Original scientific paper
Journal of Central European Agriculture, 2019, 20(4), p.1099-1110

DOI: /10.5513/JCEA01/20.4.2432

The comparison of quality characteristics of Pekin duck and Cherry Valley duck eggs from free-range raising system

---

Usporedba kvalitativnih svojstava jaja Pekinške patke i Cherry Valley patke iz sustava slobodnog uzgoja

Ante GALIĆ, Dubravko FILIPOVIĆ (✉), Stjepan PLIESTIĆ, Zlatko JANJEČIĆ, Dalibor BEDEKOVIĆ, Igor KOVAČEV, Krešimir ČOPEC, Zlatko KORONC

University of Zagreb Faculty of Agriculture, Svetošimunska 25, 10000 Zagreb, Croatia

✉ Corresponding author: dfilipovic@agr.hr

ABSTRACT

The aim of this study was to compare physical, morphological and mechanical characteristics of eggs collected from two duck breeds (Pekin duck and Cherry Valley duck). A total sample of 120 eggs (60 eggs of each duck breed) was collected from one-year-old free range raised ducks. The Cherry Valley duck eggs were significantly heavier (94.23 vs. 71.91 g) than Pekin ducks ($P<0.01$), had larger dimensions and higher shape index (73.80 vs. 70.16). There was no statistical difference between egg specific gravity. According to egg components proportion, the Cherry Valley duck eggs had higher percentage of albumen, while the Peking duck eggs had higher percentages of yolk and shell. The Pekin duck eggs had significantly higher yolk to albumen ratio and Haugh unit value ($P<0.01$). The average force required to rupture Cherry Valley duck eggs in all three axes (50.32 N) was significantly higher ($P<0.01$) than average force required to rupture Pekin duck eggs (42.64 N). The highest egg rupture force at both duck breeds tested in this study was determined in loading along the *X*-front axis, while the least resistance to rupture force was determined along the *Z*-axis.

Keywords: duck breed, egg quality, egg weight, components proportion, shell strength

SAŽETAK

Cilj ovog istraživanja bio je usporediti fizikalna, morfološka i mehanička svojstva jaja sakupljenih od dvije pasmine pataka (Pekinška patka i Cherry Valley patka). Uzorak od 120 jaja (60 jaja od svake pasmine) prikupljen je od pataka starih godinu dana. Jaja Cherry Valley patke bila su značajno teža (94,23 prema 71.,91 g) nego Pekinške patke ($P<0.01$), imale su veće dimenzije i veći indeks oblika (73,8 prema 70,16). Nije bilo statistički značajne razlike između specifične težine jaja. Shodno udjelu glavnih komponenata, jaja Cherry Valley patke su imala veći postotak bjelanjka, dok su jaja Pekinške patke imala veći postotak žumanjka i ljuske. Jaja Pekinške patke imala su značajno veći omjer žumanjka i bjelanjka i vrijednost Haugh jedinice ($P<0.01$). Prosječna sila potrebna za razbijanje jaja Cherry Valley patke u sve tri osi (50,32 N) bila je značajno veća ($P<0.01$) od prosječne sile potrebne za razbijanje jaja Pekinške patke (42,64 N). Najveća potrebna sila za razbijanje jaja kod obje pasmine ispitane u ovom istraživanju izmjerena je kod opterećenja duž prednje *X*-osi, dok je najmanja otpornost na silu razbijanja izmjerena duž *Z*-osi.

Ključne riječi: pasmina pataka, kvaliteta jaja, masa jaja, udio komponenata, čvrstoća ljuske

INTRODUCTION

After chicken, ducks are considered the most important and common component of the poultry industry around the world. Duck production has received immense attention due to its higher profitability compared to other poultry species, mainly due to higher feed conversion ratios (El-Soukkary et al., 2005). Ducks are also considered one of the most versatile poultry species due to their ability to reared under a wide range of climatic and nutritional conditions and they are shown to be resistant to common poultry diseases and feed on a variety of food (Al-Obaidi and Al-Shadeedi, 2016). Ducks can utilize cheap raw material and produce significant amount of palatable meat and large number of eggs in a short period (Basha et al., 2016). The demand for duck meat, duck eggs and associated products is increasing each year (Fouad et al., 2018). As for other poultry species, duck production has increased during the last 100 years, but mainly since the 1950s, when breeders began selection programs accompanied by improvements in nutrition, reproduction and management and duck production in 2010 was six-fold that of 1961 (Huang et al., 2012). Ducks are breeding in Croatia for more than fifty years mainly on family farms extensively (Kralik et al., 2014). Today there are only a few large farms with more than thousand ducks in Croatia, but an increasing number of family farms starting with duck raising in the backyard under free range conditions where the number varies from a few dozens to a few hundred ducks. Although intensive duck breeding in closed buildings is being applied in a number of European countries, since little care and supplementary feeds are used in backyard duck raising, this system is still popular in some countries (Huang and Lin, 2011). In recent years the interest for duck breeding in Croatia has increased thanks to the growing interest on consuming alternative kind of meat as well as duck meat, especially in the northern part of Croatia where duck meat is often offered as a local special dish.

The duck eggs have become increasingly more important in the world because of its nutrition and less capital input is required to produce it (Huang and Lin, 2011). In several countries of the Far East duck eggs are produced and consumed in large quantities by the local population thus substituting hen eggs, but duck eggs are usually not consumed in the countries in America and Europe due to the potential Salmonella risk (Pikul, 1998). In Croatia, similar to Poland, duck eggs are mainly used for reproduction which results from their high retail prices, as well as a common opinion that they carry greater microbiological contamination than hen eggs, inclusive of Salmonella type bacteria (Kokoszynski et al., 2007).

