Quality of table eggs in relation to shell colour

*N. Djokić, B. Suvajdžić, I. Vićić, N. Grković, N. Karabasil and N. Čobanović**

Abstract

The present study evaluated the quality of table eggs in relation to shell colour. The study was conducted on 60 table eggs with shells coloured white, green, blue and brown (15 eggs per colour) obtained from laying hens from the same backyard farm. The following external quality traits of table eggs were measured: egg weight, percentage of dirty and cracked eggs, egg width and length, egg shape index, eggshell colour, eggshell weight and percentage, and eggshell thickness. The following internal quality indicators of table eggs were determined: albumen weight and percentage, albumen pH value, albumen width, length and height, Haugh index, albumen index, yolk weight and percentage, yolk pH value, yolk width and height, yolk index and yolk colour. Green eggs had the lowest weight, as well as the lowest width and length. White eggs had the highest eggshell dirtiness scores and egg shape index, while brown eggs had the highest eggshell thickness and weight. Green and brown eggs had the highest albumen index and Haugh index. In addition, green eggs had the lowest yolk width and the highest yolk index. White eggs had the highest albumen and yolk width, the greatest albumen length and the lowest albumen height. Yolks of white and blue eggs had a higher sensory colour score, as well as lower L* and b* values compared to the yolks of green and brown eggs. Based on the results of this study, it can be concluded that green and brown table eggs are of better overall quality compared to white and blue table eggs.

Key words: *albumen index; albumen quality; eggshell colour; eggshell quality; yolk index*

Introduction

Table eggs are one of the oldest food products, becoming part of the human diet long before humans began to raise poultry (Al-Rubaiee, 2012). The popularity of table eggs worldwide is rooted in their high dietary and nutritional value and affordable price that make them widely accessible to both rural and urban populations, and the fact that they are not subject to major cultural or religious prohibitions (Čobanović et al., 2021; Dalle Zotte et al., 2021). The quality of table eggs is determined by their consumer acceptance with respect to shell characteristics and albumen and yolk quality traits (Pavlović et al., 2020; Dalle Zotte et al., 2021). Table eggshell quality is affected by many factors such as

Nemanja DJOKIĆ, DVM, Branko SUVAJDŽIĆ, DVM, PhD, Assistant Professor, Ivan VIĆIĆ, DVM, PhD student, Teaching Assistant, Nevena GRKOVIĆ, DVM, PhD, Assistant Professor, Nedjeljko KARABASIL, DVM, PhD, Full Professor, Nikola ČOBANOVIĆ*, (Corresponding author, e-mail: cobanovic.nikola@vet.bg.ac.rs), DVM, PhD, Assistant Professor, University of Belgrade, Faculty of Veterinary Medicine, Serbia

shell thickness, shell breaking resistance, visible shell dirtiness and defects, density, shell weight, shell percentage and shell colour (Baylan et al., 2017).

Eggshell colour is mainly genetically determined and is a characteristic of specific breed and strain, while stress, hen age (older hens lay lighter coloured eggs) and infectious disease (infectious bronchitis and egg drop syndrome) can partially influence its pigments, while ambient conditions or diet affect colour only to a negligible degree (Samiullah et al., 2015; Drabik et al., 2021). Eggshell colour within each country is dictated by consumer preference, so it represents an important economic quality parameter of table eggs (Li et al., 2006; Yang et al., 2009). Consumer preferences for eggshell colour vary worldwide, even though prices may differ, particularly if the colour differences are extreme (white, green, blue and brown) (Li et al., 2006; Drabik et al., 2021). Consumers in China, South Korea, Puerto Rico, Australia, France, Italy, United Kingdom, Portugal and Ireland prefer brown eggs, while consumers from the United States and Sweden prefer white eggs (Li et al., 2006; Aygun, 2014; Čobanović et al., 2021). However, nearly equal numbers of brown and white eggs are consumed in the Netherlands, Germany and Spain (Aygun, 2014).

Studies of egg colour from a large number of different bird species demonstrated that it depends on three major pigments, *i.e*. biliverdin-IX, zinc chelate and protoporphyrin-IX, which in varying proportions give all possible shades of eggshells (Li et al., 2006; Aygun, 2014; Baylan et al., 2017; Drabik et al., 2021) Protoporphyrin-IX is produced as a result of the breakdown of haemoglobin in the blood (Yang et al., 2009), while biliverdin-IX is synthesised in the shell gland of the oviduct and from there deposited on the eggshell (Čobanović et al., 2021; Drabik et al., 2021). However, some authors (Drabik et al., 2021) reported that protoporphyrin-IX is also synthesised in the shell gland of the oviduct and then deposited on the eggshell. The absence of pigments or their very low content is characteristic for white eggs (Drabik et al., 2021). Blue and green eggs contain relatively large amounts of biliverdin and zinc chelates, while brown eggs contain large amounts of protoporphyrin-IX and small amounts of biliverdin-IX (Aygun, 2014; Baylan et al., 2017; Drabik et al., 2021). It has also been reported that the pigment biliverdin-IX and its reduction product bilirubin are powerful antioxidants, while protoporphyrin-IX increases the resistance of the eggshell against breaking and has strong antimicrobial activity against Gram-positive bacteria (Baylan et al., 2017; Samiullah et al., 2017). Aside from these three main pigments, minerals such as iron, selenium and manganese also participate in the formation of eggshell colour, and can be found in higher concentrations in brown-shelled eggs (Drabik et al., 2021).

