meat technology
Founder and publisher: Institute of Meat Hygiene and Technology, Belgrade

UDK: 637.411.053
ID: 69478665
https://doi.org/10.18485/meattech.2022.63.1.7

Original Scientific Paper

Assessment of marketed table egg quality originating from different production systems

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A b s t r a c t: The present study evaluated the quality of marketed table eggs originating from enriched cage, barn, organic or free-range production systems. Table eggs from the free-range production system had the highest diameter, the lowest shape index and the highest frequency of normal-shaped table eggs. In addition, the lightest shell colour was found in table eggs from the free-range production system. The highest shell thickness was found in table eggs from the enriched cage production system, while the lowest shell thickness was found in table eggs from the free-range production system. Table eggs from organic and free-range production systems had better internal quality and freshness (lower albumen and yolk pH values, and a higher albumen and Haugh index) compared to table eggs from enriched cage and barn production systems. Compared to the other production systems, the best physical quality traits were recorded in table eggs from the free-range production system (the highest egg weight, weight and proportion of yolk, but the lowest weight and proportion of shell and albumen). In addition, the lightest yolk colour was found in table eggs from the organic production system. In conclusion, table eggs from organic and free-range production systems are of better overall quality compared to those from enriched cage and barn production systems.
Keywords: *albumen quality, egg freshness, eggshell colour, eggshell quality, yolk quality.*

Introduction

Owing to their highly competitive price compared to other foods, the absence of cultural and religious obstacles to their consumption, and their dietary and nutritional qualities, table eggs are consumed on a massive scale throughout the world (*Čobanović et al., 2021; Dalle Zotte et al., 2021*). A number of factors could influence the quality of table eggs within the production chain, including hen breed, genotype, physiological status and laying age, along with the production system, feeding strategy, eggshell colour, and egg processing and storage conditions (*Dalle Zotte et al., 2021; Djokić et al., 2022*).

Referring to production systems, battery cages played an important role in traditional table egg production since the 1950s (*Lordelo et al., 2017; Dalle Zotte et al., 2021; Yurtseven et al., 2021*). The objectives of this production system were to provide for laying hen's health and product safety, and minimise workload, but maximise profit and productivity (*Dalle Zotte et al., 2021*). However, there were serious hen welfare concerns regarding conventional cages, because insufficient space and restricted movement provide no or few opportunities for laying hens to express natural behaviours, such as nesting, perching, foraging and wing flapping, which led to metabolic and skeletal disorders (*Philippe et al., 2020; Yurtseven et al., 2021*). For these reasons, the breeding of laying hens in conventional cages in the European Union (EU) has been banned since 2012 and shortly afterwards in Serbia (*Terčič et al., 2012; Pavlović et al., 2020; Philippe et al., 2020; Dalle Zotte et al., 2021*).

Conventional cages were then replaced by alternative production systems, including enriched cages and non-cage systems (barn, free-range and organic), which provide more available space and specific resources including nest boxes, perches, and pecking and scratching areas (*Terčič et al., 2012; Pavlović et al., 2020; Philippe et al., 2020*). Enriched cage production systems are characterised by structural improvements aiming at enhancing hen welfare and typically consist of multiple tiers of cages installed in environmentally controlled poultry houses. Enriched cages must provide a minimum

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floor space allowance of 750 cm^2 per hen, of which 600 cm^2 is 45 cm high, a feeding area of at least 10 cm^2 for each hen and at least 10 cm for water supply, nest, littered area to express scratching and pecking behaviour, 15 cm of perch and a claw shortening device (*Lordelo et al., 2017; Pavlović et al., 2020; Dalle Zotte et al., 2021*).

In barn production systems, laying hens are reared on deep littered floors in a confined poultry house under completely controlled ambient conditions (*Lordelo et al., 2017; Dalle Zotte et al., 2021*). In this production system, laying hens are provided with automated feeding and drinking systems, perches and stepping rails to automated egg collection nest boxes (*Samiullah et al., 2017*).

In a typical free-range production system, laying hens are kept in poultry houses, which are often very similar to those in the barn production system, but birds also have access to a grassed outdoor free-range area (*Samiullah et al., 2017*). The outdoor free-range area provides a natural environment, ease of movement and enough space to allow the laying hens to express their natural behaviours in addition to exposure to sunlight, fresh air, and plenty of water and unlimited free dietary components like pastures, forages, plants, weeds, earthworms, worms and small insects (*Bughio et al., 2021; Dalle Zotte et al., 2021; Yurtseven et al., 2021*).