Eggs provide nutrition and protection to the developing chicks, therefore the egg quality is of immense importance for the hatchlings (Ashraf 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 determination of properties, such as dimension, mass, volume, density, proportions of components and eggshell structure of avian eggs provides to constitute the general patterns of avian developmental and energetic, thus providing useful insight into the relationship between different developmental strategies and their evolutionary significance (Vleck and Vleck, 1987). 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 (Onagbesan et al., 2007; Popoola et al., 2015). The mechanical characteristics of eggs represent their strength under various loads in terms of several parameters such as rupture force, deformation, firmness and toughness (Abdallah et al., 1993; De Ketelaere et al., 2002; Polat et al., 2007). Eggshell must be strong enough to prevent cracking in order to preserve the embryo until hatching (Altuntas and Sekeroglu, 2008).

The aim of this study was to determine and compare some physical, morphological, and mechanical characteristics of duck eggs obtained from the two common duck breeds in Croatia, the Pekin duck and Cherry Valley duck. The Pekin duck originates from mallard *Anas platyrhynchos* and evolved in China during last centuries

(Jung and Zhou, 1980). It was introduced to the USA in about 1873 (Scott and Dean, 1991) and to Europe a few years later, and has since become the predominant table breed in many parts of the world (Cherry and Morris, 2008). Data obtained from eggs of several forms of *Anas platyrhynchos*, such as those of Pekin duck, can be used for comparisons with a regard to many aspects, such as developmental physiology, evolution and domestication effects (Balkan and Biricik, 2008). A few studies were found in the literature about quality characteristics of Pekin duck eggs, but there is scarity of literature about quality characteristics of Cherry Valley duck eggs. Cherry Valley duck is a commercial crosses of Pekin ducks and it is one of a major duck crosses that has been used for commercial duck meat production (Chaosap and Sivapirunthep, 2018). Due to its good characteristics, this breed has been distributed all over the world, including Croatia.

MATERIALS AND METHODS

Eggs collection

Duck eggs used in this study were collected from two family farms located within a circle of 60 km of the Zagreb, capitol of Croatia. On the first farm located near Krizevci (latitude 46° 01' N, longitude 16° 32' E) Pekin ducks were breeding, and on the second farm located near Ivanić Grad (latitude 45° 43' N, longitude 16° 23' E) Cherry Valley ducks were breeding. Both farms have annual production of about hundred ducks and on both farms ducks are free range raised and fed with combined forage based on cereals and with kitchen waste. Ducks spend only the night in a closed object, while during the day they are on the fenced area with allowed access to open water. According to size and housing system those farms are similar to most duck farms in that part of Croatia. Eggs were randomly collected during May 2018 from one-year-old female ducks. A total sample of 120 eggs was evaluated, consisting of 60 eggs collected from each duck breed. Eggs are stored at room temperature for 24 h before quality characteristics measurement.

Eggs physical characteristics

Length (*L*) and width (*W*) of collected eggs were measured using an electronic digital calliper with 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 and shape index (*SI*) were calculated using the following formulas (Mohsenin, 1970; Foster and Weatherup, 1979; Altuntas and Sekeroglu, 2008):

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

$$S = \pi Dg^2$$

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

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

$$SG = (EW/V)$$

where:

L – length in mm; *W* – width in mm; D_g – geometric mean diameter in mm; **S** – surface area in mm^2; *V* – volume in mm^3; *SI* – shape index in %; *SG* – specific gravity in g cm^{-3}; *EW* – egg weight in g.

The shell thickness was randomly measured from the three different parts of shell in each egg (sharp end, blunt end and equator) using an electronic digital micrometer with accuracy of 0.001 mm and was averaged. The shell density (*SD*) was calculated using the following formula (Curtis et al., 1985):

$$SD = (SW/SxST)$$

where:

SD – shell density in g/cm; *SW* – shell weight in g; *S* – surface area in mm^2; *ST* – shell thickness in cm.

Eggs morphological characteristics

After measuring the rupture forces, eggs were broken on a flat glass surface to determine the internal egg quality characteristics. The yolk and albumen height were measured using a tripod micrometer with accuracy of 0.001 mm, while yolk diameter and albumen length and width were measured using an electronic digital calliper with accuracy of 0.01 mm. After measuring the yolk and albumen dimensions, the yolks were separated from the albumen. The chalazae were carefully removed from the yolk, using forceps, and prior to weighing the yolk. Before weighing, all yolks were also rolled on a paper towel to remove adhering albumen. The shells were carefully washed and dried for 48 h in a drying oven at 21 C and then weighed. Albumen weight was determined by subtracting yolk weight and shell weight from the original egg weight. Using the individual weight of each egg and its components, 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) were calculated (Dottavio et al., 2005).

The albumen index and yolk index were calculated using the following formulas (Heiman and Carver, 1936; Sauter et al., 1951):

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

$$YI = (YH/YD)$$

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 use of Haugh units has been accepted as a measure of the quality of the albumen in various studies on egg quality (Eisen et al., 1962). To calculate the Haugh unit, the following formula was used (Haugh, 1937):

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

where:

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

Eggs mechanical characteristics

A commonly used technique for the measurement of the shell strength is the compression of an egg between two plates. To measure the forces required to rupture egg, a universal testing machine was used to compress the egg. The egg sample was placed on the fixed plate, loaded at the compression speed of 0.33 mm/s^1 and pressed with a moving plate connected to the load cell until the egg ruptured (Nedomova et al., 2009). The forces were 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 rupture 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. The series of twenty eggs was tested for each orientation.

The deformation of duck egg before rupture was measured with inductive displacement transducer HBM WA/100. The specific deformation was obtained using the following formula (Altuntas and Sekeroglu, 2008):

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

where:

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

Energy absorbed (E_a) by an egg at the moment of rupture 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 rupture force in N; D_r is the deformation at rupture point in mm.

