Acta fytotechn zootechn, 24, 2021(3): 219–225
http://www.acta.fapz.uniag.sk

Original Paper

Various hen housing systems determine different egg quality

Ondřej Krunt*, Lukáš Zita, Adam Kraus
Czech University of Life Sciences Prague, Faculty of Agrobiology, Food and Natural Resources, Department of Animal Science, Prague, Czech Republic

Article Details: Received: 2020-12-07 | Accepted: 2021-02-19 | Available online: 2021-09-30

https://doi.org/10.15414/afz.2021.24.03.219-225

The aim of this study was to evaluate the effect of enriched cages and aviary housing system on egg quality. A total of 2520 eggs (180 eggs per age and housing system) were analysed. The egg quality parameters were measured in eggs from 44, 48, 52, 56, 60, 64 and 68-week-old hens. The analysis of the technological value included the evaluation of egg weight, shape index, surface area, volume, eggshell proportion, thickness, strength, colour, index, albumen proportion and index, Haugh units, yolk proportion, index, colour and yolk to albumen ratio. The significant interactions between housing system and age of hens were found in all observed parameters except for the egg shape index. Considering the eggshell strength, 52-week-old hens from aviary and from enriched cages had the highest values (46.90 and 46.87 N cm^{-2}, resp.), whereas the lowest values had eggs from 64-week-old hens housed in aviary (31.90 N cm^{-2}). Moreover, Haugh units were the highest in enriched cages from 48, 52 and 56-week-old hens (90.63, 89.80 and 89.28, resp.) and the lowest in aviary system from 64-week-old hens (75.38). Bearing in mind the results, the most of the highest and lowest values in eggshell quality were observed in enriched cages, while in internal quality of eggs, the most of the highest values were seen in enriched cages. That could indicate an unbalanced quality of eggshell and relatively stable internal quality depending on housing system. Regarding to the effect of age, higher quality was found in the first half of studied laying period.

Keywords: age, aviary, enriched cages, egg quality, housing system

1 Introduction

Nowadays, eggs are highly valued for their nutrition parameters due to the content of vital vitamins, minerals, optimal amount of saturated and unsaturated fatty acids with no content of carbohydrates and trans fats (Zampelas, 2012). Eggs are also an essential food, which can be supplemented with beneficial components (Bertechini & Mazzuco, 2013). Hernandez et al. (2005) see an important role of eggs in human nutrition as well as being important for producers. There are numerous possibilities of laying hens housing, simply divided to cage and non-cage systems. The egg production in cage systems is performed in two ways, in conventional cages or enriched cages. On the other hand, non-cage systems are barns, aviaries, a free range or organic housing (Molnár & Szőllősi, 2020). The European Commission (2019) states that the most used housing system is the enriched cage system (47.8%), then barn and aviary systems (29.3%), free-range housing (17%) and the less used is an organic housing, which is 5.9%. However, these proportions of housing depend on each state (Molnár & Szőllősi, 2020).

The effects, such as genotype, housing system or age are essential and their influence was confirmed by several authors, such as Kraus et al. (2019), Sokołowicz et al. (2019) and Kraus et al. (2020). A few years ago, the cage housing started to be hot topic in the scientific field and in producers as well as in consumers due to the debate about hen's well-being and housing conditions (Rahmani et al., 2019). The non-cage systems provide more space to hens, which indicate more energy requirements and so higher feed intake. However, the performance of hens is subjected to many other influences (Appleby & Hughes, 1995). Vice versa, Alm et al. (2015) reported that a limited

---

***Corresponding Author:** Ondřej Krunt, Czech University of Life Sciences Prague, Faculty of Agrobiology, Food and Natural Resources, Department of Animal Science, Kamýcká 129, 165 00 Prague, Czech Republic. e-mail: krunt@af.czu.cz ORCID: https://orcid.org/0000-0002-6173-9445

litter access of the hens influence their behaviour and potentially compromise their welfare.