The scientific literature concerning the effect of eggshell colour on external and internal quality traits of table eggs is very limited. Several studies have been conducted to determine the effect of eggshell colour on table egg quality, however, the results showed ambiguity, discrepancies and contradictory findings. Namely, some studies reported that quality of table eggs is not influenced by eggshell colour (Li et al., 2006), while others demonstrated only its impact on shell quality characteristics (Ingram et al., 2008; Yang et al., 2009, Aygun, 2014). In contrast, some studies (Al-Rubaiee, 2012; Baylan et al., 2017; Drabik et al., 2021) reported that eggshell colour has a significant effect on both the internal and external quality of table eggs. Therefore, the aim of this study was to determine the quality of table eggs in relation to shell colour (white, green, blue and brown).

Material and Methods

The study was conducted on 60 table eggs with different shell colour (white, green, blue and brown) obtained from laying hens from the same backyard farm (Figure 1). For each shell colour, a total of 15 table eggs were collected. White eggs originated from the Italian and White Leghorn hen breeds, blue eggs from the Araucana hen breed (Easter egger chickens), brown eggs from the Marans breed, while green eggs were obtained from crossbreed hens (Araucana × Marans, olive egger chickens). Laying hens used in this study were of different age: (i) Italian and White Leghorn laying hens - 3 years old; (ii) Araucana laying hens - 2 years old; (iii) Marans laying hens - 2 years old; and (iv) Araucana × Marans laying hens - 9 months old. All samples of table eggs were "A" class and "M" size (53–63 g), except for green eggs which were "S" size (<53 g). Sampling was carried out on the fifth day after the eggs were laid. The samples were transported in a hand-held refrigerator at a temperature of 0 to 4°C within two hours of sampling in the Laboratory for Sensory Testing of the Department of Hygiene and Food Technology of Animal Origin (Faculty of Veterinary Medicine, University of Belgrade) for further testing.

Eggshell quality indicators

Determination of table egg weight

The weight of table eggs was determined by measuring the weight of each egg on an electronic scale (WPS 600/C, Radwag, Radom, Poland) with an accuracy of ±0.05 g. After determination of weight, table eggs was classified based on the Serbian regulation (2019): "XL" − very large (≥73 g); "L" − large (from 63 g to 73 g); "M" − medium (from 53 g to 63 g); and "S" − small (<53 g).

Determination of table eggs with cracks

Eggshells were visually inspected for cracks. The frequency of table eggs with cracks (%) was determined by calculating the number of broken eggs and dividing by the total number of tested eggs.

Determination of eggshell cleanliness

Eggshell cleanliness was examined in two ways: i) by examining the presence of dirt on the eggshell; ii) by examining the degree of eggshell cleanliness. The eggshell was considered clean when dirt was observed on less than 5% of the shell area (Philippe et al., 2020). The degree of eggshell cleanliness was determined using a five-point scale as follows (Attia et al., 2014): grade 5 –

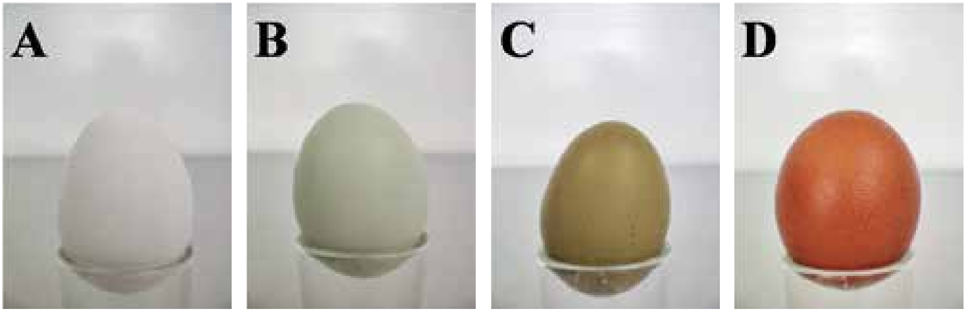

Figure 1. Table eggs with different shell Colour: **A** – White; **B** – Blue; **C** – Green; **D** – Brown

excellent (absence of dirt and traces of faecal material and/or bedding on eggshell); grade 4 – remarkably clean (remarkably clean and without traces of faecal material and/or bedding on eggshell); grade 3 – good (eggs have a clean shell and an acceptable appearance, with no traces of faecal material and/or bedding); grade 2 – fair (eggshell is dirty, but with no traces of faecal material and/or bedding); grade 1 – dirty eggs (eggshell is dirty and there are faecal material and/or bedding present on the shell).

Determination of egg shape index

Egg shape index was determined by measuring the length and width of the egg in millimetres using digital callipers (Precision Measuring, China) with an accuracy of 0.01 mm. The egg shape index was then calculated based on the following formula (Yang et al., 2009): Egg shape index = (Egg length / Egg width) x 100. Table eggs are classified based on the shape index as follows (Duman et al., 2016): i) sharp eggs − shape index less than 72; ii) normal (standard) eggs − shape index between 72 and 76; iii) round eggs − shape index greater than 76.

Determination of eggshell weight and percentage

The weight and percentage of the eggshell were determined after breaking the eggs and separating the content of the eggs (albumen and yolk) with an egg separator. Before measuring the eggshell weight, the inner membrane was not removed, and the shell was wiped with a paper towel. The shell weight was determined by measuring on an electronic scale (WPS 600/C, Radwag, Radom, Poland) with an accuracy of ± 0.05 g. After determination of eggshell weight, eggshell percentage (%) was calculated based on the following formula: Eggshell percentage = (Egg weight / Eggshell weight) x 100.

Determination of eggshell thickness

The eggshell thickness with the inner membrane was determined by measuring its thickness in millimetres on the sharp, equatorial and blunt part of the egg using digital callipers (Precision Measuring, China) with an accuracy of 0.01 mm. After determination of eggshell thickness on the sharp, equatorial and blunt part of the egg, shell thickness uniformity was calculated based on the following formula (Yan et al., 2014): Eggshell thickness = (sharp end thickness + equator thickness + blunt end thickness) / 3.

