Comparative analysis of physical, morphological, and mechanical characteristics of eggs from three pheasant subspecies

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ABSTRACT The profitability of pheasants breeding is influenced by many factors, but eggs quality is considered as the backbone for successful pheasant breeding. The objective of this study was to determine and compare various quality characteristics (physical, morphological, and mechanical) of eggs from three pheasant subspecies: common pheasant (*Phasianus colchicus colchicus*), Mongolian pheasant (*Phasianus colchicus mongolicus*), and black pheasant (*Phasianus colchicus* vs. *tenebrosus*). A total sample of 180 eggs (60 eggs of each pheasant subspecies) was collected from pheasant hens kept in aviaries in their first year of production (43−47 wk of age). The average weight and volume of eggs from common pheasants was significantly lower ($P < 0.05$) than those from Mongolian and black pheasants. No significant differences between three pheasant subspecies were observed in albumen and yolk weight and percentage, while egg shell weight and percentage were significantly higher ($P < 0.01$) at eggs from black pheasants. In comparison to eggs from Mongolian and common pheasants, eggs from black pheasants had the thickest shell and the highest shell strength and required highest force to egg breaking. The values of breaking force and other mechanical characteristics depend on the direction of the loading force during egg compression. The data obtained by evaluating certain characteristics of egg quality can be useful to breeders when choosing a pheasant subspecies, as well as for choosing quality eggs for hatching and their storage.

Key words: pheasant subspecies, egg dimensions, shape index, egg composition, breaking force

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INTRODUCTION

The common pheasant (*Phasianus colchicus colchicus*) belongs to the genus Phasianus in the family Phasianidae. Native to Asia, the pheasant was introduced as a game bird to many parts of the world. Currently pheasants are found at different latitudes in Europe, Asia, Australia and Oceania, and North America. Pheasants were first brought to Europe by the Romans and Greeks. Different subspecies that were later brought to Europe were interbred to produce birds with highly variable plumage color (Johnsgard, 1999; Kokoszynski et al., 2012; Liu et al., 2019). In Croatia pheasant was introduced at the end of the 18th century, but significant pheasant breeding began in the second half of the 20th century after the knowledge about pheasant's artificial rearing has been adopted and industrial production of their food began, and then more pheasant farms were established throughout Croatia. Pheasant farming has greatly decreased during the war in Croatia in the early 1990s, but in recent years the interest for pheasant rearing in Croatia has increased considerably. The motivation for the growth of pheasant farming is an increased demand for pheasants as hunting material and their meat for the gourmet food market (Janjecic, 2004). Pheasants are considered as one of the favourite game birds for a large number of hunters and their meat characterized low fat and high essential fatty acids and amino acids content which make it of a higher quality compared to broilers, ducks, and geese (Adamski and Kuzniacka, 2006). The European native population is estimated at 9,700 to 16,300 mature individuals with a stable trend, whereas the overall European population, including introduced populations, is estimated at 4,140,000 to 5,370,000 males, with an increasing trend (BirdLife International, 2021; Chiatante and Meriggi, 2022). According to Directive 2009/147/EC of the European Parliament (Council of the European Union, 2010), wild birds are not to be hunted during season of breeding or rearing, and the regulation of the non-hunting period is left to the EU member states. In Croatia, non-hunting period for pheasants is from 1st February till 15th September and for hunting

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pheasants a hunting license is required. Nowadays, pheasants are mainly breeding for purposes of hunting tourism, especially in countries of rich hunting tradition (Ristic et al., 2010). Although they are edible, the pheasant eggs are mainly used for reproduction, very rarely for consumption, and their market is very limited because of small and seasonal egg production (Tserveni-Goussi and Fortomaris, 2011). Pheasants are usually held in aviaries, although there are some farms where the birds are kept in cages during the reproductive period for economic reasons (Krystianiak et al., 2016).