Firmness (Q) is regarded as a ratio of compressive force to deformation at the rupture point of egg and was obtained 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 rupture force in N; D_r is the deformation at rupture point in mm.

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 60 measurements for egg physical and morphological characteristics for each duck breed and 20 measurements for egg mechanical characteristics in each of three egg compression directions and duck breed. 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 $P<0.05$ and $P<0.01$.

RESULTS AND DISCUSSION

The physical characteristics of eggs from two duck breeds are presented in Table 1. The statistically significant differences were observed between dimensions of Pekin duck and Cherry Valley duck eggs ($P<0.01$). The eggs collected from Cherry Valley ducks were in average 5.98% longer and 11.39% wider in comparison to eggs collected from Pekin ducks. Consequently, the Cherry Valley duck eggs had significantly larger geometric mean diameter, surface area and volume ($P<0.01$).

There is deficit of technical information and data in the scientific literature about quality characteristics of Cherry Valley duck eggs, so results obtained in this study were compared with quality characteristics of Pekin duck eggs and some other duck breeds eggs, and for some mechanical characteristics with those of some other poultry species. The length and width of Pekin duck eggs observed in this study were close to dimensions of Pekin duck eggs observed by Balkan and Biricik (2008) and Kralik et al. (2015), but in average shorter and wider than Pekin duck eggs observed by Al-Obaidi and Al-Shadeedi (2016). According to significantly higher length and width values ($P<0.01$) of Cherry Valley duck eggs, their average geometric mean diameter was 9.56% higher in comparison to Pekin duck eggs.

The average surface area of Pekin duck eggs observed in this study (79.86 cm^2) was close to surface area of Pekin duck eggs of 76.79 cm^2 reported by Kavitha et al. (2017) and 80.14 cm^2 reported by Balkan and Biricik (2008), but lower than average surface area of Pekin duck eggs of 88.3 cm^2 reported by Kokoszynski et al. (2007). The average volume of Pekin duck eggs observed in this study (67.23 cm^3) was close to average volume of Pekin duck eggs of 70.19 cm^3 reported by Balkan and Biricik (2008),

Table 1. Physical characteristics of Pekin duck and Cherry Valley duck eggs

Item	Pekin duck	Cherry Valley	Sig.
Length (mm)	63.88±2.42	67.70±2.42	**
Width (mm)	44.79±1.53	49.89±0.83	**
Geometric mean diameter (mm)	50.41±1.61	55.23±0.85	**
Weight (g)	71.91±5.14	94.23±4.89	**
Surface area (mm^2)	7986.42±507.55	9578.77±295.23	**
Volume (mm^3)	67227.80±6384.79	88206.05±4064.33	**
Shape index (%)	70.16±2.27	73.80±2.98	**
Specific gravity (g/cm^3)	1.06±0.02	1.07±0.02	NS
Shell thickness (mm)	0.336±0.017	0.357±0.016	**
Shell density (g/cm^3)	3.17±0.32	2.85±0.51	**

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) but higher than average volume of 63.49 cm^3 reported by Al-Obaidi and Al-Shadeedi (2016). The average values of surface area and volume of Cherry Valley duck eggs observed in this study (95.79 cm^2 and 88.21 cm^3, respectively) was significantly higher ($P<0.01$).

According to Abanikannda et al. (2007), egg length and egg width had a high positive correlation with egg weight. The Cherry Valley duck eggs were significantly heavier (94.23 vs. 71.91 g) than Pekin ducks ($P<0.01$). Egg weight is expressed in terms of size, egg size mainly influenced by body size, evolutionary status, climate, the amount of available food and some other factors, also there are enormous range in egg size among different species and within the species between individuals (Al-Obaidi and Al-Shadeedi, 2016). The size of the eggs laid by one individual may differ widely from those laid by another of the same species and breeds (Stadelman, 1995). This has also been shown in this study because the average weight of the Cherry Valley duck eggs was even 31.04% higher than weight of the Pekin duck eggs. Ipek and Sozcu (2017) classified duck eggs in three weight categories: light (<75 g), medium (76-82 g) and heavy (>83 g). According to this classification, Cherry Valley duck eggs with average weight of 94.23 g belongs to group of heavy duck eggs, while Pekin duck eggs with average weight of 71.91 g belongs to group of light duck eggs. According to Huang and Lin (2011), the average weight of duck eggs ranges from 60 to 90 g. Within that range were Pekin duck egg weights of 69.51 g (Balkan and Biricik, 2008), 77.57 g (Kralik et al., 2015), 80.7 g (Kokoszynski et al., 2007), 82.1-83.8 g (Onbasilar et al., 2007) and 82.8-86.7 g (Okruszek et al., 2008), but some authors recorded lower value like 59.03 g (Kavitha et al., 2017) or higher value like 91-45-95.56 g (Biesiada-Drzazga et al., 2014) 91.89 g (Al-Obaidi and Al-Shadeedi, 2016) and 97.31 g (Yuan et al., 2013). The weight of eggs from both duck breeds observed in this study was higher than eggs from some others duck breeds which were found in the literature: Pati duck of 57.83 g, Nageswari duck of 60.24 g and Chara-Chemballi duck of 66.23 g (Sarma et al., 2017), Dumyati duck of 61.42 g and Muscovy duck of 69.55 g (Ahmed, 2011), Mallard duck of 63.44 g (Al-Obaidi and Al-Shadeedi, 2016), Shan Ma duck of 67.30 g (Lin et al., 2016) and Brown Tsaiya duck of 64.2-67.8 g (Cheng et al., 1995).