Egg quality plays a key role for both sides of market chain. The eggshell quality (weight, share, thickness, deformation and strength) is an essential factor of egg quality because broken eggs must be discarded (De Reu et al., 2006). The quality of an eggshell then affects the intra-contamination of bacteria and determine amount of cracks (Pesavento et al., 2017). The quality of albumen and yolk interests mainly consumers (Tolimir et al., 2017). The proportion and index of albumen and yolk are parameters, which usually give a value of quality (Kraus et al., 2019). Indeed, Haugh units are the most important parameter, which express a total quality of egg content and freshness (Narushin et al., 2020). Every time, it needs to be considered that every housing system of hens breeding will not affect just the behaviour, productivity or health, but also the environment, egg quality and the presentation of the product to consumers as well (Molnár & Szőllősi, 2020).

The objective of this study was to evaluate the effect of housing system on eggshell and internal quality traits of eggs.

2 Material and methods

2.1 Birds and husbandry

A commercial brown egg-laying hybrid Bovans Brown was used in the present study. These hybrids, developed from a balanced breeding program, are universal and resistant to environmental conditions. The combination of high laying performance, laying endurance and stable egg weight guarantees the production of a large number of quality eggs. Considering housing conditions, they can adapt to different systems of housing. The production of hen housed eggs of Bovans Brown hens is 418 pcs and the average weight of eggs is 63.3 g (Hendrix Genetics, 2020).

There were used two housing systems in this study, enriched cages and aviary system. Hens were randomly divided into two groups according to the housing system (enriched cages and aviaries), which meet the requirement of Directive 1999/74/EC, where the minimum standards for a protection of layers are specified. Each group of hens consisted of 400 animals. Feeding of hens was provided ad libitum by the commercial type of feed mixture, which contained 15.02% of crude protein and 11.09 MJ of metabolizable energy. Water was also supplied ad libitum. The lighting regime scheme was 16L/8D with intensity from 5 to 10 lx. Microclimate conditions were the same during the whole experiment. The temperature was kept between 18 and 20°C and a relative humidity was 50 – 60% in both housing systems.

2.2 Egg quality analysis

The analysis of the external egg quality included evaluation of egg weight (EW), shape index (SI), surface area (ESA), volume (EV), eggshell proportion (ESP), thickness (EST), strength (ESST), colour (ESC) and index (ESI). The analysis of an internal egg quality included the evaluation of albumen proportion (AP) and index (AI), Haugh units (HU), yolk proportion (YP), index (YI), yolk colour (YC) and yolk to albumen ratio (YAR). The egg quality analysis and measurements were made according to Kraus et al. (2021). Moreover, the egg volume (EV) was calculated according to Islam & Dutta (2010). According to Ahmed et al., (2005), the eggshell index (ESI) was calculated as ESI (g 100 cm^{-2}) = (EW/ESA) × 100, where EW is the eggshell weight and ESA (cm^2) is the eggshell surface (ESA = $4.68 \times EW^{2/3}$). The yolk colour was determined by a colour scale (DSM YolkFanTM, DSM, Netherlands). The egg quality parameters were measured in eggs from 44, 48, 52, 56, 60, 64 and 68-week-old hens in the laboratory of the Department of Animal Science of the Faculty of Agrobiology, Food and Natural Resources. A total of 2520 eggs from both systems were analysed (180 eggs per age and housing system). The eggs were collected randomly to reach relevant and objective results. The eggs for the laboratory analysis were collected during one day and subsequent egg quality analysis was done the following day (after the collection, eggs were stored at the temperature of 4 °C until the laboratory analysis).

2.3 Statistical analysis

All data were processed by the computer software SAS (SAS Institute Inc. 2012. SAS User´s Guide. Statisticas. Version 9.4 ed. SAS Inst. Inc., Cary, NC, US). The effect of age and housing system on selected parameters of the technological value of the eggs was evaluated. The mixed model using the MIXED procedure of SAS:

$$y_{ijk} = \mu + A_i + HS_j + (A \times HS)_{ij} + e_{ijk}$$

where:
y_{ijk} – the value of the sign; A_i – the effect of age (44 – 68 weeks of age); HS_j – the effect of housing system (enriched cages, aviary); $(A \times HS)_{ij}$ – the effect of interaction between age and housing system; e_{ijk} – the random residual error

The significance of differences between the groups was tested by the multiple Duncan test. The value of $p \leq 0.05$ was considered as statistically significant.