Eggs provide nutrition and protection to the developing chicks, therefore, the egg quality is of immense importance for the hatchlings (Ashraf et al., 2016). In the northern hemisphere, pheasants start laying in early spring and continue until mid-summer; however, total egg production, fertility, and hatching rates vary and tend to be unsatisfactory (Kozuszek et al., 2009; Ozbey et al., 2011), with reported hatchability rates of fertilized eggs ranging between 41 and 79% (Ozbey et al., 2011; Kontecka et al., 2014). Considering the value of pheasant chicks, together with the low egg numbers and variations in fertility and hatchability, successful incubation of all eggs is particularly desirable (Demirel and Kirikci, 2009; Yamak et al., 2016). The physical characteristics of the egg play an important role in the processes of embryo development and successful hatching (Narushin and Romanov, 2002). The egg morphological characteristics such as weight and percentage of main components and the correlations among them are also very important because these factors influence egg quality, reproductive fitness of the chickens, and embryonic development (Oblakova, 2006; Popoola et al. 2015). The mechanical characteristics of eggs represent their strength under various loads in terms of several parameters such as breaking force, deformation, firmness, and toughness (Abdallah et al., 1993; De Ketelaere et al., 2002). Eggshell must be strong enough to prevent cracking in order to preserve the embryo until hatching (Altuntas and Sekeroglu, 2008).

Common pheasant (*Phasianus colchicus colchinus*) is the most widespread subspecies of pheasant in Europe, including in Croatia. The body of male pheasants is covered with dark brown plumage, their head is green-blue with a red area around the eyes, while the females have their whole body covered with gray-brown plumage. The weight of common pheasant males ranges from 1.2 to 1.6 kg, while females weigh less than 1 kg. Of the other pheasant subspecies in Croatia, the Mongolian pheasant (*Phasianus colchicus mongolicus*) is the most important as the largest pheasant subspecies, and it is easy to recognize by the white collar around the neck that is not connected in the lower part. The Mongolian pheasant is more durable in worse climatic conditions, and its females lay slightly more eggs than common pheasant females, which is why it is preferred in artificial breeding (Janjecic, 2004). The black pheasant (*Phasianus colchicus* vs. *tenebrosus)*, also known as the melanistically mutated pheasant, is a subspecies of the common pheasant that was initially bred in Europe for hunting, and is characterized by a very dark plumage color. From the point of rearing in captivity, black pheasants are considered as good egg producers characterized by high chicks rusticity and ease of artificial breeding (Bagliacca et al., 2004). The same authors reported that the average live weights of males and females of Mongolian pheasants were 1.513 and 1.322 kg, and that of black pheasants were 1.497 and 1.269 kg, respectively.

The objective of this study was to determine and compare some physical, morphological, and mechanical characteristics of pheasant eggs from those 3 subspecies, which are also the most represented subspecies of pheasant breeding in captivity in Croatia.

MATERIALS AND METHODS

Animals

Pheasant eggs used in this study were collected from experimental farm located in Dugo Selo (latitude 45° 48' N, longitude 16° 14' E), a small town near Zagreb, capital city of Croatia. On this farm 3 pheasant subspecies were kept in separate aviaries with dimensions 400 × 300 × 250 cm (width × length × height) and sex ratio was 1 male: 8 females, so the eggs were fertile. The pheasant feeding was ad libitum with a commercial diet for pheasants (19% CP and 11.7 MJ/kg ME), properly adjusted to their age.

Sample Collection

Eggs were randomly collected during May 2019 from each pheasant group in their first year of production (43 to 47 wk of age) after collected enough eggs for hatching according to the available space in aviaries. Eggs were examined within 24 hours of collection. A total sample of 180 eggs was evaluated, consisting of 60 eggs from each pheasant subspecies (Figure 1).