Additionally, there were significant differences between Pekin duck and Cherry Valley duck eggs in terms of shape index ($P<0.01$). Egg shape index is defined as the ratio between its width and length. The importance of this parameter consists in the role of egg shape in the direction of turning during incubation and determination of embryo movements for nutrients utilization (Hristakieva et al., 2017). According to Sarica and Erensayin (2004), eggs 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. Cherry Valley duck egg just like most poultry egg has an oval shape (shape index value more than 72%), with one end rounded and the other more pointed. This shape results from the egg being forced through the oviduct. Muscles contract the oviduct behind the egg, pushing it forward, whereas Peking duck egg has elliptical shape (shape index value less than 72) due to high length values (Sturkie, 1986). The shape index of Peking duck eggs observed in this study (70.16%) is lower in comparison to SI values of Peking duck eggs which are found in the literature: 72.0-73.8% (Onbasilar et al., 2007), 72.0-74.4% (Ipek and Sozcu, 2017), 72.4-73.6% (Okruszek et al., 2008), 73.75% (Kralik et al., 2015) and 74.1% (Kokoszynski et al., 2007). Similar to those values was SI of Cherry Valley duck eggs observed in this study (73.80%). Contrary to all those values, considerably lower SI of Peking duck eggs (63.47%) was reported by Kavitha et al. (2017).

Among determined egg physical characteristics in this study, the duck breed did not significantly affect only the egg specific gravity. The average egg specific gravity of both duck breeds (1.06 and 1.07 g/cm^3) was close to specific gravity of Pekin duck eggs 1.08 $g\ cm^{-3}$ reported by Okruszek et al. (2008), but much lower than specific gravity of Pekin duck eggs 1.45 g/cm^3 reported by Al-Obaidi and Al-Shadeedi (2016).

The shell thickness of Cherry Valley duck eggs was significantly higher, but shell density of these eggs was significantly lower (P<0.01) in comparison to Pekin eggs due to significantly lower surface area of Pekin eggs. Average shell thickness of Pekin duck and Cherry Valley duck eggs observed in this study was 0.336 mm and 0.357 mm, respectively. Those values were close to shell thickness of Pekin duck eggs reported by Yuan et al. (2013) in range 0.33-0.34 mm, but lower in comparison to other shell thickness values of Peking duck eggs which are found in the literature: 0.38-0.40 mm (Onbasilar et al., 2007), 0.386-0.413 mm (Ipek and Sozcu, 2017), 0.387 mm (Kokoszynski et al., 2007), 0.47 mm (Kavitha et al., 2017), 0.474 mm (Kralik et al., 2015), 0.509 mm (Balkan and Biricik, 2008) and 0.65-0.68 mm (Okruszek et al., 2008). The average shell density of Pekin duck eggs observed in this study was 3.17 g/cm^3 and this is significantly higher (P < 0.01) than shell density of Cherry Valley duck eggs (2.85 g/cm^3).

The morphological characteristics of Pekin duck and Cherry Valley duck eggs are presented in Table 2. The weight of all egg components (albumen, yolk and shell) was significantly higher at Cherry Valley duck eggs due to significantly higher total weight of these eggs (P<0.01). Statistical analysis revealed that significant differences (P<0.05) were appeared in the components percentage. Cherry Valley duck eggs had higher percentage of albumen compared with Peking duck eggs, in the same time Peking duck eggs had higher percentages of yolk and shell.

Morphological structure and egg quality depends on origin, age and ducks' food as well as environmental conditions (Biesiada-Drzazga et al., 2014). Albumen and yolk weights and their ratios provide information about internal egg quality (Baykalir and Simsek, 2018). Albumen has a vital function during embryonic development via defending the embryo against pathogens and providing nutrients to the embryo (Walsh, 1993). On the other hand, the yolk has vital importance for embryo development and is the only source of lipids for embryo tissue growth (Speake et al., 1998). In accordance with the results obtained in this study on total egg weight, weights of main egg components (albumen, yolk and shell) were also significantly higher at Cherry Valley duck eggs in comparison to Pekin duck eggs.

According to Al-Obaidi and Al-Shadeedi (2016), birds are grouped according to the relative amounts of the yolk and albumen, they fall naturally into two classes.

Table 2. Morphological characteristics of Pekin duck and Cherry Valley duck eggs

Item	Pekin duck	Cherry Valley	Sig.
Albumen weight(g)	37.58±3.87	51.72±4.06	**
Yolk weight (g)	25.26±2.67	31.21±1.93	**
Shell weight (g)	9.07±0.54	11.30±0.81	**
Albumen percentage (%)	52.19±3.08	54.85±2.29	*
Yolk percentage (%)	35.16±3.32	33.17±2.26	*
Shell percentage (%)	12.65±0.73	11.98±0.35	*
Y/A ratio	0.680±0.120	0.607±0.067	**
Albumen index	0.11±0.02	0.07±0.01	**
Yolk index	0.40±0.03	0.40±0.02	NS
HU	84.84±3.64	71.15±3.57	**

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)

Egg in which the yolk constitutes between 15 to 20 % of the total weight (lower percentage of yolk and lipids) belong to the Altricial species class, egg in which the yolk constitutes between 30 to 40 % of the total weight (high percentage of yolk and lipids) belong to the Precocial species class. So, according to yolk percentage observed in this study, Pekin duck and Cherry Valley duck eggs belong to Precocial species class. The albumen percentage was significantly higher (P<0.05) at Cherry Valley duck eggs, while yolk and shell percentages were significantly higher (P<0.05) at Pekin duck eggs. The average yolk percentage of Pekin duck eggs observed in this study (35.16%) was close to yolk percentage of Pekin duck eggs in range 36.6-37.6% reported by Ipek and Sozcu (2017) and 34.06% reported by Balkan and Biricik (2008), but higher than yolk percentage of Pekin duck eggs of 32.26% reported by Al-Obaidi and Al-Shadeedi (2016) and 28.4-33.3% reported by Applegate et al. (1998). The average shell percentage of Pekin duck eggs observed in this study (12.65%) was close to shell percentage of Pekin duck eggs of 12.39% reported by Al-Obaidi and Al-Shadeedi (2016), but higher than shell percentage of Pekin duck eggs in range 8.9-9.9% reported by Ipek and Sozcu (2017) and 8.91-9.12% reported by Okruszek et al. (2008). The yolk to albumen ratio (Y/A) was also significantly higher (P<0.01) at Pekin duck eggs which were significantly smaller (P<0.01) in comparison to Cherry Valley duck eggs. 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.

