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Influence of housing system on the physical, morphological, and mechanical properties of Japanese quail eggs

Utjecaj sustava držanja na fizikalna, morfološka i mehanička svojstva jaja japanskih prepelica

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ABSTRACT

The objective of this study was to determine the influence of housing system on the physical, morphological, and mechanical properties of Japanese quail (*Coturnix coturnix japonica*) eggs. A total of 240 eggs were collected from Japanese quails kept in two different housing systems: cage housing and aviary housing system (120 eggs from each housing system). Eggs from cage housing system were significantly (P<0.05) heavier than eggs from aviary housing system (11.85 g vs. 10.93 g), and were also longer, wider and had significantly (P<0.05) larger geometric mean diameter, surface area and volume. No statistically significant difference in albumen and yolk content was observed between eggs from cage and aviary housing system. Eggs from aviary housing system had significantly higher shell content and shell strength and required greater force to eggshell breaking. The average force required to breaking the shell of Japanese quail eggs from cage and aviary housing system in all three axes was 14.36 N and 12.70 N, respectively.

Keywords: egg dimensions, egg weight, shape index, components proportion, breaking force

SAŽETAK

Cilj ovog rada bio je utvrditi utjecaj sustava držanja na fizikalna, morfološka i mehanička svojstva jaja japanskih prepelica (*Coturnix coturnix japonica*). Ukupno je prikupljeno 240 jaja japanskih prepelica koje su držane u dva različita sustava držanja: u kaveznom sustavu i u sustavu volijera (120 jaja iz svakog sustava). Jaja iz kaveznog sustava bila su značajno (P<0,05) teža od jaja iz sustava volijera (11,85 g nasuprot 10,93 g), a također su bila duža, šira i imala su značajno veći (P<0,05) srednji geometrijski promjer, površinu i volumen. Nije primijećena statistički značajna razlika u sadržaju bjelanjka i žumanjka između jaja iz kaveznog sustava i sustava volijera. Jaja iz sustava volijera imala su značajno veći sadržaj ljuske i čvrstoću ljuske te su zahtijevala veću silu za razbijanje ljuske jajeta. Prosječna sila potrebna za razbijanje ljuske jaja japanskih prepelica iz kaveznog sustava i sustava volijera u sve tri osi iznosila je 14.36 N odnosno 12.70 N.

Ključne riječi: dimenzije jaja, masa jaja, indeks oblika, udio komponenata, sila razbijanja

INTRODUCTION

Japanese quail (*Coturnix coturnix japonica*) belongs to the order Galliformes and the family Phasianidae and is known to have been domesticated since the 12th century AD in Japan, mainly for its ability to sing. Intensive production of the species started in Japan in the 1920s, and the first egg lines were then developed by selection (Wakasugi, 1984). They were successfully introduced from Japan to America, Europe and the Near and Middle East between the 1930s and 1950s, where specific lines were bred for egg and meat production (Minvielle, 2004). Currently, Japanese quails are farmed for meat and eggs in many parts of the world and the most significant producers of Japanese quail eggs are China, Japan, Brazil and France (Ondrusikova et al., 2018).

In many countries, among all products of intensive poultry farming, Japanese quail meat and eggs convey the image of natural and festive food. This positive image could be preserved or even further developed (Minvielle, 2004). The Japanese quail breeding does not have a long tradition in Croatia, but in recent years the interest for breeding these small birds has increased due to the growing interest in consuming healthy food. Today there are only a few large producers of Japanese quail eggs in Croatia that sell eggs through retail chains, but an increasing number of family farms started breeding Japanese quail for their own needs and they sell surplus eggs directly to consumers. According to Jatoi et al. (2015), Japanese quail breeding at small-scale household level has the potential to provide an alternative source of animal protein and an additional source of household income. Other reasons for the growing interest for Japanese quail breeding are their easy maintenance, early sexual maturity, shorter generation interval, and high rate of egg production (Dukic Stojcic et al., 2012). Also, Japanese quails are inexpensive to breed and have a high immunity against common poultry diseases (Mohammed et al., 2019).