Determination of eggshell colour

Instrumental eggshell colour measurements were determined on the sharp, equatorial and blunt part of the egg using a portable colorimeter (NR110, 3NH Technology Co., Ltd, Shenzhen, China) equipped with a 8 mm aperture, 2° viewing angle, and D65 illuminant. Before measurement, the colorimeter was calibrated according to the manufacturer's instructions. The average L*, a* and b* values of three measurements on each part of the egg were taken as a final result. After determination of L*, a* and b* average values, the E value on the sharp, equatorial and blunt part of the egg was calculated based on the following formula (Baylan et al., 2017): E value= $(L^{*2} + a^{*2} + b^{*2})^{1/2}$. Using the obtained E values on the sharp, equatorial and blunt part of the egg, the E value of the whole egg was determined based on the following formula (Baylan et al., 2017): $E_{whole\ egg}$ value = E value = $(E_{Sharp\ end} + E_{Equatorial} + E_{Blunt\ end}) / 3$. A lower $E_{whole\ egg}$ value represents a darker eggshell colour.

Albumen quality indicators

Determination of albumen weight and percentage

Albumen weight was determined after breaking the eggs and separating the shell and yolk with an egg separator. Determination of albumen weight was performed by measuring on an electronic scale (WPS 600/C, Radwag, Radom, Poland) with an accuracy of ± 0.05 g. After determination of albumen weight, the percentage of albumen (%) was calculated based on the following formula: Albumen percentage = (Egg weight / albumen weight) x 100.

Determination of albumen pH

Albumen pH was determined at three different points using a pH meter (Inolab pH Level 1, WTW Gmbh Weilheim, Germany) equipped with a glass electrode (Hamilton biotrode, Bonaduz, Switzerland). The pH meter was calibrated with standard solutions pH 7.00±0.01 and pH 4.00±0.01 at 20°C (Reagecon Biomedical, Ireland) according to the manufacturer's instructions. The average of the three pH value measurements was taken as a final result.

Determination of Haugh index

The determination of the Haugh index was performed by measuring the egg weight and albumen thickness. Egg weight was measured as previously described. Thereafter, the eggshell was broken and egg content was transferred into a Petri dish, and then albumen height was measured using digital callipers (Precision Measuring, China) with an accuracy of 0.01 mm. The Haugh index was determined based on the following formula (Haugh, 1937): Haugh index = 100_{log}x (H + 7.51 –1.7 x $W^{0.37}$), with W = egg weight (g) and H = albumen height (mm).

Determination of albumen index

For determination of the albumen index, the eggshell was broken and egg content was transferred into a Petri dish. Afterwards, albumen height (at a distance of 1 cm from the edge of the yolk), length (from the longest edges of the albumen) and width (from the widest edges of the albumen) were measured using digital callipers (Precision Measuring, China) with an accuracy of 0.01 mm. The height, length and width of the albumen were determined without separating it from the yolk. After determination of albumen height, length and width, the albumen index was calculated based on the following formula (Baylan et al., 2017): Albumen index = (Albumen height / Albumen length + Albumen width) x 100.

Yolk quality indicators

Determination of yolk weight and percentage

Yolk weight was determined after breaking the eggs and separating the shell and albumen with an egg separator. The yolk weight was measured on an electronic scale (WPS 600/C, Radwag, Radom, Poland) with an accuracy of ± 0.05 g. After determination of yolk weight, the yolk percentage (%) was calculated based on the following formula: Yolk percentage = (Egg weight / Yolk weight) x 100.

Determination of yolk pH

Yolk pH value was determined at three different points using a pH meter (Inolab pH Level 1, WTW Gmbh Weilheim, Germany) equipped with a glass electrode (Hamilton biotrode, Bonaduz, Switzerland). The pH meter was calibrated with standard solutions pH 7.00±0.01 and pH 4.00±0.01 at 20°C (Reagecon Biomedical, Ireland) according to the manufacturer's instructions. The average of the three pH value measurements was taken as a final result.

Determination of yolk index

For the determination of the yolk index, the eggshell was broken and egg content was transferred into a Petri dish. Yolk width and height were measured using digital callipers (Precision Measuring, China) with an accuracy of 0.01 mm. The yolk width and height were determined without separating it from the albumen. After determination of yolk width and height (at its middle), the yolk index was calculated based on the following formula: Yolk index = (Yolk height / Yolk width) x 100.

Determination of yolk colour

Sensory and instrumental methods were used for determination of yolk colour. In order to determine yolk colour, the eggshell was broken and egg content was transferred into a Petri dish (50 mm in diameter). The sensory colour of yolk was determined by an analytical panel of three experienced sensorists based on the Roche Yolk Colour Fan standard (DSM, Basel, Switzerland), whereby colour scores ranged from 1 (pale yellow) to 16 (dark orange). Instrumental yolk colour measurements were determined using a portable colorimeter (NR110, 3NH Technology Co., Ltd, Shenzhen, China) equipped with an 8 mm aperture, 2° viewing angle, and D65 illuminant. Before measurement, the colorimeter was calibrated according to the manufacturer's instructions. During instrumental measurement of yolk colour, the colorimeter aperture was leaned on the vitelline membrane. The average L*, a*, and b* values of three yolk colour measurements were taken as a final result.