Organic production of table eggs, regulated by the Council Regulation (EC) 834/2007 (*European Union, 2007*), relies on a number of specific and restrictive production standards, including the provision of organic feed that must be free of synthetic additives and genetically modified organisms (*Lordelo et al., 2017; Dalle Zotte et al., 2021*).

Each production system has its own advantages and disadvantages, which is the main reason why all four production systems (*enriched* cage, barn, free-range and organic) still exist in Serbia and many other countries. The heterogeneity in production system, and consequently in management, can directly affect the table egg quality. However, scientific investigations into the effects of the production system on table egg quality are limited and have shown uncertainty, discrepancy and contradictory findings. Namely, table eggs from enriched cage production systems may contain more carotenoids and vitamins, as a result of chemical additives used in commercial feed mixtures, which are forbidden in organic production systems (*Dalle Zotte et al., 2021*). In contrast, some authors (*Samiullah et al., 2017; Yurtseven et al., 2021*) reported that table eggs from free-range production systems are preferable to those from other systems in terms of shell weight and thickness, albumen index and Haugh index. Other authors (*Dalle Zotte et al., 2021*) found that hens' diets in this production system may vary depending on type and quantity of herbs consumed and the ingestion of small invertebrates, thus leading to table eggs with different quality traits. Despite the fact that many consumers perceive organic table eggs as a higher quality food product and are, therefore, also willing to pay a higher price, a recent study reported (*Dalle Zotte et al., 2021*) that those eggs have lower contents of protein, fat and ash compared to table eggs from other production systems, indicating their lower quality. For barn production systems, the scientific literature reports their negative influence on table egg quality traits (weight, composition, strength, cleanliness, bacterial contamination and conservation of those qualities), with serious consequences on profitability (*Philippe et al., 2020*).

In spite of the role of different production systems on table egg quality, only scarce data and heterogeneous results are available on the quality traits of marketed table eggs, although such data are of paramount importance for consumers (*Lordelo et al., 2017; Dalle Zotte et al., 2021*). In fact, the problem for table egg consumers is that at the time of purchase (and even consumption), labels for marketed table eggs do not provide any information about the hen's breed, genotype, age or feed formulation, which are very important for the product quality. Therefore, the aim of this study was to determine the effects of different production systems (enriched cage, barn, free-range and organic) on the quality of marketed table eggs.

Materials and Methods

The study was conducted on 80 marketed table eggs obtained from brown egg-laying hens. Four large egg cartons of table eggs (n = 20) were purchased at the same local retail market, located in Belgrade, Serbia, each originating from a different egg production system (enriched cage, barn, free-range and organic). Table eggs from each production system were at the beginning of shelf life (fifth day after laying), class A and size M (53–63 g). All table eggs were kept on shaved ice (at 4 ± 1°C) in a cooler box and transported within one hour to the Sensory Analysis Laboratory (Department of Food Hygiene and Technology, Faculty of Veterinary Medicine, University of Belgrade) for further analysis.

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 determining the weight, table eggs were 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 for the presence of dirt on the eggshell; ii) by examining for the degree of eggshell cleanliness. 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 – 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 there are 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 a digital calliper (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) × 100. Table eggs were 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 determining the eggshell weight, the eggshell percentage (%) was determined based on the following formula: Eggshell percentage = (Egg weight / Eggshell weight) × 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 parts of the egg using a digital calliper (Precision Measuring, China) with an accuracy of 0.01 mm. After determination of the eggshell thickness at the three points, the shell thickness uniformity was calculated based on the following formula (*Yan et al., 2014*): Eggshell thickness = (sharp end thickness + equatorial end thickness + blunt end thickness) / 3.

Determination of eggshell colour

Sensory and instrumental methods were used for determination of eggshell colour. The sensory colour of eggshell was determined by an analytical panel of three experienced sensorists based on the Grading eggshell colour standard, whereby colour scores ranged from 1 (light) to 5 (dark) (*Karabasil et al., 2020*). 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 = $(E_{Sharp\ end} + E_{Equatorial\ part} + E_{Blunt\ end}) / 3$.