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). In many countries all over the world, especially in countries of the European Union, consumers have shown interest to buy eggs produced in alternative systems of keeping laying hens such as litter housings, aviary, or free range, to improve the welfare of hens (Englmaierova et al., 2014). These systems influence, directly and indirectly, not only the behaviour, productivity, and health of hens, but also the quality of their eggs (Tauson, 2005). The major differences between furnished cages and alternative systems with regard to welfare are related to group size, freedom of movement, and complexity of the environment (Rodenburg et al., 2005).

Japanese quails in Croatia are mostly kept in cages, although there are some farms where the birds are kept in aviaries. Birds in cages spend all their time on a wire or plastic net in a reduced space, while birds in aviaries have much more space to move and a more natural and comfortable floor area. The objectives of this study were to determine and compare physical properties (weight, dimensions, specific gravity, shape index, sphericity, shell thickness), morphological properties (egg components percentage, yolk to albumen ratio, yolk and albumen index, Haugh unit), and mechanical properties (breaking force, deformation, absorbed energy, firmness) of Japanese quail eggs from cage housing and aviary housing system.

MATERIALS AND METHODS

Eggs collection

The experimental material consisted of Japanese quail (Coturnix coturnix japonica) eggs collected in May 2019 from the experimental farm located near Sisak (45°29' N; 16°22' E), a small town 60 km southeast of Zagreb, the capital of Croatia. The 180 birds of the Japanese quail breed Pharaon were obtained at six weeks of age from one Croatian breeder, randomly divided into two groups and housed in two farm buildings with different housing systems. In the first building, 90 birds were kept in six three-floor cages with dimensions 40x30x30 cm (width x length x height) per cage and proportion 1 male and 4 females per cage. In the second building, 90 birds were kept in three aviaries with dimensions 300x200x250 cm (width x length x height) and proportion 6 males and 24 females per aviary. Thus, the floor area per bird in the cage housing system was 240 cm², while in the aviary housing system it was 2000 cm². Japanese quails in both housing systems were fed with the same commercial diets containing 21% crude protein and 12.6 MJ/kg metabolizable energy in the period of first 6 weeks, later with commercial diet containing 17% crude protein and 11.5 MJ/kg metabolizable energy. Feed and water were given ad libitum and the same lighting schedule of 16 h/day was used in both housing systems. During experimental period of four weeks, birds from cage housing system consumed 55 kg of feed (21.8 g/quail/day), while birds from aviary housing system consumed 60 kg (23.8 g/quail/day). The higher feed consumption of birds in the aviary housing system can be explained by the larger space for birds that allows them more movement, and thus the higher energy consumption which is compensated by higher feed intake. In the same period, laying hens from the cage housing system laid a total of 1625 eggs (22.6 per laying hen), while those from the aviary housing system laid a total of 1596 eggs (22.2 per laying hen).

For this study, a total sample of 240 eggs (120 eggs from each housing system) was collected from Japanese quail hens aged between 27 and 30 weeks. Determination of physical, morphological and mechanical quality properties of the eggs was carried out immediately after collection. All study procedures were conducted in accordance with Directive 2010/63/EU (European Union, 2010) for the production, care, and use of experimental animals.

Physical properties of eggs

Length (L) and width (W) of the collected eggs were measured using an electronic digital calliper with an accuracy of 0.01 mm. To evaluate the egg weight, eggs were separately weighed on a precision electronic balance reading to 0.01 g. The geometric mean diameter (D_g), surface area (S), volume (V), specific gravity (SG) and shape index (SI) were calculated using the following formulas (Altuntas and Sekeroglu, 2008):

$$D_g = (LW_2)^{1/3}$$

$$S = \pi D^2_g$$

$$V = \pi/6\ (LW^2)$$

$$SG = (EW/V)$$

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

$$\phi = (LW^2)^{1/3}/L$$

where:

L - length in mm; W - width in mm; D_g - geometric mean diameter in mm; S - surface area in mm²; V - volume in mm³; SG - specific gravity in g/cm³; EW - egg weight in g; SI - shape index in %; ϕ - sphericity in %.

Shell thickness was randomly measured at three different parts of each eggshell (sharp end, blunt end, and equator) using an electronic digital micrometer with an accuracy of 0.001 mm and averaged.