Statistical analysis

Statistical analysis of the results was conducted with SPSS software (Version 23.0, IBM Corporation, Armonk, NY, USA) (SPSS, 2015). Before any formal statistical analysis, data were checked for linearity, normality of residuals (Shapiro–Wilk and Kolmogorov–Smirnov test), outliers, and homogeneity of variance (Levene's test), and successfully passed all tests. According to the shell colour, table eggs were divided into four groups: i) white eggs (*n*=15); ii) green eggs (*n*=15); iii) blue eggs (*n*=15); and iv) brown eggs (*n*=15). One-way analysis of variance (ANOVA) was performed to detect significant differences of various eggshell, albumen and yolk quality parameters between different eggshell colours. Significant means at $P \leq 0.05$ were further compared using Tukey's test (multiple comparisons). All results were described by descriptive statistics - mean value and standard error of the mean. The Chi-squared test was used to determine the frequency of cracked eggs, dirty eggs and eggs with different shape index between different eggshell colours. Pearson correlations were calculated to determine the relationship between $E_{whole\ egg}$ value and shell, albumen and yolk quality traits of table eggs. The Pearson correlation coefficient (r_p) was classified as weak (r| < 0.35), moderate (0.36 ≥ |r| < 0.67) or strong (|r| ≥ 0.68). In all tests, statistical significance was accepted at $P < 0.05$, tendencies were accepted at $0.05 < P < 0.10$.

Results

Effects of eggshell colour on shell, albumen and yolk quality traits of table eggs

Effects of eggshell colour on shell quality of table eggs are shown in Table 1. Eggshell colour had a significant effect ($P<0.05$) on all shell quality traits, except on egg shape quality classes ($P>0.05$). Effects of eggshell colour on albumen and yolk quality of table eggs are shown in Table 2. Eggshell colour had a significant effect ($P<0.05$) on all albumen quality traits, except on albumen weight. Eggshell colour had a significant effect ($P<0.05$) on most yolk quality traits, excluding yolk pH value and yolk height ($P>0.05$).

Pearson correlations between $E_{whole\ egg}$ value and shell, albumen and yolk quality traits of table eggs

Pearson correlations between $E_{whole\ egg}$ value and shell, albumen and yolk quality traits are shown in Table 3. $E_{whole\ egg}$ value weakly positively correlated (P<0.05) with egg width and egg shape index, but weakly negatively correlated (P<0.05) with eggshell dirtiness score. In addition, a moderate negative correlation (P<0.05) was found between $E_{whole\ egg}$ value and eggshell thickness. $E_{whole\ egg}$ value moderately positively correlated (P<0.05) with albumen pH, albumen width and albumen length, but moderately negatively correlated (P<0.05) with albumen height, Haugh index and albumen index. A weak positive correlation (P<0.05) was found between $E_{whole\ egg}$ value and yolk pH value. Additionally, $E_{whole\ egg}$ value moderately negatively correlated (P<0.05) with L* and b* values of yolk and weakly negatively correlated (P<0.05) with yolk sensory colour score.

Discussion

Effects of eggshell colour on external quality of table eggs

The present study found that green eggs had a lower weight compared to table eggs of other shell colours. The table egg weight is an important indicator from the economic aspect, considering that eggs with higher weight are more prone to cracking and, thus, there is a greater possibility for microbiological contamination of yolk and albumen compared to eggs of lower weight (Soria et al., 2013; Attia et al., 2014). Therefore, the results of this study suggest that green eggs had the lowest risk of breakage in the table egg supply chain. However, it is unlikely that the difference in egg weight is a consequence of eggshell colour, but can be ascribed to other factors such as breed, diet, age and physiological condition of laying hens (Yurtseven et al., 2021). In this study, green eggs originated from olive egger laying hens (Araucana × Marans crossbreed), which were younger than other laying hen breeds and it is well known that the egg weight increases with increasing hen age (Philippe et al., 2020). Accordingly, the obtained differences in egg weight can be explained by the fact that table eggs originated from laying hens of different breeds and age.

During the examination of egg cleanliness, the percentage of dirty eggs and eggshell dirtiness scores were highest in white eggs (Table 1). Also, it was found that the eggshell dirtiness score increased with decreasing eggshell colour intensity (increased $E_{whole\ egg}$ value) (Table 3). Considering that all table eggs originated from the same backyard farm, the obtained results can be explained by the fact that the detection of dirtiness on the shell is much easier in white egg. It should be also emphasised that other factors also affect the degree of eggshell dirtiness, such as storage conditions, sanitary and hygienic conditions, and methods of egg collection and handling (Attia et al., 2014).

In this study, green eggs had the smallest width and length, while the highest shape index was recorded in white eggs (Table 1). As supporting evidence of these results, the decrease in shell colour intensity (increased $E_{whole\ egg}$ value) resulted in increased egg width and egg shape index (Table 3). In addition, the average shape index of white eggs recorded in this investigation indicates that they do not have a standard shape (between 72 and 76; Duman et al., 2016), while a high percentage of round eggs was found in this group of table eggs (53.33%, Table 1). Although the shape index may seem like a less important quality indicator of table eggs, it affects the percentage of cracked eggs, considering that round eggs or unusually long eggs do not fit perfectly in standard cardboard packaging (Philippe et al., 2020). Therefore, based on the results of the present study, it can be argued that white eggs have the highest risk of breakage in the table egg supply chain.