According to the $E_{whole\ egg}$ value, table eggs were classified as follows (*Baylan et al., 2017*): i) dark eggs ($E_{whole\ egg}$ < 64); ii) medium ($E_{whole\ egg}$ value between 64 and 67); iii) light eggs ($E_{whole\ egg}$ > 67).

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 the albumen weight, the percentage of albumen (%) was determined based on the following formula: Albumen percentage = (Egg weight / albumen weight) × 100.

Determination of albumen pH

Albumen pH was determined in 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 measurements was taken as the final result.

Determination of Haugh index

The determination of 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 a digital calliper (Precision Measuring, China) with an accuracy of 0.01 mm. The Haugh index was determined based on the following formula (*Haugh, 1937*): Haugh index = $100_{log} \times (H + 7.51 - 1.7 \times W^{0.37})$, with W = egg weight (g) and H = albumen height (mm).

Determination of albumen index

For the determination of 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 a digital calliper (Precision Measuring, China) with an accuracy of 0.01 mm. The height, length and width of the albumen were determined without separating 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) × 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 determined based on the following formula: Yolk percentage = (Egg weight / Yolk weight) × 100.

Determination of yolk pH

Yolk pH value was determined in 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 the final result.

Determination of yolk index

For the determination of yolk index, the eggshell was broken and egg content was transferred into a Petri dish. Yolk width and height were measured using a digital calliper (Precision Measuring, China) with an accuracy of 0.01 mm. The yolk width and height were determined without separating from albumen. After determination of yolk width and height (on its middle), the yolk index was calculated based on the following formula: Yolk index = (Yolk height / Yolk width) × 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 a 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, 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 tests), outliers, and homogeneity of variance (Levene's test), and successfully passed all tests. According to the production system, marketed table eggs were divided into four groups: i) enriched cage (n = 20); ii) barn (n = 20); iii) organic (n = 20); and iv) free-range (n = 20). One-way analysis of variance (ANOVA) was performed to detect significant differences of various eggshell, albumen and yolk quality parameters between different egg production systems. 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 and shell colour with respect to the egg production system. In all tests, statistical significance was accepted at $P < 0.05$, tendencies were accepted at $0.05 < P < 0.10$.

Results and Discussion

Effects of production system on the external quality traits of table eggs

Effects of the production system on shell quality of table eggs are depicted in Table 1. The present investigation found the highest ($P<0.05$) egg weight in eggs from the free-range production system, while the lowest ($P<0.05$) egg weight was recorded in eggs from the organic production system. The results of previous studies on the impact of the production system on the egg weight are not consistent. Some investigations (*Djukić-Stojčić et al., 2009; Lordelo et al., 2017; Samiullah et al., 2017; Philippe et al., 2020*) found a higher egg weight in laying hens reared in the enriched cage production system compared to those from barn and free-range production systems. Other authors (*Samiullah et al., 2017*) found the largest egg weight in laying hens from the free-range production system. On the other hand, in some studies (*Mugnai et al., 2009; Rakonjac et al., 2017; Rakonjac et al., 2018*), the influence of the production system on the egg weight was not determined. Contradictory results of the production system impact on the egg weight can be attributed to a number of influencing factors such as the flock age at the time of sampling, ambient temperature, diet and breed of laying hens (*Samiullah et al., 2017*). Therefore, it is impossible to determine the exact reason responsible for the observed differences between production systems obtained in this study, because the rearing conditions on the farms were not known and controlled (except the sell-by date). There is a possibility that laying hens from free-range production system were older than laying hens from other production systems, and it is well known that the egg weight (and of each of their components) increases with increasing hen age (*Philippe et al., 2020*).

In this study, no effects of production system on the percentage of cracked eggs were found ($P>0.05$, Table 1). Contradictory results were obtained by *Lordelo et al. (2017)*, who found a higher frequency of cracked eggs from enriched cage production system. In contrast, *Patterson et al. (2001)* found a higher frequency of cracked eggs from specific production (organic and free-range) systems compared to those from conventional (enriched cage and barn) production systems.