Morphological properties of eggs

After measuring the breaking forces, eggs were broken on a flat glass surface to determine the internal quality properties of the eggs. Yolk and albumen height were measured using a tripod micrometer with an accuracy of 0.001 mm, while yolk diameter and albumen length and width were measured using an electronic digital calliper with an accuracy of 0.01 mm. Albumen weight was determined by subtracting the yolk and shell weight from the original egg weight. The individual weight of each egg and its components were used to calculate the albumen percentage (albumen weight/egg weight x 100), yolk percentage (yolk weight/egg weight x 100), shell percentage (shell weight/egg weight x 100) and yolk to albumen ratio (yolk weight/albumen weight) (Dottavio et al., 2005). Albumen index and yolk index were calculated using the following formulas:

$$AI = AH/[(AL+AW)/2]$$

$$YI = (YH/YD)$$

where:

AI - albumen index; AH - albumen height in mm; AL - albumen length in mm; AW - albumen width in mm; YI - yolk index; YH - yolk height in mm; YD - yolk diameter in mm.

The Haugh unit was calculated using the following formula:

$$HU = 100 \log_{10} (H - 1.7W^{0.37} + 7.6)$$

where:

HU - Haugh unit; *H* - albumen height in mm; *W* - egg weight in g.

Mechanical properties of eggs

A commonly used method for measuring shell strength is to compress an egg between two plates. To measure the forces required to break an egg, a universal testing machine (Figure 1) was used. The egg sample was placed on the fixed plate and pressed with a moving plate connected to the load cell with the compression speed of 0.33 mm/s until the egg breaking (Nedomova et al., 2009). The forces were measured using the data acquisition system, which included a dynamometer HBM (Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany), an amplifier HBM Quantum MX 840 B and a personal computer. Two compression axes (X and Z) of an egg were used to determine the breaking force, specific deformation, absorbed energy and firmness. 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 (Figure 2). The series of twenty eggs were tested for each orientation.

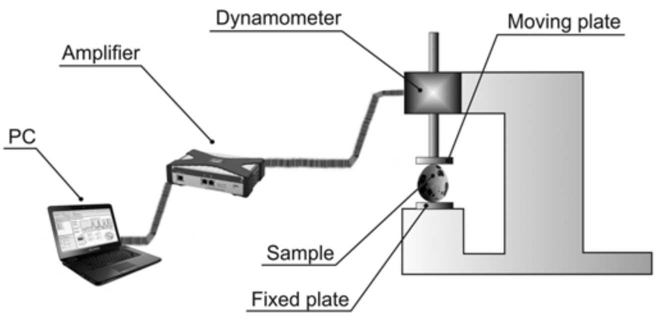

Figure 1. Schematic presentation of the universal testing machine used for measuring egg breaking forces

The deformation of Japanese quail eggs before breaking was measured with the inductive displacement transducer HBM WA/100. The specific deformation was determined using the following formula (Altuntas and Sekeroglu, 2008):

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

where ε is the specific deformation in %; L_f is the deformed egg length measured in the direction of the compression axis in mm; *L* is the undeformed egg length measured in the direction of the compression axis in mm.

The energy absorbed (E_a) by an egg at the moment of breaking was calculated using the following formula (Polat et al., 2007; Altuntas and Sekeroglu, 2008):

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

where E_a is the absorbed energy in Nmm; F_r is the breaking force in N; D_r is the deformation at breaking point in mm.

The firmness (*Q*) is considered as the ratio of compressive force to deformation at the breaking point of egg and was determined using the following formula (Altuntas and Sekeroglu, 2008):

$$Q = F_r / D_r$$

where *Q* is the firmness in N/mm; F_r is the breaking force in N; D_r is the deformation at breaking point in mm.

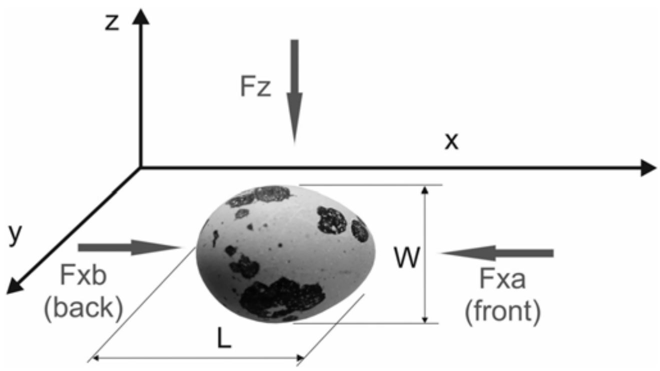

Figure 2. Characteristic dimensions of Japanese quail eggs and compression directions: length (L), width (W) and forces applied in three directions (F_{xa}; F_{xb}; F_z)