Table 1. Effects of eggshell colour on shell quality parameters of table eggs (*n*=60)

Egg colour	White	Green	Blue	Brown	*P* – value	Significance
N	15	15	15	15		
Egg weight (g)	54.10±1.26[a]	45.40±0.82[b]	52.40±0.99[a]	52.50±1.22[a]	<0.0001	*
Cracked eggs (%)	0.00	0.00	0.00	0.00	-	-
Dirty eggs (%)	60.00[a]	0.00[b]	33.33[c]	33.33[c]	0.0057	*
Eggshell dirtiness score	3.53±0.31[a]	4.53±0.13[b]	3.93±0.23[b]	4.50±0.18[b]	0.0052	*
Egg width (mm)	42.87±0.36[a]	39.71±0.28[b]	41.75±0.25[a]	41.65±0.45[a]	<0.0001	*
Egg length (mm)	55.71±0.70[a]	53.23±0.59[b]	56.45±0.63[a]	56.12±0.38[a]	0.0009	*
Egg shape index	77.04±0.70[a]	74.73±0.99[b]	74.06±0.75[b]	74.23±0.76[b]	0.0418	*
Egg shape quality classes						
Sharp eggs (%)	0.00	20.00	33.33	33.33	0.0856	t
Normal eggs (%)	46.67	33.33	40.00	26.67	0.6973	ns
Round eggs (%)	53.33	46.67	26.67	40.00	0.4936	ns
$E_{whole\ egg}$ value	86.43±1.85[a]	78.60±1.39[b]	63.62±0.81[c]	53.59±2.01[d]	<0.0001	*
Eggshell weight (g)	7.15±0.19[a]	6.28±0.17[b]	6.28±0.13[b]	7.35±0.22[a]	<0.0001	*
Eggshell percentage (%)	13.27±0.35[a]	13.83±0.26[a]	12.02±0.25[b]	13.74±0.33[a]	0.0002	*
Eggshell thickness (mm)	0.41±0.02[a]	0.54±0.01[b]	0.49±0.02[c]	0.60±0.01[d]	<0.0001	*

Note: Level of significance: * $P< 0.05$; t: tendency ($0.05 < P < 0.10$); ns: not significant ($P > 0.05$); different letters in the same row indicate a significant difference at $P<0.05$ [(a–d)].

Table 2. Effects of eggshell colour on albumen and yolk quality of table eggs (*n*=60)

Egg colour	White	Green	Blue	Brown	*P* - value	Significance
N	15	15	15	15		
Albumen quality parameters						
Albumen weight (g)	26.66±2.04	27.32±0.36	26.38±2.20	30.38±0.64	0.2247	ns
Albumen percentage (%)	49.66±3.68[a]	60.29±069[b]	54.19±1.67[c]	57.94±0.55[c]	0.0032	*
Albumen pH value	8.59±0.07[a]	8.58±0.05[a]	8.59±0.06[a]	8.06±0.09[b]	<0.0001	*
Albumen width (mm)	73.83±2.26[a]	55.97±1.07[b]	60.25±1.06[b]	59.61±1.02[b]	<0.0001	*
Albumen length (mm)	100.00±7.07[a]	71.48±1.78[b]	81.10±1.88[b]	68.97±1.26[b]	<0.0001	*
Albumen height (mm)	4.42±0.55[a]	7.27±0.30[b]	4.89±0.54[b]	8.92±0.25[c]	<0.0001	*
Haugh index	60.87±6.03[a]	89.34±1.55[b]	71.73±4.39[a]	96.04±1.03[b]	<0.0001	*
Albumen index	2.61±0.33[a]	5.79±0.37[b]	3.70±0.32[a]	6.97±0.23[c]	<0.0001	*
Yolk quality parameters						
Yolk weight (g)	18.07±0.84[a]	11.80±0.52[b]	17.48±0.66[a]	15.40±0.47[c]	<0.0001	*
Yolk percentage (%)	33.47±1.10[a]	25.88±0.74[b]	33.81±1.52[a]	29.29±0.33[b]	<0.0001	*
Yolk pH value	6.39±0.10	6.29±0.02	6.38±0.05	6.49±0.05	0.1819	ns
Yolk width (mm)	42.53±2.18[a]	32.03±0.72[b]	37.42±0.46[c]	37.96±0.63[c]	<0.0001	*
Yolk height (mm)	17.67±1.07	19.11±0.72	16.92±1.35	19.80±0.25	0.1199	ns
Yolk index	43.59±3.34[a]	59.97±2.42[b]	48.65±1.85[a]	49.94±0.85[a]	<0.0001	*
Yolk colour (sensory)	8.07±0.44[a]	11.23±0.42[b]	9.13±0.20[a]	11.07±0.37[b]	<0.0001	*
L* value	50.34±0.52[a]	50.24±0.65[a]	49.51±0.61[a]	41.84±0.86[b]	<0.0001	*
a* value	5.17±0.39[a]	3.22±0.45[b]	6.45±0.54[a]	3.58±0.32[b]	<0.0001	*
b* value	35.01±0.67[a]	32.97±0.56[a]	33.44±0.92[a]	24.41±1.05[b]	<0.0001	*

Note: Level of significance: * $P< 0.05$; ns: not significant ($P> 0.05$); different letters in the same row indicate a significant difference at $P<0.05$ [(a–c)].

Table 3. Pearson correlations between $E_{whole\ egg}$ value and shell, albumen and yolk quality traits

Parameters	$E_{whole\ egg}$ value		
	r_p	*P* - value	Strength
Shell quality parameters			
Egg weight (g)	0.189	0.145	-
Eggshell dirtiness scores	-0.288*	0.024	weak
Egg width (mm)	0.311*	0.015	weak
Egg length (mm)	0.006	0.961	-
Egg shape index	0.298*	0.020	weak
Eggshell weight (g)	0.174	0.179	-
Eggshell percentage (%)	0.026	0.840	-
Eggshell thickness (mm)	-0.603*	<0.0001	moderate
Albumen quality parameters			
Albumen weight (g)	-0.014	0.917	-
Albumen percentage (%)	-0.140	0.286	-
Albumen pH value	0.583*	<0.0001	moderate
Albumen width (mm)	0.605*	<0.0001	moderate
Albumen length (mm)	0.439*	<0.0001	moderate
Albumen height (mm)	-0.604*	<0.0001	moderate
Haugh index	-0.567*	<0.0001	moderate
Albumen index	-0.664*	<0.0001	moderate
Yolk quality parameters			
Yolk weight (g)	0.227	0.081	-
Yolk percentage (%)	0.171	0.190	-
Yolk pH value	0.246*	0.050	weak
Yolk width (mm)	0.105	0.419	-
Yolk height (mm)	-0.082	0.536	-
Yolk index	-0.135	0.302	-
Yolk colour (sensory)	-0.270*	0.035	weak
L* value	-0.505*	<0.0001	moderate
a* value	0.248	0.056	-
b* value	-0.546*	<0.0001	moderate

Note: Level of significance: * $P<0.05$.