The albumen index of Pekin duck eggs observed in this study (0.11) was significantly higher (P<0.01) than AI of Cherry Valley duck eggs (0.07), and also higher than AI of Pekin duck eggs as 0.06-0.08 reported by Onbasilar et al. (2011), 0.06-0.07 reported by Okruszek et al. (2008) and 0.07-0.09 reported by Okruszek et al. (2006), but lower than AI of Pekin duck eggs as 0.13 reported by Kavitha et al. (2017). The same value of yolk index was obtained in this study (0.40) for Pekin duck and Cherry Valley duck eggs. Similar values for YI of Pekin duck eggs was reported by Okruszek et al. (2006), Kokoszynski et al. (2007), Okruszek et al. (2008), Onbasilar et al. (2011) and Kavitha et al. (2017). According to significantly higher albumen index, Haugh unit value was also significantly higher (P<0.01) at Pekin duck eggs in comparison to Cherry Valley duck eggs (84.84 vs 71.15). Kavitha et al. (2017) and Onbasilar et al. (2011) also reported a positive correlation between albumen index and Haugh unit value. The average Haugh unit value observed in this study for Pekin duck eggs was higher than HU of Pekin duck eggs of 79.9 reported by Kokoszynski et al. (2007) and 63.1-74.0 reported by Onbasilar et al. (2011), while similar to HU of Pekin duck eggs of 84.20 reported by Kavitha et al. (2017).

Average values of mechanical characteristics of Pekin duck and Cherry Valley duck eggs are presented in Table 3. The significantly higher rupture forces were determined for Cherry Valley duck eggs in all three directions (P<0.01). The average force required to rupture Cherry Valley duck eggs in all three axes was 50.32 N, which was 18.01% higher than average force required to rupture Pekin duck eggs (42.64 N).

According to Szwaczkowski (2003), the egg shell strength can be expressed in various ways. The average egg rupture force (egg breaking strength) for Pekin duck eggs has been reported expressed in N to range 24.81-37.11 N (Okruszek et al., 2006) and 28.4-35.2 N (Okruszek et al., 2008), and expressed in kg/cm^2 to range 1.1-2.5 kg/cm^2 (Ipek and Sozcu, 2017), 2.8-3.4 kg/cm^2 (Onbasilar et al., 2011), 3.51-3.86 kg/cm^2 (Onbasilar et al., 2007), 3.26 kg/cm^2 (Yuan et al., 2013) and 3.94 kg/cm^2 (Kralik et al., 2015). In comparison to these values, Pekin duck eggs tested in this study had higher shell strength and required higher average force to egg rupture (42.64 N). The average force need to rupture Cherry Valley duck eggs tested in this study was significantly (P<0.01) higher (50.32 N). In comparison to Pekin duck eggs, lower forces to egg rupture are needed for Shan Ma duck eggs 28.8 N (Lin et al., 2016), Rouen duck eggs 3.43 kg cm^{-2} (Kralik et al., 2015), Brown Tsaiya duck eggs 3.4-3.9 kg/cm^2 (Cheng et al., 1995) and Longyan duck eggs 3.87-4.13 kg/cm^2 (Wang et al., 2014). Higher forces to egg rupture are needed for Dumyati duck eggs 5.04 kg/cm^2 and for Muscovy duck eggs 5.56 kg/cm^2 (Ahmed,

Table 3. Morphological characteristics of Pekin duck and Cherry Valley duck eggs

Item	Direction	Pekin duck	Cherry Valley	Sig.
Rupture force (N)	*X*-front	48.02±4.37	55.10±4.54	**
	X-back	43.80±5.69	51.67±3.24	**
	Z	36.11±3.66	44.19±3.34	**
Spec. deformation (%)	*X*-front	0.16±0.03	0.25±0.03	**
	X-back	0.17±0.02	0.26±0.03	**
	Z	0.22±0.03	0.40±0.03	**
Absorbed energy (Nmm)	*X*-front	2.41±0.46	4.67±1.01	**
	X-back	2.37±0.37	4.56±0.70	**
	Z	1.83±0.24	4.43±0.61	**
Firmness (N/mm)	*X*-front	488.95±83.10	329.92±30.17	**
	X-back	406.67±57.01	296.56±37.18	**
	Z	363.14±86.16	221.42±15.04	**

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)

2011). The highest egg rupture force at both duck breeds tested in this study was determined in loading along the *X*-front axis, while the least resistance to rupture force was 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.