Experimental Design

Length and width 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, surface area, volume, specific gravity, and shape index were calculated using the following formulas (Altuntas and Sekeroglu, 2008):

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

$$S = \pi D_g^2$$

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

$$SG = (EW/V)$$

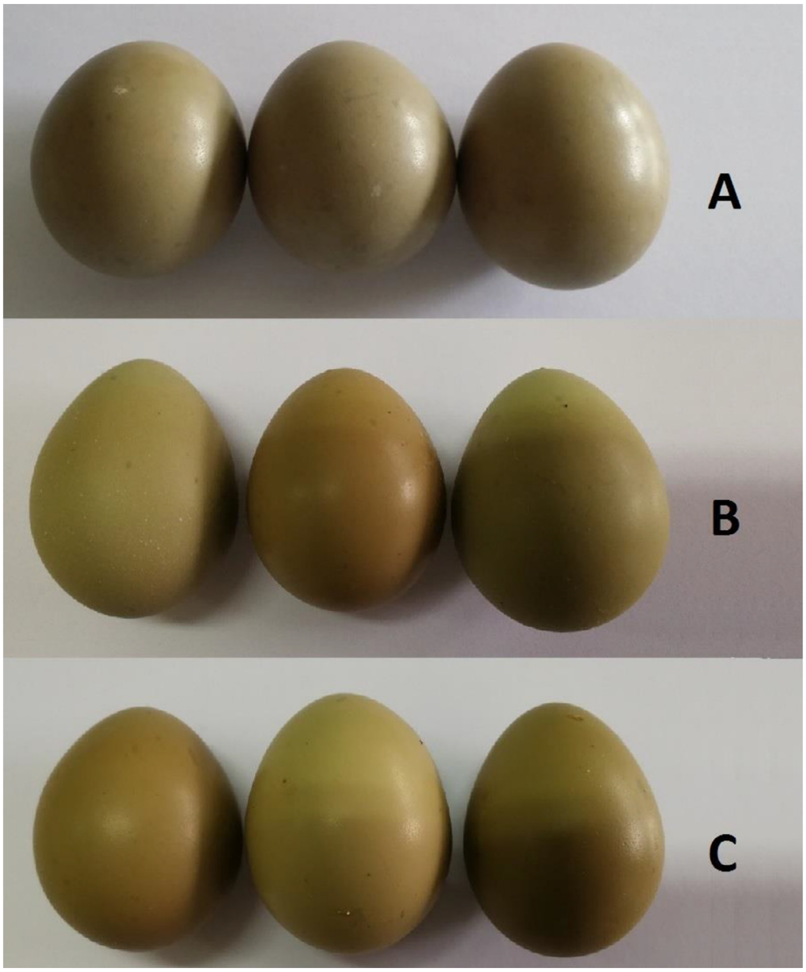

Figure 1. Tested eggs from three pheasant subspecies. (A) Common pheasant, (B) Mongolian pheasant, (C) Black pheasant.

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

where L is the length in mm, W is the width in mm, D_g is the geometric mean diameter in mm, S is the surface area in cm^2, V is the volume in cm^3, EW is the egg weight in g, SG is the specific gravity in g/cm^3, SI is the shape index in %.

The shell thickness was randomly measured from the 3 different parts of shell in each egg using an electronic digital micrometer with accuracy of 0.001 mm and was averaged. A total sample of 180 eggs was used for the determination of mentioned physical characteristics.

To evaluate the egg weight, eggs, and egg components were separately weighed on a precision electronic balance reading to 0.01 g. After measuring the breaking forces, eggs were broken on a flat glass surface to determine the internal quality characteristics 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 × 100), yolk percentage (yolk weight/egg weight × 100), shell percentage (shell weight/egg weight × 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 is the albumen index, AH is the albumen height in mm, AL is the albumen length in mm, AW is the albumen width in mm, YI is the yolk index, YH is the yolk height in mm, YD is the 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 is the Haugh unit, H is the albumen height, W is the egg weight.

A commonly used technique for the measurement of the shell strength is the compression of an egg between 2 plates. To measure the forces required to breaking egg, a universal testing machine 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 breaking (Nedomova et al., 2009). The forces were

Table 1. Physical characteristics of eggs from three pheasant subspecies.