Statistical data analysis was performed using SAS software (SAS Institute, 2004). Results were expressed as the mean ± standard deviation (SD) of 120 measurements for egg physical and morphological properties for each housing system of Japanese quails and 40 measurements for egg mechanical properties in each of the three egg compression directions and housing systems. The significance of the differences between the values of the observed parameters was evaluated using analysis of variance (ANOVA). Fisher's least significant difference

(LSD) test was used to compare means, and differences were considered as significant at the probability levels P<0.05 and P<0.01.

RESULTS AND DISCUSSION

The physical properties of Japanese quail eggs from two different housing systems are shown in Table 1. Statistically significant differences were found between the dimensions of Japanese quail eggs from different housing systems (P<0.05 and P<0.01).

The eggs collected from the cage housing system were on average 4.59% longer and 3.66% wider compared to the eggs collected from the aviary housing system. Consequently, Japanese quail eggs from cage housing system had significantly larger geometric mean diameter and surface area (P<0.05), and volume (P<0.01).

In the scientific literature there is a deficit of technical information and data on quality properties of Japanese quail eggs from aviary housing systems, therefore the results of this study were compared with the quality properties of Japanese quail eggs from cage housing systems, and for some mechanical properties with those of some other poultry species.

The length and width of Japanese quail eggs from cage housing system observed in this study were close to the average dimensions of Japanese quail eggs observed by Kul and Seker (2004), Yilmaz et al. (2011), and Hrncar et al. (2014), while the length and width of eggs from aviary housing system were close to results of Song et al. (2000), Bagh et al. (2016), and Sabir et al. (2016). The length and width of eggs from both housing systems were higher than those observed by Tabeekh (2011) and Chimezie et al. (2017), but lower than those observed by Polat et al. (2007), Genchev (2012), Hanusova et al. (2016), and Lukanov et al. (2019). The average geometric mean diameter of Japanese quail eggs from both housing systems was lower than the geometric mean diameter observed by Polat et al. (2007).

The average surface area of Japanese quail eggs from both housing systems observed in this study was close to the surface area of Japanese quail eggs of 22.5-25.3 cm^2 reported by Wilkanowska and Kokoszynski (2012) and El-Tarabany et al. (2015), but lower than the average surface area of Japanese quail eggs of 25.97 cm^2 reported by Song et al. (2000), 26.09 cm^2 reported by Polat et al. (2007), 26.08-27.67 cm^2 reported by Lukanov

Table 1. Physical properties of Japanese quail eggs from two different housing systems

Item	Cage housing	Aviary housing	Sig.
Length (mm)	33.25±1.58^a	31.79±1.21^b	*
Width (mm)	25.78±0.64^a	24.87±0.62^b	*
Geometric mean diameter (mm)	28.06±0.75^a	26.99±0.71^b	*
Surface area (mm^2)	2473.84±133.94^a	2288.76±119.68^b	*
Volume (mm^3)	11585.18±950.67^a	10309.04±806.42^b	**
Weight (g)	11.85±1.01^a	10.93±0.84^b	*
Specific gravity (g/cm^3)	1.02±0.01^b	1.06±0.01^a	*
Shape index (%)	77.69±3.46^a	78.30±2.57^a	ns
Sphericity (%)	84.49±2.51^a	84.94±1.87^a	ns
Shell thickness (mm)	0.187±0.011^a	0.192±0.011^a	ns

Within the column (Sig.), values in same rows marked with * and ** differ significantly (P<0.05) and (P<0.01), respectively or the difference is not significant (ns) et al. (2019) and 27.14-27.50 cm^2 reported by Genchev (2012). The average volume of Japanese quail eggs from both housing systems observed in this study was higher than the volume of 9.70-10.40 cm^3 reported by Bagh et al. (2016), but lower than the volume of 13.07-13.34 cm^3 reported by Genchev et al. (2012).