Instrumental examination of shell colour revealed that brown eggs had the darkest colour (the lowest $E_{whole\ egg}$ value), while the lightest shell colour was recorded in white eggs (the highest $E_{whole\ egg}$ value) (Table 1). This is in line with the results obtained by Baylan et al. (2017), who reported that eggs with darker shell colour have lower E values, while eggs with lighter shell colour have higher E values.

Previous studies have demonstrated that the weight, percentage and thickness of the eggshell, together with the egg shape index, are important physical parameters of the table egg quality, due to their impact on shell strength, and, therefore, on the frequency of cracked and broken eggs during handling, packaging, transportation and storage (Dalle Zotte et al., 2021). In this study, the highest eggshell weight and thickness were recorded in brown eggs (Table 1). These results are further supported because the increase in shell colour intensity (decreased $E_{whole\ egg}$ value) resulted in increased eggshell thickness (Table 3). The obtained results suggest that darker coloured eggs have better physical properties and mechanical behaviour of the shell during handling, packaging, transport and storage. This indicates that the higher eggshell weight and thickness significantly reduce economic losses and the risk of microbiological contamination of egg content (Samiullah et al., 2017; Sharaf Eddin et al., 2019). Some authors (Ingram et al., 2008) have hypothesised that higher eggshell strength and thickness in brown eggs indicate a possible link between the processes of pigmentation and calcification of the shell, which implies that higher amounts of deposited protoporphyrin-IX lead to greater accumulation of calcium and phosphorus (Drabik et al., 2021). As the process of eggshell formation lasts longer, more pigments and minerals (calcium and phosphorus) are deposited into the shell, making it thicker and stronger and also resulting in a darker colour (Yang et al., 2009). In contrast, white eggs had the lowest eggshell thickness (Table 1), which further confirmed that those egg samples had the highest risk of cracking in the table egg supply chain. This can be explained by the absence or very low content of protoporphyrin-IX in white eggs, which resulted in lower deposition of calcium and phosphorus in the shell and consequently its thinner thickness.

Effects of eggshell colour on internal quality of table eggs

Although consumers are concerned about the external damages and the appearance of table eggs, from the aspect of overall table egg quality, the internal quality traits are much more important (Mertens et al., 2011; Hisasaga et al., 2020). In this study, brown eggs had the lowest albumen pH value, while the highest albumen index and Haugh index were found in brown and green eggs (Table 2). Further, increased shell colour intensity (decreased $E_{whole\ egg}$ value) resulted in a decreased albumen pH value, albumen width and albumen length and increased albumen height, Haugh index and albumen index (Table 3). Aging of table eggs, i.e., their longer storage, leads to both physical and chemical processes, and results in albumen liquefaction, decreased albumen height, albumen index and Haugh index, and increased albumen pH (Eke et al., 2013; Yamak et al., 2020; Philippe et al., 2020). The results obtained in this study indicate that brown and green eggs have higher freshness and better internal quality compared to white and blue eggs. Since the table eggs examined in this study had the same storage duration, higher freshness and better internal quality of green eggs can be attributed to the high antimicrobial activity of lysozyme and powerful antioxidant properties of biliverdin-IX (Drabik et al., 2021). On the other hand, the longer shelf life and better internal quality of brown eggs can be ascribed to the fact that protoporphyrin-IX has antimicrobial activity against Gram-positive bacteria, and, consequently, the growth of microorganisms is lower than in table eggs of other shell colours (Baylan et al., 2017; Samiullah et al., 2017). It could also be argued that the greater eggshell thickness of brown eggs represents a physical barrier that prevents the penetration of microorganisms and protects the egg content, which limits the effects of transportation and storage conditions on albumen and yolk quality traits.

The yolk index is one of the most important indicators of freshness and internal quality of table eggs, which decreases during aging (storage) (Čobanović et al., 2021). In this study, the lowest yolk width and the highest yolk index were found in green eggs (Table 2), supporting previous findings that those egg samples had better internal quality than table eggs of other shell colours. Several studies (Mertens et al., 2011; Attia et al., 2014) reported that a low yolk index may be the result of increased vitelline membrane permeability, leading to diffusion of water from the albumen to the yolk, increasing its size and weakening the vitelline membrane. The optimal values for the yolk index range from 32 to 58%, while values below 32% indicate a low internal quality of table eggs (Čobanović et al., 2021). This indicates that table eggs from all examined groups in this study had good internal quality (Table 2).