During the examination of egg cleanliness, the percentage of dirty eggs and eggshell dirtiness scores did not differ ($P>0.05$) between production systems (Table 1). In contrast, some authors (*Englmaierova et al., 2014*) reported a higher degree of shell dirtiness and contamination in table eggs from the enriched cage production system compared to those from barn and free-range production systems, while others (*Djukić-Stojčić et al., 2009; Philippe et al., 2020*) found a higher percentage of dirty eggs in the free-range production system compared to other production systems. Eggs laid outside the nest are an important factor that negatively affects the production profitability, because they are associated with a higher degree of dirtiness and bacterial contamination, higher frequency of being cracked, as well as higher workload as a result of manual egg collection (*Philippe et al., 2020*). The cleanliness of table eggs originating from organic and free-range production systems directly depends on the season, the number of misplaced eggs and the work organisation on the farm (frequency of egg collection and nest cleaning) (*Djukić-Stojčić et al., 2009*). Therefore, the obtained results can be explained by the fact that the study was conducted during summertime in the temperate climate zone, when sunny and dry days prevail with very rare and short-term precipitation, which resulted in a lower degree of shell dirtiness of table eggs from organic and free-range production systems.

In this investigation, the lowest (P<0.05) egg width was recorded in eggs from organic production system, while the highest (P<0.05) egg length and the lowest (P<0.05) egg shape index were found in eggs from free-range production system (Table 1). Also, the highest (P<0.05) percentage of normal-shaped eggs and the lowest (P<0.05) percentage of round eggs was recorded in the free-range production system (Table 1). Other studies have found a higher egg shape index in table eggs from the conventional cage and barn production systems than in those from the enriched cage production system (*Philippe et al., 2020*). However, some studies have not found any relationship between the production system and egg shape index (*Đukić-Stojčić et al., 2009; Rakonjac et al., 2018; Dalle Zotte et al., 2021*). Although the egg shape index may seem like a less important quality indicator of table eggs, it affects the percentage of cracked eggs, whereby the sharp egg shape increases the risk of eggs rolling out of the nest, which can result in shell damage (*Philippe et al., 2020*). Likewise, round eggs and unusually long eggs do not fit in cardboard packaging, making them more likely to be damaged or broken during handling, packaging, transportation and storage compared to normal-shaped eggs (*Čobanović et al., 2021*). Accordingly, it can be argued that table eggs from free-range production system have the most acceptable shape and the lowest risk of breakage throughout the table egg supply chain.

In this study, the lightest (P<0.05) eggshell colour (the lowest eggshell sensory colour scores and the highest $E_{\text{whole egg}}$ value) and highest (P<0.05) percentage of light eggs were found in eggs from the free-range production system (Table 1). Contrary to the results obtained in this study, *Djukić-Stojčić et al. (2009)* did not find any impact of the production system on the eggshell colour, while *Lordelo et al. (2017)* determined a darker shell colour in eggs originating from the enriched cage production system. Although shell colour is not an indicator of nutritional composition and/or internal quality of table eggs, most consumers show a greater tendency to purchase brown eggs, paying special attention to the intensity and uniformity of shell colour within the cardboard packaging (*Lordelo et al., 2017*). It is unlikely that the difference in eggshell colour is a consequence of the production system impact, but can be ascribed to the different breed, age or physiological state of the laying hens (*Lordelo et al., 2017*). However, it is very difficult to determine the exact reasons responsible for the observed differences between production systems obtained in this study, because the rearing conditions on the farms were not known or controlled (except the sell-by date). As mentioned before, there is a possibility that laying hens from the free-range production system were older than laying hens from other production systems, which may explain the lighter shell colour of table eggs from this production system. This phenomenon is directly related to the increase in the egg size and weight as hens age, which occurs without any proportional increase in the amount of protoporphyrin pigments deposited on the eggshell surface. As a consequence, the larger eggshell surface of older laying hens is covered with an unchanged amount of pigments, which results in a lighter egg colour (*Lordelo et al., 2017; Samiullah et al., 2017; Čobanović et al., 2021*).