Japanese quail eggs from cage housing system observed in this study were significantly heavier (11.85 vs. 10.93 g) than eggs from aviary housing system ($P<0.05$). The average weight of Japanese quail eggs from both housing systems observed in this study was close to values of 10.34 g reported by Song et al. (2000), 10.58-11.60 g reported by Bagh et al. (2016), 11.28 g reported by Kul and Seker (2004), and 11.9 g reported by Sari et al. (2016), but some authors recorded lower values such as 7.04 g (Tabeekh, 2011) and 9.22 g (Sato et al., 1989) or higher values such as 12.50 g (Yilmaz et al., 2011), 12.53 g (Alasahan et al., 2015), 12.69 g (Polat et al., 2007), 12.76 g (Narinc et al., 2015), 12.79-14.04 g (Lukanov et al., 2019) and 13.25-13.71 g (Genchev, 2012). Kul and Seker (2004) considered that the differences between the results of the studies of Japanese quail egg quality could result from genetic structure, health condition, flock age, use of different content diets in feeding, and the differences in quail care and management conditions.

Japanese quail eggs from aviary housing system had significantly higher specific gravity (specific weight) compared to eggs from cage housing system ($P<0.05$) and this value (1.06 g/cm^3) was close to values 1.052 g/cm^3 (Nowaczewski et al., 2010), 1.067 g/cm^3 (Yannakopoulos and Tserveni-Gousi, 1986), 1.069 g/cm^3 (Narinc et al., 2015), and 1.070 g/cm^3 (Sato et al., 1989). According to Roberts (2004), egg specific gravity is a good indicator of shell weight, thickness and strength, which was also shown in this study, because the eggs from aviary housing system had significantly higher strength ($P < 0.01$).

The egg shape index is defined as the ratio between its width and length. The importance of this parameter consists of the role of egg shape in the direction of turning during incubation and the determination of embryo movements for nutrients utilization (Hristakieva et al., 2017). In this study, egg shape index and egg sphericity were used to evaluate the egg shape. Eggs are available in different shapes and can be characterised as sharp, normal (standard) and round using a shape index (SI), if they have a SI value of <72, between 72 and 76, and >76, respectively (Sarica and Erensayin, 2004). According to this classification and the calculation of SI, Japanese quail eggs from both housing systems investigated in this study can be characterised as round. There was no statistically significant difference ($P<0.05$ and $P<0.01$) in SI of Japanese quail eggs from two housing systems (Table 1). The average values of eggs SI (77.69 and 78.30%) were similar to those reported by Zita et al. (2012) with 77.85%, Yilmaz et al. (2011) with 77.89%, Lotfi et al. (2012) with 78.12%, Buchar et al. (2015) with 78.15% and Lukanov et al. (2019) with values between 77.55 and 78.31%. The lower SI of Japanese quail eggs was reported by Kul and Seker (2004) as 74.90% and Bagh et al. (2016) as between 69.93 and 72.88%, while the higher SI was reported by Nowaczewski et al. (2010) as 79.2%. According to Lukanov et al. (2019), the SI values of Japanese quail eggs were slightly higher than those considered as ideal in chicken eggs, as expressed by a rounder shape. Another characteristic of Japanese quail eggs is that they are more pointed than those of chickens, but this was not evident from the SI values.

Egg sphericity is less commonly used to assess egg shape. In this study, the housing system had no significant effect on the sphericity of Japanese quail eggs. The average sphericity of Japanese quail eggs from both housing systems (84.94 and 84.49%) was close to the average sphericity of Japanese quail eggs (84.83%) reported by Buchar et al. (2015).

No statistical difference in shell thickness was observed between Japanese quail eggs from case housing (0.187 mm) and aviary housing system (0.192 mm). A similar average shell thickness of Japanese quail eggs of 0.190 mm was reported by Zita et al. (2012). The shell thickness values of Japanese quail eggs observed in this study were higher than the shell thicknesses of Japanese quail eggs reported by Ondrusikova et al. (2018) from 0.10 to 0.14

mm, and Song et al. (2000) with 0.174 mm, but lower compared to other shell thickness values of Japanese quail eggs found in the literature: 0.200 (Nowaczewski et al., 2010), 0.208-0.226 mm (Wilkanowska and Kokoszynski, 2012), 0.22 mm (Lotfi et al., 2012), 0.23 mm (Yilmaz et al., 2011), 0.231 mm (Kul and Seker, 2004), 0.257-0.259 mm (Hanusova et al., 2016), 0.25-0.27 mm (Bagh et al., 2016) and 0.28-0.30 mm (Jatoi et al., 2015). According to Harms et al. (1990), egg size and eggshell thickness are strongly related, but this was not confirmed in this study as there was no significant difference in egg shell thickness.