Tables show the average values of each treatment, interactions among these treatments and the standard error of the mean (SEM). The two way interaction effects and their mean values are reported in tables and discussed in the text when significant.

3 Results and discussion

The results of this study are shown in the tables. Egg and eggshell quality is presented in Table 1 and the quality of egg content in Table 2.

Regarding the EW, the significant interaction ($P = 0.0001$) between housing system and age of hens was found. The heaviest eggs were from aviaries from 60-week-old hens, while the lightest eggs were from cages from 68-week-old hens (69.70 vs. 60.51 g, resp.). Breeding hens in aviary system has been developed as the new option of their well-being. The present study showed the EW was affected by housing system and the age. Also Ahammed et al. (2014) confirmed our results, comparing conventional cages, barns and aviaries with the best results of EW in aviary system in hens from 41 to 60 weeks of age. Discussing the EW, several factors have influence on it. These are genotype, hen age, housing system etc. (Yakubu et al., 2007; Jones et al., 2018). In some studies (Krawczyk, 2009; Kraus et al., 2019), increasing of EW with age was found, but our study cannot confirm this statement.

Moreover, ESA was also affected by a two way interaction ($P = 0.0001$) between housing system and hen age with the same results as in EW. The ESA with age linearly decreased in enriched cages, while in aviary system this trend could not be confirmed. The highest ESA was found in aviary system in 60-week-old hens, where the values were higher by +7.13 cm^2 than in 68-week-old hens housed in enriched cages probably due to the highest weight of these eggs. On the contrary, Galic et al. (2019) observed a higher ESA in cage or free-range housing. Moreover, Ahmad et al. (2019) found the interaction between housing system and genotype with results of higher ESA 26-week-old Rhode Island Red hens in all studied systems (intensive, semi-intensive or free range) compared to Naked Neck or Black Australorp, their results also indicate a connection between egg weight and ESA due to higher egg weight in Rhode Island Red hens. The effect of genotype, hen age or housing system was confirmed in several studies, where was also noted that brown-egg-laying genotypes had eggs with higher ESA or EV (Islam and Dutta, 2010; Rayan et al., 2010). Considering the EV, a two way interaction between housing system and age ($P = 0.0029$) was detected in favour of 48-week-old hens from enriched cages, who had the highest values in contrast with 44-week-old caged-hens and 52-week-old hens from aviary system.

The ESP was affected by the interaction ($P = 0.0002$) of previously mentioned factors, when significantly the highest values were determined in eggs from 52-week-old hens housed in enriched cages (10.64%), while the lowest values were in 48 and 56-week-old hens in enriched cages (9.86 and 9.85%, resp.) and in 60-week-old hens housed in aviary system (9.81%). The effect of age on ESP was found in study of Samiullah et al. (2014), who also found the same interaction as in the present study.

The significant interaction ($P = 0.0001$) between housing system and age was determined also for EST, where the highest values were found in eggs from 52-week-old hens housed in enriched cages (0.386 mm), while the lowest values were in eggs from 44 and 56-week-old hens housed in enriched cages (0.346 mm). Likewise, thicker shells in cages were observed by Tůmová and Ebeid (2003). On the contrary, the thickest eggshells were found in aviary system and in barn system by Ahammed et al. (2014) than in cages and also Hidalgo et al. (2008) registered the lowest thickness in eggs from cages compared to barns. Considering the age, the results are not consistent due to fluctuating values up and down among the age.

Moreover, ESS was affected ($P = 0.0001$) by housing system and age of hens as well. Eggs from 52-week-old hens from aviary and from enriched cages had the highest values (46.90 and 46.87 N cm^{-2}, resp.), whereas the lowest values were in eggs from 64-week-old hens housed in aviary (31.90 N cm^{-2}). The same interaction found Vlčková et al. (2018). The ESS (also eggshell weight, share, thickness or deformation) is an essential factor of egg quality in context of eliminating the formation of cracks and subsequent food safety in bacteria penetration to egg content point of view (De Reu et al., 2006). The effect of housing system on ESS was observed also by Sokołowicz et al. (2018), but in contrary, Yilmaz Dikmen et al. (2017) or Hidalgo et al. (2008) did not find any effect of hens housing. A better eggshell strength reported Ahammed et al. (2014) in aviary and in general in systems, where birds had more free movement. These results show that the scientific literature is inconsistent from eggshell point of view.