The weight, percentage and thickness of the eggshell, together with the egg shape index, are important physical indicators of the table egg quality, considering that they affect the resistance of the shell to breakage and, consequently, reduce the percentage of cracked eggs during handling, packaging, transportation and storage (*Dalle Zotte et al., 2021*). Although each production system for laying hens has a number of differences that can have a significant impact on the eggshell characteristics, literature data indicate that the production system is not a decisive factor influencing the formation of eggshell properties (*Lordelo et al., 2017; Samiullah et al., 2017; Dalle Zotte et al., 2021*). Factors that are well known to influence the eggshell characteristics are the age of the laying hens, diet, stress and light regime (*Dalle Zotte et al., 2021*). Contrary to the results of previous studies, in the present study, the lowest (P<0.05) eggshell weight, eggshell percentage and eggshell thickness were determined in eggs originating from the free-range production system (Table 1), which is in accordance with the results obtained by *Terčič et al. (2012)* and *Dalle*

Table 1. Effects of production system on shell quality of table eggs (n=80).

Production system	Enriched cage	Barn	Organic	Free-range	*P* - value	Significance
N	20	20	20	20		
Egg weight (g)	55.52 ± 0.47[a]	55.85 ± 0,39[a]	53.54 ± 0.63[b]	59.08 ± 0.71[c]	<0.0001	*
Cracked eggs (%)	5.00	5.00	0.00	0.00	0.5678	ns
Dirty eggs (%)	10.00	0.00	0.00	5.00	0.2828	ns
Eggshell dirtiness scores	1.55 ± 0.21	1.45 ± 0.14	1.25 ± 0.10	1.55 ± 0.18	0.5264	ns
Egg width (mm)	43.58 ± 0.17[a]	43.57 ± 0.13[a]	42.71 ± 0.16[b]	43.65 ± 0.20[a]	0.0002	*
Egg length (mm)	55.72 ± 0,31[a]	55.89 ± 0.31[a]	54.85 ± 0.37[a]	58.71 ± 0.40[b]	<0.0001	*
Egg shape index	78.26 ± 0.52[a]	78.00 ± 0.52[a]	78.05 ± 0.52[a]	74.42 ± 0.60[b]	<0.0001	*
Egg shape quality classes						
Sharp eggs (%)	0.00	0.00	0.00	20.00	0.0055	*
Normal eggs (%)	25.00[a]	15.00[a]	15.00[a]	55.00[b]	0.0130	*
Round eggs (%)	75.00[a]	85.0[0]a	85.00[a]	25.00[b]	<0.0001	*
Eggshell colour (sensory)	3.34 ± 0.13[a]	3.30 ± 0.09[a]	3.25 ± 0.12[a]	1.93 ± 0.08[b]	<0.0001	*
$E_{whole\ egg}$	66.63 ± 0.65[ab]	65.2 ± 0.61[a]	68.38 ± 0.60[b]	79.74 ± 0.76[c]	<0.0001	*
Egg colour quality classes						
Light eggs (%)	55.00[a]	15.00[b]	60.00[a]	100.00[c]	<0.0001	*
Normal (medium) eggs (%)	25.00[a]	65.00[b]	40.00[ab]	0.00[c]	0.0001	*
Dark eggs (%)	20.00	20.00	0.00	0.00	0.0308	*
Eggshell weight (g)	7.24 ± 0.14[a]	7.48 ± 0.10[a]	7.21 ± 0.14[a]	6.71 ± 0.14[b]	0.0008	*
Eggshell percentage (%)	13.01 ± 0.22[a]	13.41 ± 0.19[a]	13.49 ± 0.29[a]	11.39 ± 0.28[b]	<0.0001	*
Eggshell thickness (mm)	0.39 ± 0.01[a]	0.30 ± 0.01[b]	0.22 ± 0.01[c]	0.14 ± 0.004[d]	<0.0001	*

Legend: 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–d)].

Zotte et al. (2021). On the other hand, the highest (*P*<0.05) shell thickness was recorded in eggs originating from the enriched cage production system (Table 1). This can be attributed to a better realisation of the genetic potential of the laying hens from the enriched cage production system due to better ambient environment and optimised nutrition, which might have led to more efficient utilisation of calcium and phosphorus during the process of eggshell formation (*Philippe et al., 2020; Bughio et al., 2021*). In barn, organic and free-range production systems, laying hens have a larger available floor surface, which significantly stimulates the movement of the animals, so minerals are used more for development and preservation of bones than for formation of eggshell (*Philippe et al., 2020*).