The morphological properties of Japanese quail eggs from two different housing systems are shown in Table 2. In agreement with the results obtained in this study for total egg weight, the albumen and yolk weights were also significantly higher (P<0.01) in Japanese quail eggs from cage housing, while there was no significant difference in shell weight.

Albumen and yolk weights and their ratio provide information about internal egg quality (Baykalir and Simsek, 2018). Eggs in which the yolk constitutes between 15 and 20% of the total weight (low proportion of yolk and lipids) belong to the Altricial species class, while eggs in which the yolk constitutes between 30 and 40% of the total weight (high proportion of yolk and lipids) belong to the Precocial species class (Al-Obaidi and Al-Shadeedi, 2016). Thus, according to the yolk percentage observed in this study, Japanese quail eggs from both housing systems belong to the Precocial species class.

No statistical difference in albumen and yolk content was observed between the Japanese quail eggs from cage and aviary housing system. The average albumen percentage of Japanese quail eggs observed in this study was close to 56.1% reported by Sari et al. (2016) and 56.93% reported by Zita et al. (2012). Higher values ranging from 59 to 62% were reported by Song et al. (2000), Kul and Seker (2004), Nowaczewski et al. (2010), Yilmaz et al. (2011), Alasahan et al. (2015) and Hanusova et al. (2016). The average yolk percentage observed in this study was close to 32.43% reported by Hrncar et al. (2014), 32.57% reported by Lotfi et al. (2012) and 32.94% reported by Prelipcean et al. (2012). Japanese quail eggs have higher percentage of yolk than chicken eggs (Hanusova et al., 2016). The significantly higher eggshell percentage was observed in Japanese quail eggs from aviary housing system in this study and this percentage (12.53%) was close to the shell percentage of Japanese quail eggs of 12.65% reported by Zita et al. (2012).

Table 2. Morphological properties of Japanese quail eggs from two different housing systems

Item	Cage housing	Aviary housing	Sig.
Albumen weight (g)	6.64±0.64a	6.03±0.60b	**
Albumen percentage (%)	56.03±4.34a	55.17±3.48a	ns
Yolk weight (g)	3.87±0.69a	3.53±0.38b	**
Yolk percentage (%)	32.66±3.36a	32.30±2.48a	ns
Shell weight (g)	1.34±0.19a	1.37±0.23a	ns
Shell percentage (%)	11.31±1.68b	12.53±1.65a	**
Y:A ratio	0.583±0.082a	0.585±0.089a	ns
Albumen index	11.40±2.65a	10.58±1.44b	*
Yolk index	44.12±4.40a	44.41±3.77a	ns
Haugh unit	86.89±3.36a	86.85±2.13a	ns

Within the column (Sig.), values in same rows marked with * and ** differ significantly (P<0.05) and (P<0.01), respectively or the difference is not significant (ns)

Some authors reported much lower shell percentage of Japanese quail eggs such as 7.3% (Song et al., 2000), 7.47% (Kul and Seker, 2004), 8.03% (Nowaczewski et al., 2010), while Yilmaz et al. (2011) reported extremely low shell percentage of Japanese quail eggs (5.53%). The highest range of shell percentage of Japanese quail eggs found in the literature was between 14.62 and 15.09%, reported by Dukic Stojcic et al. (2012). Such deviations between results may be due to different breeding factors, which is related to egg weight and feed composition, which correlates with eggshell thickness and therefore its ratio (Ondrusikova et al., 2018). According to Mohammed and Gharib (2017), housing systems can have a significant effect on eggshell quality characteristics like shell weight, ratio, and thickness. Englmaierova et al. (2014) compared different housing systems and observed higher shell percentage in eggs from aviary housing system than in eggs from cages.

No statistical differences in yolk to albumen (Y/A) ratio, yolk index and Haugh unit value were observed between Japanese quail eggs from cage and aviary housing system in this study, while albumen index of eggs from cage housing system was significantly higher ($P<0.05$). The Y/A ratio of Japanese quail eggs from both housing systems observed in this study was higher than the Y/A ratio of Japanese quail eggs 0.52 reported by Song et al. (2000) and 0.53 reported by Yilmaz et al. (2011).