Egg yolk pigments are a mixture of carotene and xanthophylls, which together belong to a large group of carotenoids (Spasevski, 2018). The most common carotene is β-carotene, while the most common xanthophyll is lutein (Attia et al., 2014). It is important to emphasise the large oscillations in the amount of carotenoid pigments in yolk, where β-carotene content varies from 11 to 87 mg/kg (Bovšková et al., 2014), while xanthophyll content varies from 0.3 to 0.5 mg (Spasevski, 2018). The wide range of variation in the content of yolk pigments can be explained by a number of factors that affect their amount. Sensory examination revealed that brown and green eggs had a darker yolk colour (the lowest sensory colour scores) compared to white and blue eggs (Table 1). In addition, instrumental examination of yolk colour revealed the lowest L* and b* values in brown eggs (Table 1). Further, the decrease in shell colour intensity (increased $E_{whole\ egg}$ value) resulted in increased yolk sensory colour score and decreased L* and b* values of yolk (Table 3). However, eggshell colour cannot be considered a factor that can affect yolk colour, considering that it mostly depends on the laying hen diet. Since laying hens cannot synthesise carotenoids by their own biochemical processes, they ingest as much as 60% of carotenoid pigments through feed (Samiullah et al., 2017; Philippe et al., 2020; Dalle Zotte et al., 2021).

Conclusion

This study showed that brown eggs had the highest external quality traits (highest eggshell weight and thickness), while white eggs had the lowest quality of eggshell (lowest eggshell dirtiness score and the highest egg shell index). The highest albumen quality was recorded in brown and green eggs (highest albumen index and Haugh index), while the lowest albumen quality was recorded in white eggs (highest albumen width and length, but lowest albumen height). In addition, green eggs had the highest yolk quality (lowest yolk width and highest yolk index), while the lowest yolk quality was recorded in white eggs (highest yolk width). It can, therefore, be concluded that green and brown table eggs are of better overall quality compared to white and blue table eggs.

Acknowledgment

The study was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Contract number 451-03-68/2022-14/200143).

References

1. Al-RUBAIEE, M. A. M. (2012): Comparison of egg quality of brown and white shell eggs produced by

Iraqi local chicken breeds. Res. Opin. Anim. Vet. Sci. 2, 318-320.

2. ATTIA, Y. A., M. A. AL-HARTHI and M. M. SHIBOOB (2014): Evaluation of quality and nutrient contents of table eggs from different sources in the retail market. Ital. J. Anim. Sci. 13, 369-376. 10.4081/ijas.2014.3294
3. AYGUN, A. (2014): The relationship between eggshell colour and egg quality traits in table eggs. Indian J. Anim. Res. 48, 290-294. 10.5958/j.0976-0555.48.3.061
4. BAYLAN, M., L. B. CELIK, G. C. AKPINAR, S. ALASAHAN, A. KUCUKGUL and S. C. DOGAN (2017): Influence of eggshell colour on egg yolk antibody level, incubation results, and growth in broiler breeders. Rev. Bras. de Zootec. 46, 105-112. 10.1590/s1806-92902017000200004
5. BOVŠKOVÁ, H., K. MIKOVA and Z. PANOVSKÁ (2014): Evaluation of egg yolk colour. Czech J. Food Sci. 32, 213-217. 10.17221/47/2013-CJFS
6. ČOBANOVIĆ, N., B. SUVAJDŽIĆ i N. KARABASIL (2021): Ocena kvaliteta konzumnih jaja, 30. Savetovanje živinara (online), 03-05. novembar, Beograd, Živinarstvo, 7/8, 4-36.
7. DALLE ZOTTE, A., M. CULLERE, E. PELLATTIERO, A. SARTORI, A. MARANGON and V. BONDESAN (2021): Is the farming method (cage, barn, organic) a relevant factor for marketed egg quality traits? Livestock Sci. 246, 104453. 10.1016/j.livsci.2021.104453
8. DRABIK, K., M. KARWOWSKA, K. WENGERSKA, T. PRÓCHNIAK, A. ADAMCZUK and J. BATKOWSKA (2021): The variability of quality traits of table eggs and eggshell mineral composition depending on hens' breed and eggshell color. Animals 11, 1204. 10.3390/ani11051204
9. DUMAN, M., A. ŞEKEROĞLU, A. YILDIRIM, H. ELEROĞLU and Ö. CAMCI (2016): Relation between egg shape index and egg quality characteristics. Europ. Poult. Sci. 80, 1-9.
10. EKE, M. O., N. I. OLAITAN and J. H. OCHEFU (2013): Effect of storage conditions on the quality attributes of shell (table) eggs. Niger. Food J. 31, 18-24. 10.1016/S0189-7241(15)30072-2
11. HAUGH, R. R. (1937): The Haugh unit for measuring egg quality. US Egg Poult. Magazine 43, 522-555, 572-573.
12. HISASAGA, C., S. E. GRIFFIN and K. J. TARRANT (2020): Survey of egg quality in commercially available table eggs. Poult. Sci. 99, 7202-7206. 10.1016/j.psj.2020.09.049
13. INGRAM, D. R., L. F. HATTEN and K. D. HOMAN (2008): A study on the relationship between eggshell color and eggshell quality in commercial broiler breeders. Int. J. Poult. Sci. 7, 700-703. 10.3923/ijps.2008.700.703
14. LI, X. Y., G. Y. XU, Z. C. HOU, R. ZHAO and N. YANG (2006): Variation of eggshell colour in different egg-type chickens. Arch. für Geflugelkunde 70, 278-282.
15. MERTENS, K., B. KEMPS, C. PERIANU, J. DE BAERDEMAEKER, E. DECUYPERE, B. DE KETELAERE and M. BAIN (2011): Advances in egg defect detection, quality assessment and automated sorting and grading. In: Nys, Y., Bain, M. and Van Immerseel, F.: Improving the safety and quality of eggs and egg products, Nouzilly, France, pp. 209-241. 10.1533/9780857093912.2.209
16. PAVLOVIĆ, M., S. IVANOVIĆ and K. NEŠIĆ (2020): Egg production in Serbia. Worlds Poult. Sci. J. 76, 259-269. 10.1080/00439339.2020.1750327
17. PHILIPPE, F. X., Y. MAHMOUDI, D. CINQ-MARS, M. LEFRANÇOIS, N. MOULA, J. PALACIOS, F. PELLETIER and S. GODBOUT (2020): Comparison of egg production, quality and composition in three production systems for laying hens. Livestock Sci. 232, 103917. 10.1016/j.livsci.2020.103917
18. SAMIULLAH, S., J. R. ROBERTS and K. CHOUSALKAR (2015): Eggshell color in brown-egg laying hens - a review. Poult. Sci. 94, 2566-2575. 10.3382/ps/pev202
19. SAMIULLAH, S., A. S. OMAR, J. ROBERTS and K. CHOUSALKAR (2017): Effect of production system and flock age on eggshell and egg internal quality measurements. Poult. Sci. 96, 246-258. 10.3382/ps/pew289
20. SERBIAN REGULATION (2019): Regulation on egg quality. Official Gazette of the Republic of Serbia, 7.
21. SHARAF EDDIN, A., S. A. IBRAHIM and R. TAHERGORABI (2019): Egg quality and safety with an overview of edible coating application for egg preservation. Food Chem. 296, 29-39. 10.1016/j.foodchem.2019.05.182
22. SORIA, M. A., D. J. BUENO and I. I. C. BERNIGAUD (2013): Comparison of quality parameters in hen's eggs according to egg shell color. Int. J. Poult. Sci. 12, 224-234. 10.3923/ijps.2013.224.234
23. SPASEVSKI, N. (2018): Effects of different sources of natural pigments inclusion on the egg yolk colour and flaxseed, camelina seed and hempseed based co-extrudates on the fatty acids profile in eggs, Dissertation, Faculty of Technology, University of Novi Sad.
24. SPSS (Statistical Package for Social Sciences) (2015): version S23.0., SPSS Inc., Armonk, NY: IBM Corp., USA.
25. YAMAK, U. S., M. SARICA, K. ERENSOY and V. AYHAN (2021): The effects of storage conditions on quality changes of table eggs. J. Verbrauch. Lebensm. 16, 71-81. 10.1007/s00003-020-01299-6
26. YAN, Y. Y., C. J. SUN, L. LIAN, J. X. ZHENG, G. Y. XU and N. YANG (2013): Effect of uniformity of eggshell thickness on eggshell quality in chickens. J. Poult. Sci. 51, 338-342. 10.2141/jpsa.0130032
27. YANG, H. M., Z. Y. WANG and J. LU (2009): Study on the relationship between eggshell colors and egg quality as well as shell ultrastructure in Yangzhou chicken. Afr. J. Biotechnol. 8, 2898-2902.
28. YURTSEVEN, E. P., A. ŞEKEROĞLU, B. TAINIKA, M. DUMAN and Y. E. ŞENTÜRK (2021): Effect of Production System and Age on Egg Quality Parameters: A Case of Niğde Province Çamardı District, Turkey. TURJAF 9, 1407-1412. 10.24925/turjaf.v9i8.1407-1412.4241