Effects of production system on the internal quality traits of table eggs

Effects of production system on internal quality of table eggs are depicted in Table 2. The present investigation found the lowest (*P*<0.05) percentages of albumen, but the highest (*P*<0.05) weight and percentage of yolk in eggs originating from the free-range production system. The ratio of table egg components is of little importance for consumers, but, on the other hand, it is of great importance for the egg product industry, because egg yolk has a higher market value than does albumen (*Lordelo et al., 2017*). There are contradictory results in the literature on the impact of the production system on physical internal quality traits of table egg quality. In some cases, it was found that table eggs originating from free-range/organic production systems have a higher proportion of albumen and lower proportion of yolk compared to table eggs from conventional production systems (*Lordelo et al., 2017; Samiullah et al., 2017; Dalle Zotte et al., 2021*), while in other cases, no influence of the production system on the internal quality traits of table eggs was determined (*Türker and Alkan, 2019*). The results of this study indicate that the physical internal quality indicators of table egg (weight and percentage albumen and yolk) differ in relation to the production system, confirming the great diversity of production in terms of farm conditions, genotype, diet and environmental conditions, which directly affects the quality of table eggs (*Dalle Zotte et al., 2021*). The albumen/yolk ratio in eggs is influenced by a number of factors, such as egg weight, laying hen age and genetic factors (*Dalle Zotte et al., 2021*). In this study, all table eggs were of the same weight class (size M; 53–63 g), which limited the influence of egg weight as a key factor in the proportion of albumen and yolk in the egg. Also, genetic factors cannot be considered decisive, considering that the same laying hen hybrids are generally reared in both alternative and conventional production systems (*Dalle Zotte et al., 2021*). Therefore, the identified differences could be attributed to other factors such as laying hen age, diet and welfare conditions on the farm of origin (*Philippe et al., 2020*). Accordingly, better welfare conditions in terms of greater available floor space and access to grass pasture probably contributed to increased movement of laying hens from free-range production system and probably resulted in better utilisation of nutrients and improvement of health status (especially in the birds' ovaries), which ultimately resulted in improved internal egg quality.

Although the table eggs tested in this study were of the same age and originated from the same local retail market where they were stored in refrigerated display cabinets at a temperature of +7±1°C, table eggs from enriched cage and barn production systems had a higher (P<0.05) width and length of albumen and lower (P<0.05) albumen index and higher pH of albumen and yolk compared to those from organic and free-range production systems (Table 2). In addition, the highest (P<0.05) albumen height, as well as the highest (P<0.05) albumen and Haugh index were recorded for organic eggs. Similar results were obtained in earlier studies (*Djukić-Stojčić et al., 2009; Lordelo et al., 2017; Samiullah et al., 2017; Rakonjac et al., 2018*). The albumen pH of a newly laid eggs is between 7.6 and 7.9 (*Philippe et al., 2020; Dalle Zotte et al., 2021*), while the pH of fresh eggs ranges from 7.6 to 8.5 (*Abdel-Nour et al., 2011; Eke et al., 2013; Čobanović et al., 2021*). During storage, albumen protein is decomposed and water and carbon dioxide are progressively lost from the egg, leading to a decrease in albumen height and an increase in albumen and yolk pH, resulting in a lower albumen, yolk and Haugh index (*Lordelo et al., 2017; Philippe et al., 2020; Dalle Zotte et al., 2021*). Alterations in the albumen pH are very intense during the first four days of storage, when it reaches values around 9, while after eight days the pH reaches values around 9.15 (*Dalle Zotte et al., 2021*). This indicates that albumen pH values of table eggs from organic and free-range production systems were characteristic for eggs stored for about four days, while eggs from enriched cage and floor production systems had pH values typical for eggs stored for about eight days (*Dalle Zotte et al., 2021*). Accordingly, the results of this study suggest that table eggs from enriched cage and barn production systems have a greater ability to support bacterial growth and are not suitable for longer storage durations. The better internal quality and freshness of table eggs from organic and free-range production systems can be explained by lower exposure of laying hens to stress and ammonia from the bedding, and higher vitamin C content in albumen due to intake of fresh grass as a result of access to pasture, which lowers pH of albumen and yolk and positively affects their consistency (*Rakonjac et al., 2018; Philippe et al., 2020; Dalle Zotte et al., 2021*).