The albumen index (AI) of Japanese quail eggs from cage housing system (11.40) was significantly higher ($P<0.05$) than the AI from aviary housing system (10.58). The AI observed in this study from both housing systems was higher than the AI of Japanese quail eggs 8.82 (Nowaczewski et al., 2010), 9.37 (Kul and Seker, 2004), 9.45 (Lotfi et al., 2012), 9.91 (Yilmaz et al., 2011), 10.12 (Hrncar et al., 2014), and 10.39 (Zita et al., 2012), but lower than the AI of Japanese quail eggs 12.00 (Alasahan et al., 2015), and 13.15-14.10 (Bagh et al., 2016). The higher AI of Japanese quails' eggs from cages than those reared on the floor was also observed by Alam et al. (2008). Kraus et al. (2019) stated that AI was significantly influenced by hen age, housing systems and their interaction. The yolk index (YI) of Japanese quail eggs from both housing systems observed in this study (44.12 and 44.41) was close to YI of Japanese quail eggs reported by Sari et al. (2016) and higher YI of Japanese quail eggs reported by Kul and Seker (2004), Lotfi et al. (2012) and Hrncar et al. (2014) in the range 36.70-43.22. No significant differences in YI of Japanese quails' eggs from different housing systems, similar to our study, were also observed by Padmakumar et al. (2000) and Badawi (2017). The Haugh units (HU) of Japanese quail eggs from both housing systems (86.89 and 86.85) observed in this study are almost in agreement with those of Japanese quails with different feather colours reported by Inci et al. (2015). Higher HU values of Japanese quail eggs were shown by Genchev (2012), Alasahan et al. (2015), Bagh et al. (2016) and Sari et al. (2016), while lower HU values were shown by Ondrusikova et al. (2018), Chimezie et al. (2017), Kul and Seker (2004) and Zita et al. (2012). No significant differences in HU of eggs from different housing systems was also found by Padmakumar et al. (2000) for Japanese quails and Sekeroglu et al. (2010) for old hybrid of brown layer hens.

The average values of the mechanical properties of Japanese quail eggs from two different housing systems are presented in Table 3. The significantly higher breaking forces were obtained for Japanese quail eggs from aviary housing in all three directions ($P < 0.01$).

The average force required to break Japanese quail eggs from aviary housing system in all three axes was 14.36 N, which was 13.07% higher than the average force required to breaking Japanese quail eggs from cage housing of 12.70 N. The reason for the significantly higher eggshell strength of Japanese quail eggs from aviary housing system could be a significantly higher proportion of shell compared to eggs from cage housing system.

The average egg breaking force or egg breaking strength for Japanese quail eggs expressed in N has been reported in ranges 6.46-6.59 N (Hrncar et al., 2014), 6.83-10.51 N (Polat et al., 2007), and 9.0-11.4 N (Buchar et al., 2015). Compared to these values, Japanese quail eggs tested in this study had higher shell strength and required a higher average force to break the egg.

Table 3. Mechanical properties of Japanese quail eggs from two different housing systems

Item	Direction	Cage housing	Aviary housing	Sig.
Breaking force (N)	*X*-front	14.05±1.83[b]	15.81±2.47[a]	**
	X-back	12.64±1.07[b]	14.56±1.80[a]	**
	Z	11.42±1.45[b]	12.71±1.68[a]	**
Spec. deformation (%)	*X*-front	0.68±0.04[a]	0.71±0.08[a]	*
	X-back	0.70±0.03[a]	0.74±0.07[a]	*
	Z	0.87±0.09[a]	0.89±0.04[a]	ns
Absorbed energy (Nmm)	*X*-front	1.54±0.20[b]	1.81±0.32[a]	**
	X-back	1.47±0.16[b]	1.73±0.19[a]	**
	Z	1.28±0.19[b]	1.41±0.18[a]	**
Firmness (N/mm)	*X*-front	64.44±10.56[a]	69.64±14.48[a]	**
	X-back	54.47±5.99[b]	61.86±11.38[a]	**
	Z	51.84±11.39[b]	57.35±8.77[a]	**

Within the column (Sig.), values in same rows marked with * and ** differ significantly (P < 0.05) and (P < 0.01), respectively or the difference is not significant (ns)