Bearing in mind the ESC, it was influenced by two way interaction ($P = 0.0064$) between housing system and age, when the highest values were observed in eggs from 52-week-old hens housed in aviary and the lowest in enriched cages in eggs from 52-week-old hens (45.36 vs. 27.48%, resp.). On the other hand, neither Đukić-Stojčić et al. (2009) nor Ahammed et al. (2014) observed the effect of housing system on ESC. Similar to our results, Kraus et al. (2019) found the same significant interaction as in present study. They found the darkest eggs came from 32-week-old hens housed in enriched cages and the lightest eggs from 64-week-old hens from litter (25.18 vs. 31.97%, resp.).

Evenly, ESI was affected by housing system and age (*P* = 0.0059) with the best results for eggs from 52-week-old hens from aviary (9.10 g 100 cm^{-2}) and the worst results for eggs from 48 and 56-week-old hens housed in enriched cages (8.41 and 8.38 g 100 cm^{-2}, resp.). According to Ahmed et al. (2005), ESI is associated with the size of crystals, which affect a shell strength. Due to that statement, this parameter is really important from eggshell point of view.

From internal egg quality point of view, some characteristics, which are presented in Table 2, were measured.

AP and AI were significantly influenced by a two way interaction (*P* = 0.0001) between housing system and age. The highest values of AP were obtained from eggs, which were from 52-week-old hens housed in enriched cages and from 64-week-old hens housed in aviary system (63.41 and 63.41%, resp.). Oppositely, the lowest values were detected in eggs from 48 and 52-week-old aviary-housed hens (61.86 and 61.74%, resp.) and from 68-week-old enrich cages-housed hens (61.79%). The AI values were the highest in eggs from 48-week-old hens housed in enriched cages (10.45%) and the lowest values in eggs from 68-week-old hens housed in aviary system (6.90%). The same interactions confirmed significantly Yilmaz Dikmen et al. (2017) and Kraus et al. (2019). Kraus et al. (2019) observed the highest AP and AI in eggs from 42-week-old hens housed in enriched cages compared to litter. Moreover, HU were measured with best results (*P* = 0.0001) of eggs from enriched cages from 48, 52 and 56-week-old hens (90.63, 89.80 and 89.28, resp.) and the worst results of eggs from aviary system from 64-week-old hens (75.38). Likewise, Ahammed et al. (2014) observed a higher HU in eggs from conventional cages than aviary and barn system in hens from 41 to 60-week-old hens. Also Samiullah et al. (2014), Yilmaz Dikmen et al. (2017) and Kraus et al. (2019) found the interaction between hens' age and housing system with the effect on HU. On the contrary to our results, Yilmaz Dikmen et al. (2017) reported higher HU in free range housing system than in cages.

Table 1 Housing system and age interactions in egg and eggshell quality parameters