The present study found the lightest (P<0.05) yolk colour (highest L* value, but the lowest a* value and sensory colour scores) in table eggs originating from the organic production system, which is in line with previous investigations (*Terčić et al., 2012; Lordelo et al., 2017; Dalle Zotte et al., 2021*). The intensity of yolk colour primarily depends on the content of carotenoid pigments in laying hen diet, with darker yellow yolk colour being more desirable for consumers in many countries (*Samiullah et al., 2017; Philippe et al., 2020*). In conventional poultry farming, synthetic pigments, xanthophylls, are commonly used in commercial feed mixture for laying hens to obtain a darker yellow yolk colour. In contrast, the use of synthetic xanthophyll pigments in laying hen diets in organic production systems is banned in the EU (*Lordelo et al., 2017; Samiullah et al., 2017; Rakonjac et al., 2018*). This may explain why table eggs from the *enriched* cage and barn production systems have more intense yellow yolk colour compared to eggs from organic production system (Table 2). However, the results of other studies (*Lordelo et al., 2017; Rakonjac et al., 2018*) found that the access of laying hens to the pasture, as in the case of organic and free-range production systems, allows birds to eat fresh grass, which is a rich source of carotenoid pigments and results in an increase in the yolk colour intensity. Some authors (*Hammershøj and Johansen, 2016*) found that the access of laying hens to the grass pasture in the organic production system can contribute to a two-fold increase of carotenoid pigments in table eggs. However, in free and organic production system, the availability, quality, quantity and type of grass, as well as time spent on the pasture are very important factors that affect the table egg quality and can vary significantly in different geographical areas and during different seasons (*Hammershøj and Johansen, 2016; Lordelo et al., 2017; Rakonjac et al., 2018*). Due to the previously mentioned reasons and the fact that laying hens from the enriched cage and barn production systems consume the same amount of synthetic carotenoids throughout the year, it is generally considered that egg yolks from free-range and organic production systems are of lighter yellow colour (*Dalle Zotte et al., 2021*). Hence, the results of this study are in accordance with the usual observations that table eggs from enriched cage and barn production systems have a darker yellow yolk colour.

In addition, a lighter ($P<0.05$) yolk colour was recorded in table eggs from the free-range production system compared to in those from enriched cage and barn production systems (Table 2), which is agreement with the results obtained by *Djukić-Stojčić et al. (2009)*. This indicate that the amount of xanthophyll pigments in the diet for laying hens from free-range production system was lower than in those from conventional production systems. This can be ascribed

Table 2. Effects of production system on albumen and yolk quality of table eggs (n=80).

Production system	Enriched cage	Barn	Organic	Free-range	*P* - value	Significance
N	20	20	20	20		
Albumen quality parameters						
Albumen weight (g)	35.50 ± 1.67	37.24 ± 1.42^a	31.93 ± 0.92^b	33.05 ± 0.63	0.0135	*
Albumen percentage (%)	59.05 ± 1.05^a	60.17 ± 0.69^a	58.26 ± 0.82^a	55.88 ± 0.59^b	0.0027	*
Albumen pH value	9.10 ± 0.05^a	9.18 ± 0.05^a	8.79 ± 0.05^b	8.82 ± 0.07^b	<0.0001	*
Albumen width (mm)	118.40 ± 3.92^a	125.10 ± 4.62^a	73.14 ± 3.39^b	75.75 ± 1.58^b	<0.0001	*
Albumen length (mm)	146.20 ± 1.97^a	146.10 ± 2.96^a	93.58 ± 4.02^b	94.88 ± 1.57^b	<0.0001	*
Albumen height (mm)	9.19 ± 0.80^a	12.59 ± 0.50^b	15.08 ± 1.14^c	12.63 ± 0.54^b	<0.0001	*
Haugh index	92.68 ± 4.62^a	106.20 ± 2.82^b	115.60 ± 2.95^c	111.10 ± 1.72^d	<0.0001	*
Albumen index	3.47 ± 0.29^a	4.75 ± 0.25^a	9.28 ± 0.72^b	7.44 ± 0.34^c	<0.0001	*
Yolk quality parameters						
Yolk weight (g)	15.46 ± 0.57^a	14.84 ± 0.39^a	15.16 ± 0.34^a	19.32 ± 0.35^b	<0.0001	*
Yolk percentage (%)	27.98 ± 1.01^a	26.54 ± 0.66^a	28.25 ± 0.71^a	32.73 ± 0.52^b	<0.0001	*
Yolk pH value	6.96 ± 0.10^a	7.13 ± 0.13^a	6.28 ± 0.03^b	6.28 ± 0.02^b	<0.0001	*
Yolk width (mm)	42.09 ± 0.69	42.77 ± 0.62	41.46 ± 0.63^a	43.94 ± 0.44^b	0.0237	*
Yolk height (mm)	20.41 ± 0.97	22.63 ± 0.87	22.03 ± 1.31	21.86 ± 0.55	0.4515	ns
Yolk index	49.03 ± 2.70	53.54 ± 2.36	52.71 ± 3.13	49.73 ± 1.07	0.4940	ns
Yolk colour (sensory)	13.18 ± 0.15^a	12.74 ± 0.25^a	7.67 ± 0.63^b	10.45 ± 0.23^c	<0.0001	*
L* value	43.43 ± 0.56^a	45.23 ± 0.58^a	48.60 ± 0.85^b	46.16 ± 0.84^a	0.0001	*
a* value	9.58 ± 0.22^a	9.63 ± 0.35^a	3.88 ± 0.53^b	5.53 ± 0.28^c	<0.0001	*
b* value	28.82 ± 1.19	32.47 ± 1.19	32.30 ± 1.42	30.56 ± 0.93	0.1482	ns