In this study the specific egg shell deformation during compression of Cherry Valley duck eggs was observed in range 0.25-0.40% and it was significantly higher (P<0.01) than specific deformation during compression of Pekin duck eggs in range 0.16-0.22%. The specific deformation values of Pekin duck eggs in range 0.35-0.39% reported by Okruszek et al. (2008) and in range 0.32-0.42% reported by Okruszek et al. (2006) are closer to the values for Cherry Valley duck eggs observed in this study. The specific deformation values for eggs compressed along the *Z*-axis were significantly higher than for those compressed along the both *X*-axes. 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 absorbed energy was determined as a function of rupture force and deformation on the surface of egg. In this study, the highest absorbed energy was determined in loading along the *X*-front axis, while the least energy was determined along the *Z*-axis at both duck breed eggs. The significantly higher absorbed energy was determined for Cherry Valley duck eggs in all three directions (P<0.01). The average values of absorbed energy for Cherry Valley duck eggs 4.43-4.67 Nmm (depending of compression direction) were higher than absorbed energy for Pekin duck eggs observed in this study and also higher than those reported for Lohmann chicken eggs 3.29-3.53 Nmm (Altuntas and Sekeroglu, 2008) and for Hisex

Brown chicken eggs 2.80-5.10 Nmm (Nedomova et al., 2009), but lower than absorbed energy for goose eggs 8.68-19.99 Nmm (Nedomova et al., 2014).

The firmness values determined along the *Z*-axis were significantly lower than those determined along both *X*-axes at eggs from both duck breeds and this indicated that lower force was required to rupture eggs along the *Z*-axis. The firmness values for eggs compressed along *X*-front axis were significantly higher than along *X*-back axis. Significantly higher firmness was determined for Pekin duck eggs in all three directions. The egg firmness value of Pekin duck and Cherry Valley duck eggs observed in this study were higher than those reported for Lohmann chicken eggs 111.05-140.52 N/mm (Altuntas and Sekeroglu, 2008) and for Hisex Brown chicken eggs 158.59-269.90 N/mm (Nedomova et al., 2009).

CONCLUSIONS

Based on the obtained results in this study, it can be concluded that duck breed had significant influence on egg quality characteristics. Statistically significant differences ($P<0.05$ or $P<0.01$) between Pekin duck and Cherry Valley duck eggs were observed in all physical, morphological and mechanical characteristics except specific gravity and yolk index. The Cherry Valley duck eggs were significantly bigger and heavier and had significantly thicker egg shell. The Pekin duck eggs had significantly higher yolk percentage and yolk to albumen ratio. According to obtained mechanical properties, Cherry Valley duck eggs had stronger shell and required greater force to rupture egg than Pekin duck eggs. Results obtained in this study suggest that the values of rupture force and other mechanical properties (specific deformation, absorbed energy and firmness) depend on the direction of the loading force during egg compression.

REFERENCES

Abanikannda, O. T. F., Olutogun, O., Leigh, A. O., Ajayi, L. A. (2007) Statistical modeling of egg weight and egg dimensions in commercial layers. International Journal of Poultry Science, 6 (1), 59-63. DOI: http://dx.doi.org/10.3923/ijps.2007.59.63

Abdallah, A. G., Harms, R. H., El-Husseiny, O. (1993) Various methods of measuring shell quality in relation to percentage of cracked eggs. Poultry Science, 72 (11), 2038-2043. DOI: https://doi.org/10.3382/ps.0722038

Ahmed, A. M. H. (2011) Comparative study on the mechanical properties and ultrastructural eggshell traits for Dumyati and Muscovy ducks. Egyptian Journal of Animal Production, 48 (1), 105-118.

Ahn, D. U., Kim, S. M., Shu, H. (1997) Effect of egg size and strain and age of hens on the solid content of chicken eggs. Poultry Science, 76 (6), 914-919. DOI: https://doi.org/10.1093/ps/76.6.914

Al-Obaidi, F. A., Al-Shadeedi, S. M. J. (2016) Comparison study of egg morphology, component and chemical composition of Mallard duck and domestic Pekin duck. Journal of Genetic and Environmental Resources Conservation, 4 (1), 5-9. Available at: http://jgerc.com/wp-content/uploads/2017/12/2-5.pdf

Altuntas, E., Sekeroglu, A. (2008) Effect of egg shape index on mechanical characteristics of chicken eggs. Journal of Food Engineering, 85 (4), 606-612. DOI: https://doi.org/10.1016/j.jfoodeng.2007.08.022

Applegate, T. J., Harper, D., Lilburn, M. S. (1998) Effect of hen production age on egg composition and embryo development in commercial Pekin ducks. Poultry Science, 77 (11), 1608-1612. DOI: https://doi.org/10.1093/ps/77.11.1608

Ashraf, S., Javid, A., Ashraf, M., Akram, M., Malik, S., Irfan, Altaf, M. (2016) Influence of egg weight on egg quality parameters and growth traits in ring necked pheasants (*Phasianus colchicus*) in captivity. Journal of Animal and Plant Science, 26 (2), 331-338.

Balkan, M., Biricik, M. (2008) Main egg characteristics in the Peking duck (*Anas platyrhynchos* f. dom.). DU Ziya Gokalp Egitim Fakultesi Dergisi, 11,142-150.

Basha, H. A., Abd el Naby, W. S. H., Heikal, H. S. M. (2016) Genetic diversity and phylogenetic relationship among three duck breeds and geese using RAPD markers. Advances in Animal and Veterinary Sciences, 4 (9), 462-467. DOI: http://dx.doi.org/10.14737/journal.aavs/2016/4.9.462.467

Baykalir, Y., Simsek, U. G. (2018) Impact of different rearing systems and age on Bovans White layer's performance, egg quality traits and synthesis of heat shock protein 70 kDa. Annals of Animal Science, 18 (4), 1045-1060. DOI: https://doi.org/10.2478/aoas-2018-0027

Biesiada-Drzazga, B., Charuta, A., Banaszewska, D. (2014) Evaluation of particular traits of Pekin duck breed star 53 of French origin eggs during egg laying. Veterinarija ir Zootechnika, 67 (89), 3-9.