Item	Parameter									
Housing system	Age (weeks)	EW (g)	SI (%)	ESA (cm^2)	EV (cm^3)	ESP (%)	EST (mm)	ESS (N cm^{-2})	ESC (%)	ESI (g 100 cm^{-2})
Enriched cages	44	68.16^{abc}	76.96	78.06^{abc}	55.06^{f}	10.10^{def}	0.346^{h}	42.33^{bcde}	29.34^{bc}	8.80^{bcde}
	48	63.84^{ef}	78.53	74.71^{ef}	59.47^{ade}	9.86^{f}	0.351^{fgh}	42.14^{bcde}	28.05^{bc}	8.41^{g}
	52	61.62^{gh}	76.98	72.97^{gh}	56.29^{def}	10.64^{a}	0.386^{a}	46.87^{a}	27.48^{c}	8.97^{ab}
	56	63.53^{ef}	76.88	74.47^{ef}	58.76^{ab}	9.85^{f}	0.346^{h}	37.97^{f}	29.77^{bc}	8.39^{g}
	60	62.51^{fg}	77.03	73.66^{fg}	58.49^{ab}	10.19^{de}	0.358^{defg}	41.27^{de}	31.86^{bc}	8.63^{defg}
	64	62.98^{fg}	75.91	74.03^{fg}	57.55^{bcd}	10.59^{ab}	0.379^{ab}	42.55^{bcd}	28.43^{bc}	8.97^{ab}
	68	60.51^{h}	76.98	72.09^{h}	56.76^{cde}	10.18^{de}	0.348^{gh}	41.42^{de}	30.57^{bc}	8.53^{fg}
Aviary	44	65.93^{d}	77.47	76.33^{d}	55.85^{ef}	10.32^{bcd}	0.367^{cd}	45.28^{ab}	29.64^{bc}	8.90^{abc}
	48	68.60^{ab}	78.16	78.37^{ab}	58.44^{abc}	10.25^{cde}	0.360^{cdef}	45.04^{abc}	31.99^{bc}	8.95^{ab}
	52	65.99^{d}	78.07	76.37^{d}	54.91^{f}	10.56^{abc}	0.368^{bcd}	46.89^{a}	45.36^{a}	9.10^{a}
	56	65.28^{de}	77.61	75.83^{de}	55.42^{ef}	10.32^{bcd}	0.371^{bc}	41.95^{cde}	32.67^{bc}	8.87^{abcd}
	60	69.37^{a}	76.59	79.22^{a}	59.14^{ab}	9.81^{f}	0.359^{defg}	39.30^{ef}	34.56^{b}	8.62^{efg}
	64	66.63^{cd}	75.84	76.86^{cd}	56.07^{def}	10.38^{abcd}	0.364^{cde}	31.89^{g}	30.82^{bc}	8.98^{ab}
	68	67.87^{bc}	76.47	77.81^{bc}	57.70^{bcd}	9.99^{ef}	0.365^{efgh}	41.60^{de}	34.03^{bc}	8.70^{cdef}
P-value										
Housing system		0.0001	0.4907	0.0001	0.0331	0.5616	0.0865	0.5501	0.0002	0.0001
Age		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0453	0.0001
Housing system × age		0.0001	0.1407	0.0001	0.0029	0.0002	0.0001	0.0001	0.0064	0.0059
SEM		0.194	0.098	0.150	0.170	0.030	0.001	0.336	0.653	0.025

EW – egg weight; SI – egg shape index; ESA – egg surface area; EV – egg volume; ESP – eggshell proportion; EST – eggshell thickness; ESS – eggshell strength; ESC – eggshell colour; ESI – eggshell index; SEM – standard error of means; values marked with different superscript letters for each parameter are significantly different ($P \leq 0.05$)

Table 2 Housing system and age interactions in egg content quality parameters

Item	Parameter							
Housing system	Age (weeks)	AP (%)	AI (%)	HU	YP (%)	YI (%)	YC	YAR
Enriched cage	44	63.22^{ab}	9.21^{cd}	82.87^{bc}	26.68^{efg}	41.84^{d}	12.07^{ef}	42.38^{cd}
	48	63.05^{ab}	10.45^{a}	90.63^{a}	27.08^{cde}	46.51^{a}	12.82^{b}	43.11^{bc}
	52	63.41^{a}	9.80^{bc}	89.28^{a}	25.95^{g}	45.02^{b}	12.25^{cde}	41.06^{d}
	56	63.07^{ab}	10.30^{ab}	89.80^{a}	27.07^{cde}	44.98^{b}	12.60^{bc}	43.08^{bc}
	60	62.98^{ab}	7.60^{fg}	79.03^{de}	26.83^{def}	43.43^{c}	12.58^{bc}	42.77^{bcd}
	64	62.12^{cd}	7.60^{fg}	78.54^{de}	27.31^{abcde}	40.47^{ef}	13.23^{a}	44.22^{ab}
	68	61.79^{d}	6.89^{h}	82.18^{bc}	28.03^{a}	41.50^{d}	12.55^{bcd}	45.58^{a}
Aviary	44	62.79^{abc}	9.21^{cd}	82.37^{bc}	26.90^{def}	41.24^{de}	11.72^{fg}	42.98^{bc}
	48	61.86^{d}	8.36^{e}	80.67^{cd}	27.88^{ab}	41.99^{d}	12.30^{cde}	45.29^{a}
	52	61.77^{d}	8.13^{ef}	80.40^{cd}	27.67^{abc}	41.88^{d}	11.68^{fg}	45.03^{a}
	56	62.73^{abc}	8.73^{de}	83.59^{b}	26.94^{cdef}	41.30^{de}	12.18^{de}	43.09^{bc}
	60	63.06^{ab}	8.62^{de}	83.15^{bc}	27.13^{bcde}	44.47^{b}	11.63^{g}	43.16^{bc}
	64	63.41^{a}	7.44^{gh}	75.38^{f}	26.22^{fg}	40.27^{f}	11.20^{h}	41.46^{cd}
	68	62.48^{bcd}	7.19^{gh}	77.08^{ef}	27.53^{ef}	41.23^{de}	12.02^{efg}	44.29^{ab}
P-value								
Housing system		0.1733	0.0001	0.0001	0.2022	0.0001	0.0001	0.1915
Age		0.0329	0.0001	0.0001	0.0004	0.0001	0.0001	0.0020
Housing system × age		0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
SEM		0.082	0.072	0.313	0.075	0.110	0.041	0.175

