher Y:A ratios than larger eggs.

Mechanical characteristics

Average values of egg mechanical characteristics measured in this study are presented in Table 4. The average force required to rupture ISA Brown hen eggs from aviary housing in all three axes was 38.11 N, which was 5.0% higher than average force required to rupture eggs from free range system in all three axes (36.28 N). The average forces required to rupture eggs from both housing systems observed in this study were higher than cage housed hen eggs 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 (Altuntas and Sekeroglu, 2008). So, in comparison to cage housed hen eggs, ISA Brown hen eggs from two alternative housing systems tested in this study had higher shell strength and required greater force to egg rupture. Angelovicova et al. (2014) also reported higher shell strength of eggs from free range system (39.18 N) than shell strength of eggs from cage system (38.18 N). The highest forces required to rupture eggs from both housing systems were determined in loading along the *X*-front axis and the lowest forces were determined along the *Z*-axis. These relations are corresponding to those of Altuntas and Sekeroglu (2008) for Lohmann hen eggs with shape index 72-76% and higher than 76%, which was similar shape indexes of eggs tested in this study.

The average specific deformation during egg compression in all three axes was 8.8% lower on eggs from free range system. The specific deformation values for eggs compressed along the *Z*-axis were significantly higher than for those compressed along *X*-axes in both housing systems. The same relation was also observed by Altuntas and Sekeroglu (2008) with something higher average values (0.36-0.59%) for Lohmann hen eggs.

The absorbed energy was determined as a function of rupture force and deformation on the egg surface. The average absorbed energy in all three axes was 16.7% higher for eggs from aviary housing than for eggs from free range system. The highest absorbed energy was determined in loading along the *X*-front axis, while the least energy was determined along the *Z*-axis for eggs from both housing systems. So, loading along the *Z*-axis required the least amount of energy to rupture the egg shell. Similar values of absorbed energy (3.11-3.71 N mm) were reported for Lohmann hen eggs by Altuntas and Sekeroglu (2008), while something greater values were observed for Hisex Brown hen eggs (2.80-5.10 N mm) by Nedomova et al. (2009) and (2.26-6.13 N mm) by Trnka et al. (2012).

The average firmness in all three axes of eggs from free range system was 4.6% higher than average firmness of eggs from aviary housing. The firmness values determined along the *Z*-axis were significantly lower than those determined along *X*-axes on eggs from both housing systems. This indicated that the lowest force was required to rupture eggs along the *Z*-axis. Same relation, but with less values (111.05-140.52 N mm^{-1}) was reported by Altuntas and Sekeroglu (2008) for Lohmann hen eggs. Similar average values of firmness as in this study (158.59-269.90 N mm^{-1}) were reported by Nedomova et al. (2009) for Hisex Brown hen eggs.

Many authors discussed influence of laying hens housing system on egg quality characteristics and most of them concluded that the system had an impact on egg quality characteristics. Mertens et al. (2006) stated that laying hens housing system had an impact on the quality of egg shell and reported in their results that shell strength of eggs produced in cages was higher than of eggs produced by free range laying hens. Lewko and Gornowicz (2011) also concluded that egg quality characteristics significantly depend on the housing system for laying hens.

Conclusion

Based on the obtained results in this study, it can be concluded that housing system of laying hens had significant influence on egg quality characteristics. Statistically significant difference (P<0.05) between ISA Brown hen eggs from aviary housing and free-range system was observed in egg weight, shape index and shell thickness. Eggs from aviary housing were significantly heavier and had significantly thicker egg shell. The eggs from free range system had significantly higher yolk percentage and yolk to albumen ratio. According to obtained mechanical properties, eggs from aviary housing had stronger shell and required greater force to rupture egg than eggs from free range system. The average value of rupture force (*Fr*) on the major (*X*) axis is considerably larger than that on the minor (*Z*) axis. This indicates that an upright position along the major axis is more effective than a horizontal position for reducing egg shell damage during handling and transport.

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acs83_51