Legend: Level of significance: * $P < 0.05$; ns: not significant ($P > 0.05$); different letters in the same row indicate a significant difference at $P < 0.05^{(a–d)}$.

to the fact that free-range laying hens had access to the grass pasture, so they consumed less commercial feed mixture supplemented with the synthetic pigment, xanthophyll, which resulted in lighter yellow yolk colour (*Samiullah et al., 2017*).

Conclusion

This study showed that for external quality traits of table eggs, the free-range production system outperforms in egg weight and shape index, while the enriched cage production system is superior in eggshell thickness. The free-range and organic production systems are preferable for most of examined albumen quality traits. Therefore, these two production systems are better for desired quality parameters such as albumen pH value, albumen width, albumen length, albumen height, Haugh index and albumen index. In addition, the free-range production system is superior in all the yolk quality traits excluding yolk colour. It can, therefore, be concluded that table eggs from organic and free-range production systems are of better overall quality compared to those from enriched cage and barn production systems.

Ispitivanje kvaliteta konzumnih jaja poreklom iz različitih proizvodnih sistema

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A p s t r a k t: Cilj istraživanja ovog rada bio je da se ispita kvalitet konzumnih jaja poreklom iz kaveznog, podnog, organskog i slobodnog proizvodnog sistema. Konzumna jaja iz slobodnog uzgoja imala su najveću dužinu, najmanji indeks oblika i najveću učestalost jaja normalnog oblika. Osim toga, najsvetlija boja ljuske utvrđena je kod konzumnih jaja iz slobodnog uzgoja. Najveća debljina ljuske je utvrđena kod konzumnih jaja iz kaveznog uzgoja, dok su najmanju debljinu ljuske imala konzumna jaja iz slobodnog uzgoja. Konzumna jaja iz organskog i slobodnog uzgoja imala su bolji unutrašnji kvalitet i svežinu (manja pH vrednost belanca i žumanca, a veći indeks belanca) u poređenju sa onim iz kaveznog i podnog uzgoja. U poređenju sa ostalim proizvodnim sistemima, najbolje fizičke karakteristike su utvrđene kod konzumnih jaja iz slobodnog uzgoja (najveća masa jaja i masa i procenat žumanca, a najmanja masa i procenat ljuske i masa belanca). Pored toga, najsvetlija boja žumanca je utvrđena kod konzumnih jaja iz organskog uzgoja. Na osnovu rezultata ovog istraživanja može da se zaključi da su konzumna jaja iz organskog i slobodnog uzgoja boljeg kvaliteta u odnosu na ona iz kaveznog i podnog uzgoja.

Ključne reči: *boja ljuske, boja žumanca, kvalitet belanca, kvalitet ljuske, kvalitet žumanca, svežina jaja.*

Disclosure statement: No potential conflict of interest was reported by authors.

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).

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Paper received: March 2nd 2022.
Paper corrected: April 26th 2022.
Paper accepted: April 27th 2022.