AP – albumen proportion; AI – albumen index; HU – Haugh units; YP – yolk proportion; YI – yolk index; YC – yolk colour; YAR – yolk to albumen ratio; SEM – standard error of means; Values marked with different superscript letters for each parameter are significantly different ($P \leq 0.05$)

The significant interactions ($P = 0.0001$) between housing system and age were also found for YP, YI, YC and YAR. The highest YP was observed in eggs from 68-week-old hens and the lowest values were found in eggs from 52-week-old hens, both housed in enriched cages (28.03 vs. 25.95%, resp.). The best results of YI were detected in eggs from 48-week-old enrich cage-housed hens compared to the worst results, which were found in eggs from 64-week-old hens housed in aviary system. Both factors (YP and YI) fluctuated with the age. The YI was influenced by the two way interaction of housing system and age in study of Kraus et al. (2019). A higher YI in enriched cages and aviaries was found in study of Englemaierová et al. (2014) compared to conventional cages and litter system. Yilmaz Dikmen et al. (2017) observed a higher YI in free range eggs than in eggs from conventional and enriched cages. They also reported the trend of decreasing YI with age. The highest YC was determined in eggs from 64-week-old hens from enriched cages compared to eggs from hens of the same age housed in aviary (13.23 vs. 11.20, resp.). Sokołowicz et al. (2018) confirmed the effect of housing system with better results in organic and free range eggs compared to eggs from litter. However, Ahammed et al. (2014) did not proof the effect of housing, when YC did not differ in aviary, barn or conventional cage. These differences are caused by the use of housing systems with a possibility to consume grass. The YAR values were on the highest level in eggs from 68-week-old hens, which were housed in enriched cages (45.58) and in eggs from aviaries, where were 48 and 52-week-old hens (45.29 and 45.03, resp.). On the contrary, the lowest values were obtained from eggs in 52-week-old hens housed in enriched cages (41.06). Kraus et al. (2019) also confirmed a significant interaction between housing system and age of hens and its influence on YAR. They reported the highest YAR from 32-week-old hens from litter (46) and the lowest from 42-week-old hens housed in enriched cages (38). Oppositely, Yilmaz Dikmen et al. (2017) did not observe the interaction between factors mentioned above.

4 Conclusions

This topic is of an importance for a complex assessment of available housing conditions due to the pressure of banning cage-housing in some countries, such as Czech Republic, where the official ban of this housing type will come into force in 2027. The results of the present study indicate a higher quality of eggs in first weeks of studied laying period. According to the most important results, the eggshell strength was the highest in 52-week-old hens from aviary and from enriched cages (46.90 and 46.87 N cm^{-2}, resp.), whereas the lowest values had eggs from 64-week-old hens housed in aviary (31.90 N cm^{-2}). Moreover, Haugh units were the highest in enriched cages from 48, 52 and 56-week-old hens (90.63, 89.80 and 89.28, resp.) and the lowest in aviary system from 64-week-old hens (75.38). Considering the housing system, there is no possibility to clearly declare a better egg quality, however the most of better values were observed in enriched cages. Indeed, further research is needed to optimize more detailed results.