Parameter	Common pheasant	Mongolian pheasant	Black pheasant	Sig.
Length (mm)	45.24 ± 1.11^{a}	45.89 ± 1.92^{ab}	46.67 ± 1.25^{b}	*
Width (mm)	36.28 ± 0.58^{a}	36.53 ± 1.40^{a}	36.77 ± 1.13^{a}	ns
Geometric mean diameter (mm)	39.05 ± 0.52^{a}	39.41 ± 1.35^{a}	39.81 ± 0.96^{a}	ns
Surface area (cm^2)	47.89 ± 1.26^{a}	48.83 ± 3.33^{ab}	49.79 ± 2.24^{b}	*
Volume (cm^3)	31.17 ± 1.23^{a}	32.14 ± 3.27^{ab}	33.07 ± 2.25^{b}	*
Weight (g)	32.67 ± 1.52^{a}	33.35 ± 3.37^{b}	33.72 ± 2.35^{b}	*
Specific gravity (g/cm^3)	1.05 ± 0.02^{a}	1.04 ± 0.02^{a}	1.02 ± 0.01^{a}	ns
Shape index (%)	80.26 ± 2.34^{a}	79.68 ± 3.25^{a}	78.84 ± 3.11^{a}	ns
Shell thickness (mm)	0.261 ± 0.016^{a}	0.279 ± 0.023^{b}	0.290 ± 0.011^{c}	**

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

measured by the data acquisition system, which included dynamometer HBM (Hottinger Baldwin Messtechnik GmbH, Darmstadt, Germany), amplifier HBM Quantum MX 840 B and 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 2 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. A sample of 60 eggs from three pheasant subspecies (20 eggs for each orientation) was used for the determination of egg mechanical characteristics.

The deformation of pheasant 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):

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

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, L is the underformed egg length measured in the direction of the compression axis in mm.

The energy absorbed 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 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.

Statistical Analysis

Statistical data analysis was performed using SAS software (SAS Institute, 2004). Results were expressed as the mean ± standard deviation (**SD**) of 60 measurements for egg physical and morphological characteristics for each pheasant subspecies and 20 measurements for egg mechanical characteristics in each of the 3 egg compression directions and pheasant subspecies. 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 characteristics of the eggs collected from 3 pheasant subspecies are presented in Table 1. According to average egg dimensions, the biggest eggs were collected from black pheasants, followed by eggs from Mongolian pheasants, but there were no significant differences between eggs from these 2 pheasant subspecies. In comparison to eggs from black and Mongolian pheasants, eggs from common pheasants were significantly smaller. The egg dimensions observed in this study were similar to those obtained by Nowaczewski et al. (2013a) with 42.2 to 45.6 mm length and 35.8 to 37.2 mm width for 4 groups of pheasant eggs with different egg shell color and slightly higher than those obtained by Kokoszynski et al. (2011) for game pheasant eggs with 42.1 to 43.8 mm length and 33.5 to 35.6 mm width and Song et al. (2000) with average length and width of 42.3 and 33.7 mm, respectively. On the other hand, Al-Obaidi (2017) reported much lower dimensions of eggs from three pheasant species (ring-necked, golden, and silver pheasant) with 21.57 to 22.46 mm length and 15.63 to 16.25 mm width.

Significantly higher length, surface area, and volume ($P < 0.05$) were observed at eggs from black pheasants in comparison to eggs from common pheasants. The average surface area of eggs from three pheasant subspecies observed in this study (47.89–49.79 cm^2) was very close to surface area of 4 groups of pheasant eggs with different egg shell color reported by Kozuszek et al. (2009) with 47.2 to 49.2 cm^2 for 4 groups of pheasant eggs with different egg shell color but higher than those obtained by Kokoszynski et al. (2011) with 42.1 to 46.7 cm^2. The average volume of eggs from all 3 pheasant subspecies observed in this study (31.17−33.07 cm^3) was much higher than average volume of eggs from ring necked pheasants with 23.10 cm^3 reported by Ashraf et al. (2016).