Chaosap, C., Sivapirunthep, P. (2018) Meat characteristics from four different cutting parts of Cherry Valley duck. MATEC Web of Conferences, 192 (4), 03056. DOI: https://doi.org/10.1051/matecconf/201819203056

Cheng, Y. S., Rouvier, R., Poivey, J. P., Tai, C. (1995) Genetic parameters of body weight, egg production and shell quality traits in the Brown Tsaiya laying duck. Genetics Selection Evolution, 27, 459-472. DOI: https://doi.org/10.1186/1297-9686-27-5-459

Cherry, P., Morris, T. R. (2008) Domestic duck production: science and practice. Wallingford: CAB International.

Curtis, P. A., Gardner, F. A., Mellor, D. B. (1985) A comparison of selected quality and compositional characteristics of brown and white shell eggs. I. Shell quality. Poultry Science, 64 (2), 297–301. DOI: http://dx.doi.org/10.3382/ps.0640297

De Ketelaere, B., Govaerts, T., Couke, P., Dewil, E., Visscher, J., Decuypere, E., De Baerdemaeker, J. (2002) Measuring the eggshell strength of 6 different genetic strains of laying hens: techniques and comparisons. British Poultry Science, 43 (2), 238-244. DOI: https://doi.org/10.1080/00071660120121454

Dottavio, A. M., Canet, Z. E., Faletti, C., Alvarez, M., Font, M.T., Di Masso, R. J. (2005) Yolk:albumen ratio in experimental hybrid layers with different paternal genotype. Archivos de Zootecnia, 54 (205), 87-95.

Eisen, E. J., Bohre, B. B., McKean, H. E. (1962) The Haugh unit as a measure of egg albumen quality. Poultry Science, 41 (5), 1461-1468. DOI: http://dx.doi.org/10.3382/ps.0411461

El-Soukkary, F. A. H, Mohamed, H. M. A., Dawoodand, A. A. A., Abd-El Sayed, S. Y. (2005) Physico-chemical, microbiological and lipid characteristics of duck meat. Minufiya Journal of Agricultural Research, 30, 527-548.

Foster, W. H., Weatherup, S. T. C. (1979) The use of specific gravity of the egg to estimate shell thickness. British Poultry Science, 20 (5), 439-443. DOI: https://doi.org/10.1080/00071667908416605

Fouad, A. M., Ruan, D., Wang, S., Chen, W., Xia, W., Zheng, C. (2018) Nutritional requirements of meat-type and egg-type ducks: what do we know? Journal of Animal Science and Biotechnology, 9 (1), 1-11. DOI: https://doi.org/10.1186/s40104-017-0217-x

Haugh, R. R. (1937) The Haugh unit for measuring egg quality. US Egg Poultry Magazine, 43, 572-573.

Heiman, V, Carver, J. S. (1936) The albumen index as a physical measurement of observed egg quality. Poultry Science, 15 (2), 141-148. DOI: https://doi.org/10.3382/ps.0150141

Hristakieva, P., Oblakova, M., Mincheva, N., Lalev, M., Kaliasheva, K. (2017) Phenotypic correlations between the egg weight, shape of egg, shell thickness, weight loss and hatchling weight of pheasants. Slovak Journal of Animal Science, 50 (2), 90-94.

Huang, J. F., Lin, C. C. (2011) Production, composition and quality of duck eggs. In: Nys, Y., Bain, M., Van Immerseel, F., eds. Improving the safety and quality of eggs and egg products. Cambridge: Woodhead Publishing, 487-508.

Huang, J. F., Pingel, H., Guy, G., Lukaszewicz, E., Baeza, E., Wang, S. D. (2012) A century of progress in waterfowl production, and a history of the WPSA Waterfowl Working Group. World's Poultry Science Journal, 68 (3), 551-563. DOI: https://doi.org/10.1017/S0043933912000645

Ipek, A., Sozcu, A. (2017) Comparison of hatching egg characteristics, embryo development, yolk absorption, hatch window and hatchability of Pekin Duck eggs of different weights. Poultry Science, 96 (10), 3593-3599. DOI: https://doi.org/10.3382/ps/pex181

Jung, Y., Zhou, Y. P. (1980) The Pekin duck in China. World Animal Review, 34, 11-14.

Kavitha, K., Raj Manohar, G., Vairamutnu, S., Ramamurthy, N. (2017) Comparative study of egg quality traits in White Pekin and Indigenous ducks of Tamil Nadu. International Journal of Science, Environment and Technology, 6 (6), 3520-3523.

Kokoszynski, D., Bernacki, Z., Korytkowska, H. (2007) Eggshell and egg content traits in Peking duck eggs from the P44 reserve flock raised in Poland. Journal of Central European Agriculture, 8 (1), 9-16. Available at: https://jcea.agr.hr/en/issues/article/398

Kralik, Z., Grčević, M., Radišić, Z., Mahmutović, H. (2015) The quality of eggs of different duck breeds. In: Pospišil, M., ed. Proceedings of 50th Croatian & 10th International Symposium on Agriculture; Opatija, Croatia, 16-20 February 2015, University of Zagreb Faculty of Agriculture, 443-446.

Kralik, Z., Visković, M., Mahmutović, H. (2014) Technological quality of duck meat. Krmiva. 56 (4), 157-162. Available at: https://hrcak.srce.hr/143530

Lin, R. L., Chen, H. P., Rouvier, R., Marie-Etancelin, C. (2016) Genetic parameters of body weight, egg production and shell quality traits in the Shan Ma laying duck (*Anas platyrhynchos*). Poultry Science, 95 (11), 2514–2519. DOI: https://doi.org/10.3382/ps/pew222

Mohsenin, N. N. (1970) Physical characteristics of plant and animal materials. Vol. 1. Structure, physical characteristics and mechanical properties. New York: Gordon & Breach Science Publishers.

