Interaction between housing system and genotype in relation to internal and external egg quality parameters

E. Tůmová[1], M. Englmaierová[2], Z. Ledvinka[1], V. Charvátová[1]

[1]Department of Animal Husbandry, Faculty of Agrobiology, Food and Natural Resources, Czech University of Life Sciences Prague, Prague, Czech Republic
[2]Institute of Animal Science, Prague-Uhříněves, Czech Republic

ABSTRACT: The effect of three housing systems (conventional cages, enriched cages and litter) on egg quality parameters was evaluated in two experiments with four brown laying strains ISA Brown, Hisex Brown, Bovans Brown and Moravia BSL. During 40 weeks of lay the total number of 7200 eggs was produced and analysed for egg weight, egg component weight and eggshell quality indicators. In 60 eggs, pore density in the small-end, large-end and equatorial areas was determined. Significant interactions between genotype and housing were found out in egg weight ($P \leq 0.001$), yolk and albumen weight ($P \leq 0.001$) and yolk colour ($P \leq 0.001$). Haugh units were the highest in eggs laid in cages and the lowest in the ISA Brown strain. Eggshell quality indicators were affected more by genotype than by housing. The interaction between genotype and housing was not significant for eggshell thickness but it was significant for eggshell weight and strength. Although eggshell thickness was lower in eggs produced in cages, eggshell strength was higher. A significant negative correlation was found out between pore density and housing system. Results of the study suggest that the ability of a strain to produce eggs of high quality in a particular housing system should be considered, even within brown strains.

Keywords: laying hen; conventional cage; enriched cage; litter; genotype; egg physical measurements; pore density

The concern of consumers in Europe for eggs from housing systems which are considerate to laying hens resulted in Regulation 74/1999 and the development of alternative housing systems. All housing systems for laying hens offer a number of potential advantages and disadvantages. Data from a number of studies revealed differences in egg quality depending on the housing system. Moorthy et al. (2000), Leyendecker et al. (2001a) and Jenderal et al. (2004) reported higher egg weights in cages, while Tůmová and Ebeid (2005), Pištěková et al. (2006), Zemková et al. (2007) found out heavier eggs on litter. Quality traits such as egg shell thickness, Haugh unit score and yolk index were reported to be higher in cages than on litter (Roland et al., 1997; Moorthy et al., 2000; Tůmová and Ebeid, 2005; Lichovníková and Zeman, 2008). These results are presumably contradictory because laying hens were kept in different conditions and different strains were used. Commercially available genotypes produce eggs of different weights, thus the weights of components and their proportions presumably also vary (Johnston and Gous, 2007). Notwithstanding, Hartmann et al. (2000) revealed

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the negative genetic correlations between egg quality and genotype. Main deviations in egg composition, egg weight and eggshell quality are between brown and white hybrids (Halaj and Grofík, 1994; Heil and Hartmann, 1997; Tůmová et al., 2007; Singh et al., 2009). However, differences within brown egg strains have been described (Zita et al., 2009) mainly in albumen and eggshell quality characteristics.

Not each genotype performs well in each housing system and the interaction between the housing system and other factors plays an important role. van den Brand et al. (2004) described interactions between laying hen age and housing systems in egg weight, eggshell content, albumen height and albumen pH. Free-range layers showed more variation in most egg characteristics at a given age. Significant interactions between genotype, housing system and oviposition time were found out (Tůmová et al., 2009). The number of eggs recorded at each collection time was influenced by genotype, with each hybrid having a particular laying pattern. In addition, the housing system influenced an oviposition pattern: eggs produced by hens on litter were laid later in the day compared to those from hens housed in cages, mainly in the genotype with lower production. Interactions of all factors were demonstrated in Haugh units and eggshell strength. Results were higher in cages than on litter, and lower in the Moravia BSL genotype in comparison with ISA Brown or Hisex Brown (Tůmová et al., 2009).