The average weight of eggs from common pheasants was significantly lower ($P < 0.05$) than those of Mongolian and black pheasants. The main reason why the eggs from black and Mongolian pheasants were significantly bigger and heavier compared to common pheasants is the female size. The average weights of black and Mongolian pheasant females were 1.3 and 1.2 kg, respectively, while the average weight of common pheasant females was 0.9 kg. The effect of live weight of the pheasant female on egg weight have studied Kirikci et al. (2004) and found that heaviest eggs were obtained from the heavy group and the lightest eggs were obtained from the light group of pheasant females. Ashraf et al. (2016) classified pheasant eggs in 3 weight categories: light (20−26 g), medium (27 −32 g), and heavy (33−40 g). According to this classification, eggs from all 3 pheasant subspecies observed in this study belong to group of heavy pheasant eggs. The egg size is very important in pheasants breeding because the bigger and heavier eggs lead to bigger and heavier chicks. Caglayan et al. (2010) have determined a significant effect of pheasant egg weight on egg hatchability and chick weight and concluded that egg weight is especially important factor to obtaining chicks in sufficient numbers. The average weight of eggs from three pheasant subspecies (32.67−33.72 g) observed in this study was very close to pheasant egg weight values of 32.7 to 33.6 g reported by Caglayan et al. (2010) and 32.0 to 33.3 g reported by Kozuszek et al. (2009). Similar values, but in a wider range, were also reported by Nowaczewski et al. (2013b) with 31.8 to 33.4 g and by Demirel and Kirikci (2009) with 31.56 to 33.17 g. However, the egg weights from present study were higher than the values of 30.22 to 32.19 g reported by Gunlu et al. (2018) and 31.47 reported by Aygun and Olgun (2019). Slightly higher average weight of pheasant eggs (34.5 g) was reported by Mangiagalli et al. (2003). These differences may be due to genotypes of the pheasants, the ages of the breeding pheasants or the care and feeding of the birds (Demirel and Kirikci, 2009). The study of Kokoszynski et al. (2011) showed that laying pheasants fed the complete diet produced significantly heavier eggs than pheasants receiving the experimental diet low in crude protein and high in energy (30.8 vs. 26.3 g).

There were no differences among the three pheasant subspecies with respect to egg specific gravity and shape index. The standard values of egg specific gravity usually range from 1.0 to 1.10 g/cm^3, so the values of specific gravity of pheasant eggs observed in this study (1.02−1.05 g/cm^3) indicated that the eggs of these 3 pheasant subspecies belong to eggs of low to medium specific gravity. Higher values of specific gravity of pheasant eggs were reported by Tserveni-Gousi and Yannakopoulos (1990) of 1.07 g/cm^3 and by Kozuszek et al. (2009) in the range 1.066 to 1.071 g/cm^3. Significantly lower specific gravity of pheasant eggs in the range 0.93 to 0.94 g/cm^3 was reported by Kirikci et al. (2004). According to Rozempolska-Rucinska et al. (2011), the egg specific gravity is a trait that broadly characterizes the quality of eggs that are used in hatching. The egg specific gravity indirectly defines the shape of an egg, resistance, and structure of the shell, that is, traits that are essential for a normal hatching process.

Eggs are available in different shapes and can be characterized 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). According to that classification and calculated SI, eggs collected from 3 pheasant subspecies evaluated in this study can be characterized as round. The average values of pheasant eggs shape index observed in this study (78.84−80.26%) was similar to those reported by Tserveni-Gousi and Yannakopoulos (1990) 80.24%, Garip et al. (2010) 80.58%, Kirikci et al. (2003) 80.69%, Kirikci et al. (2004) 79.62−81.23%, Demirel and Kirikci (2009) 79.80−81.06% and Kokoszynski et al. (2011) 79.6−81.3%. Wider range of pheasant egg shape index was reported by Kirikci et al. (2005) 77.87−81.24% and Esen et al. (2010) 77.49−84.14%.