Acknowledgments

This study was funded by an “S” grant from the Ministry of Education, Youth and Sports of the Czech Republic. We are grateful to Richard Hardy for English language correction of the manuscript.

References

Ahammed, M. et al. (2014). Comparison of aviary, barn and conventional cage raising of chickens on laying performance and egg quality. *Asian-Australasian journal of animal sciences*, 27(8), 1196–1203. doi: https://doi.org/10.5713/ajas.2013.13394

Ahmad, S. et al. (2019). Productive Performance, Egg Characteristics and Hatching Traits of Three Chicken Genotypes under Free-Range, Semi-Intensive, and Intensive Housing Systems. *Brazilian Journal of Poultry Science*, 21(2). doi: https://doi.org/10.1590/1806-9061-2018-0935

Ahmed, A. M. H. et al. (2005). Changes in eggshell mechanical properties, crystallographic texture and in matrix proteins induced by moult in hens. *British Poultry Science*, 46(3), 268–279. doi: https://doi.org/10.1080/00071660500065425

Alm, M. et al. (2015). Welfare and performance in layers following temporary exclusion from the litter area on introduction to the layer facility. *Poultry Science*, 94(4), 565–573. doi: https://doi.org/10.3382/ps/pev021

Appleby, M. C., & Hughes, B. O. (1995). The Edinburgh modified gage for laying hens. *British Poultry Science*, 36(5), 707–718. doi: https://doi.org/10.1080/00071669508417815

Bertechini, A. G., & Mazzuco, H. (2013). The table egg: A review. *Ciência e Agrotecnoligia*, 37(2), 115–122. doi: https://doi.org/10.1590/S1413-70542013000200001

De Reu, K. et al. (2006). Bacterial eggshell contamination in the egg collection chains of different housing systems for laying hens. *British Poultry Science*, 47(2), 163–172. doi: https://doi.org/10.1080/00071660600610773

Đukić-Stojčić, M. et al. (2009). The quality of table eggs produced in different housing systems. *Biotechnology in Animal Husbandry*, 25(5/6), 1103–1108.

Englmaierová, M. et al. (2014). Effects of laying hens housing system on laying performance, egg quality characteristics, and egg microbial contamination. *Czech Journal of Animal Science*, 59(8), 345–352. doi: https://doi.org/10.17221/7585-CJAS

European Commission. (2019). EU Market Situation for Eggs. European Commission, DG Agriculture and Rural Development, Committee for the Common Organisation of the Agricultural Markets: Brussels. Retrieved October 5, 2020 from https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/markets/overviews/market-overview-sector_en

Galic, A. et al. (2019). Physical and mechanical characteristics of Hisex Brown hen eggs from three different housing systems. *South African Journal of Animal Science*, 49(3), 468–476. doi: https://doi.org/10.4314/sajas.v49i3.7

Hidalgo, A. et al. (2008). A market study on the quality characteristics of eggs from different housing systems. *Food Chemistry*, 106(3), 1031–1038. doi: https://doi.org/10.1016/j.foodchem.2007.07.019

Herndrix Genetics. (2020). *Integra – Bovans Brown*. Hendrix Genetics. Retrieved October 5, 2020 from https://www.integrazabcice.cz/cs/produkty/bovans-brown-cz/

Hernandez, J. M. et al. (2005). Egg quality–meeting consumer expectations. *International Poultry Production*, 13(3), 20–23.

Islam, M. S., & Dutta, R. K. (2010). Egg quality traits of indigenous, exotic and crossbred chickens (*Gallus domesticus* L.) in Rajshahi, Bangladesh. *Journal of Life and Earth Science*, 5, 63–67. doi: https://doi.org/10.3329/jles.v5i0.7352

Jones, D. R. et al. (2018). Hen genetic strain and extended cold storage influence on physical egg quality from cage-free aviary housing system. *Poultry Science*, 97(7), 2347–2355. doi: https://doi.org/10.3382/ps/pex052

Kraus, A. et al. (2019). The effect of different housing system on quality parameters of eggs in relationship to the age in brown egg-laying hens. *Bulgarian Journal of Agricultural Science*, 25(6), 1246–1253.