Kvaliteta konzumnih jaja u odnosu na boju ljuske

Nemanja DJOKIĆ, dr. med. vet., dr. sc. Branko SUVAJDŽIĆ, dr. med. vet., docent, dr. sc. Ivan VIĆIĆ, dr. med. vet., poslijedoktorant, viši asistant, dr. sc. Nevena GRKOVIĆ, dr. med. vet., docentica, dr. sc. Nedjeljko KARABASIL, dr. med. vet., redoviti profesor, dr. sc. Nikola ČOBANOVIĆ, dr. med. vet., docent, Univerzitet u Beogradu, Fakultet veterinarske medicine, Beograd, Srbija

Cilj je istraživanja ovoga rada bio istražiti kvalitetu konzumnih jaja u odnosu na boju ljuske. Istraživanje je provedeno na 60 konzumnih jaja različite boje ljuske (bijela, zelena, plava i smeđa) podrijetlom s istog privatnog gospodarstva (15 jaja po grupi). Od vanjskih parametara kvaliteta konzumnih jaja ispitivani su: masa, postotak s oštećenjem ljuske, postotak prljavih, dužina i širina, indeks oblika, boja ljuske, masa i postotak ljuske i debljina ljuske. Od unutarnjih parametara kvaliteta konzumnih jaja ispitivani su: masa i postotak bjelanjka, pH bjelanjka, širina, dužina i visina bjelanjka, Hugov indeks, indeks bjelanjka, masa i postotak žutanjka, pH žutanjka, širina i visina žutanjka, indeks žutanjka i boja žutanjka. Zelena jaja su imala najmanju masu, kao i najmanju dužinu i širinu. Bijela jaja su imala najveći stupanj zaprljanosti ljuske i najveći indeks oblika, dok su smeđa jaja imala najveću debljinu i masu ljuske. Zelena i smeđa jaja su imala najveći indek bjelanjka i Hugov indeks. Pored toga, zelena jaja su imala i najmanju širinu žumanjka i najveći indeks žutanjka. Kod bijelih jaja utvrđena je najveća širina žutanjka i bjelanjka, najveća dužina bjelanjka, a najmanja visina bjelanjka. Bijela i plava jaja su imala veću senzornu ocjenu za boju žumanjka, kao i manju L* i b* vrijednost instrumentalno određene boje žumanjka u usporedbi sa zelenim i smeđim jajima. Na osnovi rezultata ovog istraživanja može se zaključiti da su konzumna jaja sa zelenom i smeđom bojom ljuske bolje kvalitete u odnosu na jaja s bijelom i plavom bojom ljuske.

Ključne riječi: *boja ljuske, indeks bjelanka, indeks žutanjka, kvaliteta bjelanka, kvaliteta ljuske*