Statistically significant differences ($P < 0.01$) between eggs from 3 pheasant subspecies were also observed in egg shell thickness. The thinnest shell was observed at eggs from common pheasants, eggs from Mongolian pheasants had 6.9% thicker shell, while the thickest shell was observed at eggs from black pheasants, 11.1% thicker compared to eggs from common pheasants. From the obtained results, can be seen a direct correlation between weight and shell thickness of eggs from three pheasant subspecies, where heavier eggs had a thicker shell. According to Ketta and Tumova (2018), egg shell thickness plays a major role of quality parameters of the egg shell. A fairly wide range of egg shell thickness values can be found in the literature. The range of average shell thickness of eggs from three pheasant subspecies observed in this study (0.261−0.290 mm) was very close to range reported by Kozuszek et al. (2009) 0.253−0.288 mm. Higher ranges of egg shell thickness were reported by Ozbey et al. (2011) 0.263−0.311 mm, Nowaczewski et al. (2013a) 0.282 −0.315 mm, Kokoszynski et al. (2011) 0.280−0.310 mm, Esen et al. (2010) 0.283−0.336 mm and Mangiagalli et al. (2003) 304−346 mm, while lower ranges were reported by Kirikci et al. (2004) 0.220−0.260 mm and Kirikci et al. (2005) 0.202−0.230 mm.

The morphological characteristics of the eggs collected from 3 pheasant subspecies are presented in Table 2. There were not significant differences between 3 pheasant subspecies with respect to albumen and yolk weight and percentage.

The yolk percentage of pheasant eggs observed in this study (32.38−32.84%) was close to yolk percentage of 32.63% reported by Aygun and Olgun (2019). Similar values of yolk percentage, but in a wider range 31.8 to 35.0%, were reported by Kozuszek et al. (2009), while much higher values were reported by Kokoszynski et al. (2011) 37.4−37.6% and Ashraf et al. (2016) 38.33−38.78%. Something lower values of yolk percentage 31.07 to 31.27% were reported by Al-Obaidi (2017). The pheasant

Table 2. Morphological characteristics of eggs from three pheasant subspecies.

Parameter	Common pheasant	Mongolian pheasant	Black pheasant	Sig.
Albumen weight (g)	17.86 ± 2.23^{a}	18.18 ± 2.26^{a}	18.36 ± 1.17^{a}	ns
Albumen percentage (%)	54.67 ± 0.97^{a}	54.51 ± 2.39^{a}	54.45 ± 1.71^{a}	ns
Yolk weight (g)	10.83 ± 0.85^{a}	10.95 ± 0.80^{a}	10.92 ± 0.62^{a}	ns
Yolk percentage (%)	33.15 ± 0.90^{a}	32.83 ± 2.04^{a}	32.38 ± 1.44^{a}	ns
Shell weight (g)	3.98 ± 0.34^{a}	4.22 ± 0.37^{b}	4.44 ± 0.53^{c}	**
Shell percentage (%)	12.18 ± 0.76^{a}	12.66 ± 0.56^{b}	13.17 ± 0.82^{c}	**
Y:A ratio	0.606 ± 0.039^{a}	0.602 ± 0.062^{a}	0.595 ± 0.045^{a}	ns
Albumen index	1.79 ± 0.16^{a}	1.83 ± 0.18^{a}	1.92 ± 0.21^{b}	*
Yolk index	39.72 ± 1.96^{a}	40.06 ± 2.51^{a}	41.57 ± 2.87^{b}	*
Haugh unit	75.83 ± 1.65^{a}	76.19 ± 2.37^{a}	79.91 ± 2.62^{b}	*

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

egg albumen percentage observed in this study 54.45 to 54.98% was slightly lower than values of 55.69, 56.20, and 56.93% reported by Song et al. (2000), Garip et al. (2010) and Aygun and Olgun (2019), respectively, but significantly higher than values in range 47.91 to 51.28% reported by Ashraf et al. (2016).

Statistically significant differences ($P < 0.01$) were observed in egg shell weight and percentage. The highest egg shell weight and percentage was observed at eggs from black peasants and the lowest at eggs from common peasants. The egg shell percentage values from this study 12.18 to 13.17% were similar to those reported by Ashraf et al. (2016) 11.62−13.54%, but other egg shell percentages found in the literature were lower: 8.7−8.9% (Kozuszek et al., 2009), 9.5−9.7% (Kokoszynski et al., 2011), 9.89−10.16% (Al-Obaidi, 2017), 9.88−10.40% (Kirikci et al., 2005).