Other authors reported the breaking strength of Japanese quail eggs expressed in kg/cm^2: 0.97 kg/cm^2 (Sato et al., 1989), 1.25 kg/cm^2 (Lotfi et al., 2012), and 1.05-1.72 kg/cm^2 (Dukic Stojcic et al., 2012). The average breaking strength of Japanese quail eggs from aviary housing obtained in this study was close to the breaking strength of Japanese quail eggs 1.46 kg/cm^2 reported by Narinc et al. (2015) and 1.468 kg/cm^2 reported by Zita et al. (2012). The highest Japanese quail egg breaking strength found in the literature was reported by Fathi et al. (2016) with 2.19 kg/cm^2 of the selected line of Japanese quail and the authors stated that the higher eggshell strength could be attributed to the calcite material and the structure of eggshells of the selected birds being more condensed than that of unselected birds. The highest egg breaking force in eggs from both housing systems tested in this study was obtained when they were loaded along the *X*-front axis, while the lowest resistance to break force was obtained along the *Z*-axis. These relationships are in agreement with those reported by Polat et al. (2007) for Japanese quail eggs and Altuntas and Sekeroglu (2008) for Lohmann chicken eggs.

In this study, the average specific eggshell deformation during compression of Japanese quail eggs from aviary housing was significantly higher (P < 0.05) than the specific deformation of Japanese quail eggs from cage housing when loaded along both *X*-axes. The specific deformation values for Japanese quail eggs from both housing systems were significantly higher when loaded along the *Z*-axis than when loaded along both *X*-axes. The same relationship was also observed by Altuntas and Sekeroglu (2008) for Lohmann chicken eggs, while Polat et al. (2007) found the highest deformation value along the X-front axis for Japanese quail eggs.

The absorbed energy was determined as a function of the breaking force and the deformation on the surface of an egg. In this study, the highest absorbed energy was determined for loading along the *X*-front axis, while the lowest energy was determined along the *Z*-axis for Japanese quail eggs from both housing systems. The significantly higher absorbed energy was determined for Japanese quail eggs from the aviary housing system in all three directions (P < 0.01). The average values of absorbed energy for Japanese quail eggs observed in this study ranged from 1.28 to 1.81 Nmm (depending on the pressure direction and the housing system) and were lower than the absorbed energy for Japanese quail eggs reported by Polat et al. (2007), which ranged from 3.41 to 7.88 Nmm. For comparison, Nedomova et al. (2009) reported absorbed energy for Hisex Brown chicken eggs in the range of 2.80-5.10 Nmm and Altuntas and Sekeroglu (2008) reported absorbed energy for Lohmann chicken eggs ranging from 3.29 to 3.53 Nmm.

The firmness values obtained along the *Z*-axis were significantly lower than those obtained along both *X*-axes for Japanese quail eggs from both housing systems, suggesting that a lower force was required to break the eggs along the *Z*-axis. The firmness values for eggs compressed along the *X*-front axis were significantly higher than along the X-back axis. The significantly higher firmness (P < 0.01) was obtained for Japanese quail eggs from the aviary housing system in all three directions. The firmness values of Japanese quail eggs from both housing systems observed in this study were lower than the values 111.05-140.52 N/mm reported by Altuntas and Sekeroglu (2008) for Lohmann chicken eggs and values 158.59-269.90 N/mm reported by Nedomova et al. (2009) for Hisex Brown chicken eggs.

CONCLUSIONS

Results of the experimental study presented in this paper indicate that the housing system had a significant influence on the physical, morphological and mechanical properties of Japanese quails. Eggs from the cage housing system were significantly (P<0.05) heavier than eggs from the aviary housing system (11.85 g vs. 10.93 g) and were also longer and wider and had significantly (P<0.05) larger geometric mean diameter, surface area and volume. No statistical differences in albumen and yolk content were observed between the eggs from cage and aviary housing system. The average force required to breaking Japanese quail eggs from cage and aviary housing system in all three axes was 14.36 N and 12.70 N, respectively. According to the obtained mechanical properties, Japanese quail eggs from the aviary housing system had a significantly stronger shell and required a greater force and energy (P<0.01) to break the egg than eggs from the cage housing system. The results of this study also indicate that the values of tested mechanical properties significantly depend on the direction of loading force.

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