Narushin, V. G., Romanov, M. N. (2002) Egg physical characteristics and hatchability. World's Poultry Science Journal, 58 (3), 297-303. DOI: https://doi.org/10.1079/WPS20020023

Nedomova, S., Severa, L., Buchar, J. (2009) Influence of hen egg shape on eggshell compressive strength. International Agrophysics. 23 (3), 249-256.

Nedomova, S., Buchar, J., Strnkova, J. (2014) Goose's eggshell strength at compressive loading. Potravinarstvo. 8 (1), 54-61. DOI: http://dx.doi.org/10.5219/346

Okruszek, A., Ksiazkiewicz, J., Woloszyn, J., Kisiel, T., Orkusz, A., Biernat, J. (2006) Effect of laying period and duck origin on egg characteristics. Archiv Tierzucht, 49 (4), 400-410. DOI: https://doi.org/10.5194/aab-49-400-2006

Okruszek, A., Ksiazkiewicz, J., Woloszyn, J., Biernat, J., Haraf, G., Orkusz, A. (2008) Selected egg quality traits of Pekin type ducks from conservative flocks. Archiv für Geflügelkunde, 72 (6), 269-274.

Onagbesan, O., Bruggeman, V., De Smit, L., Debonne, M., Witters, A., Tona, K., Everaert, N., Decuypere, E. (2007) Gas exchange during storage and incubation of Avian eggs: Effects on embryogenesis, hatchability, chick quality and post-hatch growth. World's Poultry Science Journal, 63 (4), 557-573. DOI: http://dx.doi.org/10.1017/S0043933907001614

Onbasilar, E. E., Erdem, E., Poyraz, O., Yalcin, S. (2011) Effects of hen production cycle and egg weight on egg quality and composition, hatchability, duckling quality, and first-week body weight in Pekin ducks. Poultry Science, 90 (11), 2642-2647. DOI: https://doi.org/10.3382/ps.2011-01359

Onbasilar, E. E., Poyraz, O., Erdem, E. (2007) Effects of egg storage period on hatching egg quality, hatchability, chick quality and relative growth in Pekin ducks. Archiv für Geflügelkunde, 71 (4), 187-191.

Pikul, J. (1998) Characteristics of duck eggs and the quality of duck eggs products. Archiv für Geflügelkunde, 62 (2), 72-82.

Polat, R., Tarhan, S., Cetin, M., Atay, U. (2007) Mechanical behaviour under compression loading and some physical parameters of Japanese quail (*Coturnix coturnix japonica*) eggs. Czech Journal of Animal Science, 52 (2), 50-56. DOI: https://doi.org/10.17221/2262-CJAS

Popoola, M. A., Alemede, C. I., Aremu, A., Ola, S. I. (2015) Morphometric parameters of whole egg and egg yolk of five Nigerian domesticated avian species. IOSR Journal of Agriculture and Veterinary Science. 8 (3), 41-45.

Sarica, M., Erensayin, C. (2004) Poultry products. In: Turkoglu, M., Sarica, M., eds. Poultry science breeding and diseases. Ankara: Bey-Ofset, 161-207.

Sarma, M., Nahardeka, N., Islam, R., Borah, M., Deka, P., Mahanta, J. (2017) Fatty acid profiles and physical qualities of different varieties of chicken and duck eggs. International Journal of Livestock Research, 7 (5), 105-111. DOI: http://dx.doi.org/10.5455/ijlr.20170415115028

SAS Institute, (2004) SAS/STAT User's Guide for Personal Computer. Cary, NC: SAS Institute Inc.

Sauter, E. A., Stadelman, W. J., Harns, V., McLaren, B. A. (1951) Methods for measuring yolk index. Poultry Science, 30 (4), 629-630. DOI: http://dx.doi.org/10.3382/ps.0300629

Scott, M. L., Dean, W. F. (1991) Nutrition and management of ducks. Ithaca, NY: M. L. Scott of Ithaca.

Speake, B. K., Murray, A. M., Noble, R. C. (1998) Transport and transformations of yolk lipids during development of the avian embryo. Progress in Lipid Research, 37 (1), 1-32. DOI: https://doi.org/10.1016/S0163-7827(97)00012-X

Stadelman, W. J. (1995) Quality identification of shell eggs. In: Stadelman, W. J., Cotterill, O. J., eds. Egg science and technology. New York: Food Products Press, 39-47.

Sturkie, P. D. (1986) Avian physiology. Berlin: Springer.

Szwaczkowski, T. (2003) Use of mixed model methodology in poultry breeding: Estimation of genetics parameters. In: Muir, W. M., Aggrey, S. E., eds. Poultry genetics, breeding and biotechnology. Wallingford: CAB International, 165-201.

Vleck, C. M., Vleck, D. (1987) Metabolism and energetics of avian embryos. Journal of Experimental Zoology, 1, 111-125.

Walsh, T. J. (1993) The effects of flock age, storage humidity, carbon dioxide, and length storage on albumen characteristics, weight loss and embryonic development of broiler eggs. Master's thesis. Raleigh: North Carolina State University.

Wang, S., Chen, W., Zhang, H. X., Ruan, D., Lin, Y. C. (2014) Influence of particle size and calcium source on production performance, egg quality and bone parameters in laying ducks. Poultry Science, 93 (10), 2560-2566.
DOI: https://doi.org/10.3382/ps.2014-03962

Yuan, J., Wang, B., Huang, Z., Fan, Y., Huang, C., Hou, Z. (2013) Comparison of egg quality traits, egg weight loss and hatchability between striped and normal duck eggs. British Poultry Science, 54 (2), 265-269.
DOI: https://doi.org/10.1080/00071668.2013.770449