There was also no significant difference in yolk to albumen (**Y/A**) ratio between 3 pheasant subspecies. The average Y/A ratios of eggs from 3 pheasant subspecies observed in this study (0.595−0.606) were very close to the pheasant eggs Y/A ratios of Mangiagalli et al. (2003) and Tserveni-Gousi and Yannakopoulos (1990), but they did not express this ratio specifically in their papers. The higher Y/A ratio of pheasant eggs 0.65 was reported by Song et al. (2000).

The values of albumen index, yolk index, and Haugh units were significantly higher at eggs from black peasants than at eggs from other 2 peasant subspecies ($P < 0.05$). The albumen index (**AI**) of eggs from 3 pheasant subspecies observed in this study (1.79−1.92) was similar to the AI ranges of pheasant eggs 1.85 to 1.92 (Esen et al., 2010) and 1.89−1.98 (Ozbey et al., 2011), but lower than AI value range 2.66 to 2.94 reported by Ashraf et al. (2016). The yolk index (**YI**) values of pheasant eggs observed in this study (39.72−41.57) were close to YI values reported by Demirel and Kirikci (2009) and slightly lower than those reported by Gunlu et al. (2018) and Kirikci et al. (2005). According to significantly higher AI, average Haugh units (**HU**) value was also significantly higher ($P < 0.05$) in eggs from black pheasant than in eggs from 2 other subspecies. Demirel and Kirikci (2009) and Ozbey et al. (2011) also reported a positive correlation between AI and HU value, while Gunlu et al. (2018) reported opposite correlation. The average HU values observed in this study (75.83−79.91) were slightly lower than HU of pheasant eggs reported by Gunlu et al. (2018) and Kirikci et al. (2005), while much higher values 88.65 to 95.27 and 89.87 to 96.43 were reported by Esen et al. (2010) and Ozbey et al. (2011), respectively. The HU is usually used to evaluate the quality of eggs for consumption, that is, their freshness. However, the freshness of the breeding eggs is also important. The HU value of fresh eggs is higher, and if the eggs are stored longer the HU value decreases. Ipek et al. (2006) determined a significantly higher hatchability of fresher pheasant eggs in comparison to eggs stored for two weeks.

The mechanical characteristics of the eggs collected from three pheasant subspecies are presented in Table 3.

Table 3. Mechanical characteristics of eggs from three pheasant subspecies.

Parameter	Direction	Common pheasant	Mongolian pheasant	Black pheasant	Sig.
Breaking force (N)	X-front	26.24 ± 2.20^{a}	29.37 ± 2.77^{b}	34.25 ± 3.86^{c}	**
	X-back	21.97 ± 2.69^{a}	24.12 ± 1.75^{b}	28.01 ± 2.44^{c}	**
	Z	17.15 ± 1.80^{a}	20.17 ± 1.58^{b}	22.03 ± 1.64^{c}	**
Specific deformation (%)	X-front	0.31 ± 0.04^{a}	0.33 ± 0.06^{b}	0.36 ± 0.05^{c}	**
	X-back	0.33 ± 0.05^{a}	0.35 ± 0.04^{b}	0.40 ± 0.04^{c}	**
	Z	0.43 ± 0.05^{b}	0.40 ± 0.07^{a}	0.46 ± 0.08^{c}	**
Absorbed energy (Nmm)	X-front	1.82 ± 0.14^{a}	2.19 ± 0.38^{b}	2.82 ± 0.44^{c}	**
	X-back	1.68 ± 0.39^{a}	1.97 ± 0.33^{b}	2.60 ± 0.28^{c}	**
	Z	1.36 ± 0.26^{a}	1.87 ± 0.37^{b}	2.33 ± 0.56^{c}	**
Firmness (N/mm)	X-front	192.21 ± 42.06^{a}	204.76 ± 56.36^{b}	210.20 ± 34.77^{b}	*
	X-back	146.85 ± 30.27^{a}	149.86 ± 17.57^{a}	152.23 ± 24.76^{a}	ns
	Z	109.36 ± 11.49^{a}	111.61 ± 24.34^{a}	107.01 ± 12.91^{a}	ns