Kraus, A. et al. (2021). Determination of selected biochemical parameters in blood serum and egg quality of Czech and Slovak native hens depending on the housing system and hen age. *Poultry Science*, 100(2), 1142–1153. doi: https://doi.org/10.1016/j.psj.2020.10.039

Krawczyk, J. (2009). Effect of layer age and egg production on level on changes in quality traits of eggs from hen conversation breeds and commercial hybrids. *Animal Science*, 9(2), 185–193.

Molnár, S., & Szőllősi, L. (2020). Sustainability and Quality Aspects of Different Table Egg Production Systems: A Literature Review. *Sustainability*, 12(19), 7884. doi: https://doi.org/10.3390/su12197884

Narushin, V. G. et al. (2020). A novel egg quality index as an alternative to Haugh unit score. *Journal of Food Engineering*, 289, 110176. doi: https://doi.org/10.1016/j.jfoodeng.2020.110176

Pesavento, G. et al. (2017). Free-range and organic farming: Eggshell contamination by mesophilic bacteria and unusual pathogens. *Journal of Applied Poultry Research*, 26(4), 509–517. doi: https://doi.org/10.3382/japr/pfx023

Rahmani, D. et al. (2019). Are consumers' egg preferences influenced by animal-welfare conditions and environmental impacts? *Sustainability*, 11(22), 6218. doi: https://doi.org/10.3390/su11226218

Rayan, G. N. et al. (2010). Impact of layer breeder flock age and strain on mechanical and ultra-structural properties of eggshell in chicken. *International Journal of Poultry Science*, 9(2) 139–147. doi: https://doi.org/10.3923/ijps.2010.139.147

Samiullah, S. et al. (2014). Effect of production system and flock age on egg quality and total bacterial load in commercial laying hens. *The Journal of Applied Poultry Research*, 23(1), 59–70. doi: https://doi.org/10.3382/japr.2013-00805

Sokołowicz, Z. et al. (2019). Effect of layer genotype on physical characteristics and nutritive value of organic eggs. *CyTa – Journal of Food*, 17(1), 11–19. doi: https://doi.org/10.1080/19476337.2018.1541480

Sokołowicz, Z. et al. (2018). Effect of alternative housing system and hen genotype on egg quality characteristics. *Emirates Journal of Food and Agriculture*, 30(8), 695–703. doi: https://doi.org/10.9755/ejfa.2018.v30.i8.1753

Tolimir, N. et al. (2017). Consumer criteria for purchasing eggs and the quality of eggs in the markets of the city of Belgrade. *Biotechnology in Animal Husbandry*, 33(4), 425–437. doi: https://doi.org/10.2298/BAH1704425T

Tůmová, E., & Ebeid, T. (2003). Effect of housing system on performance and egg quality characteristics in laying hens. *Scientia Agriculturae Bohemica*, 34(2), 73–80.

Vlčková, J. et al. (2018). Effect of housing system and age of laying hens on eggshell quality, microbial contamination, and penetration of microorganisms into eggs. *Czech Journal of Animal Science*, 63(2), 51–60. doi: https://doi.org/10.17221/77/2017-CJAS

Yakubu, A. et al. (2007). Effects of genotype and housing system on the laying performance of chickens in different seasons in the semi-humid tropics. *International Journal of Poultry Science*, 6(6), 434–439. doi: https://doi.org/10.3923/ijps.2007.434.439

Yılmaz Dikmen, B. et al. (2017). Impact of different housing systems and age of layers on egg quality characteristics. *Turkish Journal of Veterinary and Animal Science*, 41(1), 77–84. doi: https://doi.org/10.3906/vet-1604-71

Zampelas, A. (2012). Still questioning the association between egg consumption and the risk of cardiovascular diseases. *Atherosclerosis*, 224(2), 318–319. doi: https://doi.org/10.1016/j.atherosclerosis.2012.08.024