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

The results indicated that eggs from black pheasants tested in this study had higher shell strength and required significantly higher force to egg breaking ($P < 0.01$) than eggs from common and Mongolian pheasants. The average force required to breaking eggs from black pheasant in all three axes was 28.19 N, which was 14.8% higher than average force required to breaking eggs from Mongolian pheasants (24.55 N) and 29.4% higher than average force required to breaking eggs from common pheasants (21.79 N). There is very little information data in the scientific literature about mechanical characteristics of pheasant eggs. The average egg breaking force (egg breaking strength) for pheasant eggs has been reported expressed in kg/cm^2 to range 1.84 to 2.80 by Krystianiak et al. (2016). In comparison to these values, pheasant eggs tested in this study required similar average forces to egg breaking (21.79−28.19 N). The higher force need to breaking pheasant eggs of 3.94 kg/cm^2 was reported by Aygun and Olgun (2019). The highest forces required to breaking eggs from all 3 pheasant subspecies 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 Polat et al. (2007) for Japanese quail eggs and Altuntas and Sekeroglu (2008) for Lohmann chicken eggs. The strength of the egg is dependent not only on thickness of shell but also on its construction material and the egg breaking strength (Nys et al., 1999). In cases, where shell weight and thickness are good but shell breaking strength is poor, the explanation lies with the ultrastructure of the shell, or how well the shell has been constructed (Ashraf et al., 2016).

In this study, the average specific egg shell deformation during compression of pheasant eggs was observed in range 0.31 to 0.46%. The specific deformation during compression of eggs from black pheasant was significantly higher than from other 2 pheasant subspecies ($P < 0.01$). The specific deformation values for eggs compressed along the Z-axis were significantly higher than for those compressed along the both X-axes at eggs from all 3 pheasant subspecies. The same relation was also observed by Altuntas and Sekeroglu (2008) for Lohmann chicken eggs, while Polat et al. (2007) for Japanese quail eggs found the highest deformation value along the X-front axis.

The significantly higher absorbed energy was also determined for black peasant eggs in all 3 directions ($P < 0.01$). The highest absorbed energy was determined in loading along the X-front axis, while the least energy was determined along the Z-axis at eggs from all 3 pheasant subspecies. So, loading along the Z-axis required the least amount of energy to breaking the pheasant egg shell. The average values of absorbed energy for pheasant eggs observed in this study 1.85 to 2.28 Nmm (depending of compression direction) were lower to those reported for Hisex Brown chicken eggs of 2.80 to 5.10 Nmm reported by Nedomova et al. (2009), but higher than absorbed energy of 1.28 to 1.81 Nmm reported by Galic et al. (2021) for Japanese quail eggs.

The highest firmness during compression along the X-front axis was observed at eggs from common pheasant ($P < 0.05$), while there were no significant differences during compression along X-back axis and Z-axis between pheasant subspecies. The average firmness value of pheasant eggs observed in this study 109.33 to 202.39 N/mm (depending of compression direction) were higher than those reported by Galic et al. (2021) for Japanese quail eggs of 51.84 to 69.64 N/mm, but lower than firmness values of 158.59 to 269.90 N/mm reported by Nedomova et al. (2009) for Hisex Brown chicken eggs. The firmness values determined along the Z-axis were significantly lower than those determined along both X-axes at eggs from all 3 pheasant subspecies. This indicated that the lowest force was required to breaking eggs along the Z-axis.

In conclusion, the current study indicated that pheasant subspecies had significant influence on some egg quality characteristics. Considering that the Mongolian and black pheasants are less widespread pheasant subspecies in Croatia compared to the common pheasant, they can be recommended to breeders as subspecies whose females lay bigger eggs and more resistant to breakage than the eggs from common pheasant.

DISCLOSURES

The authors declare no conflicts of interest.

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