Leyendecker et al. (2001b) revealed significant interactions between genotype and housing system (battery cages, aviary and intensive free-range housing). Both layer lines (white egg Lohmann LSL and brown egg Lohmann Tradition) differed in their ability to be used in alternative housing systems. Comparing egg quality traits from different housing systems did not reveal an explicit advantage of one housing system. Both layer lines exhibited higher Haugh units in the aviary. Eggshell thickness was higher in the intensive free-range system for both layer lines, and eggshell density only for the Lohmann Tradition. The Lohmann Tradition hens laid eggs with similar shell thickness and density. Yolk weight increased in battery cages for both layer lines. The highest grade of yolk colour was found out in the free-range system for LSL hens and in battery cages for Lohmann Tradition hens. The results of this study clearly demonstrated that layer line specific reactions were to be expected in the three tested hen housing systems. Significant interactions between hybrid and housing system in egg weight and egg index were determined by Wall and Tauson (2002). Vits et al. (2005) reported a significant interaction between housing system and layer line in relation to Haugh units and shell density. Campo et al. (2007) compared housing on litter and free range and indicated that brown egg hens laid heavier eggs and eggs with greater shell strength in comparison with white or tinted egg hens. Better measurements were received in deep litter housing than in free range. Singh et al. (2009) revealed a significant 3-way interaction between housing, strain and age for yolk and albumen weight, albumen height and yolk colour.

The aim of the present study was to evaluate interactions of egg quality parameters in three brown laying strains housed in conventional and enriched cages or on litter.

MATERIAL AND METHODS

The egg quality parameters were evaluated in two experiments conducted with four brown-egg strains over the entire laying period. In the first experiment, a total of 3000 eggs was measured from two housing systems (conventional cages Eurovent, 550 cm^2/hen, and floor housing, 7 birds/m^2) and three brown-egg strains (ISA Brown, Hisex Brown and Moravia BSL). Moravia BSL is a black hybrid bred in the Czech Republic for outdoor housing systems and extensive farming, being a three-line cross based on Rhode Island Red (male line) and Barred Plymouth Rock (female line) breeds. Eggs were collected between 20 and 60 weeks of age at two-week intervals, on two consecutive days, 30 eggs from each genotype in cages (3 × 30 × 20) and 20 eggs from litter (3 × 20 × 20).

In the second experiment, eggs for the quality evaluation were collected from hens housed in conventional cages Eurovent (550 cm^2/hen), litter (7 birds/m^2) and enriched cages SKN-O 30-60 (Kovobel®, Domažlice, Czech Republic) (750 cm^2 per hen). Eggs were sampled from three genotypes (ISA Brown, Bovans Brown and Moravia BSL) in the period from 22 to 64 weeks of age. Once every two weeks, on two consecutive days, eggs were evaluated (conventional cages, 30 eggs from each genotype, 3 × 30 × 20; 20 eggs from litter, 3 × 20 × 20; and 20 eggs from enriched cages, 3 × 20 × 20) giving a total of 4200 eggs.

Freshly laid eggs were individually weighed, and all the components of each egg were measured. Albumen weight was calculated by subtracting yolk weight and shell weight from egg weight. Eggshell weight was determined after drying. Albumen height and Haugh units were evaluated with a QCH apparatus (TSS, York, UK). Haugh units were automatically calculated within the system based on egg weight and albumen height (Haugh, 1937). Shell strength was determined by the shell-breaking method using a QC-SPA device (TSS, York, UK). Eggshell colour was measured with a QCR colour reflectometer (TSS, York, UK). The reflectometer works by taking a percentage reading between black and white with the former expressed as 0% and the latter pure white 100%. Yolk colour was determined by the colorimetric method and a QCC device (TSS, York, UK) and results are expressed in standard DSM Roche. Eggshell thickness was measured with a QCT shell thickness micrometer (TSS, York, UK). The surface area of each egg was calculated using the equation reported by Thomson et al. (1985): 4.67 (egg weight)$^{2/3}$. Eggshell index was calculated: SI = (shell weight/shell surface) × 100 (Ahmed et al., 2005).

In the second experiment, in the second half of the laying period, pore density in the egg shell was evaluated in 60 eggs from each genotype from conventional cages and floor housing. For pore density determination, shells were boiled in a 5% NaOH solution for 15 min to remove shell membranes and then rinsed three times in distilled water. Rinsed egg shells were dried in an oven heated to 50°C. The inside surface of shells was dyed with methylene blue. The dye solution was made by dissolving 0.5 g of 89% methylene blue crystals in one litre of 70% ethanol. The pores appeared as blue dots on the outside surface due to capillary action. The pore density was determined on the sharp and blunt end of each egg and on the equator.

Two-way analysis of variance (housing and genotype) for egg quality evaluation was used. In the statistical analysis, the GLM procedure of SAS (SAS, 2003) was applied. The relationship between eggshell characteristics and pore density was evaluated by estimating Pearson's correlation coefficient.

RESULTS

A significant interaction between genotype and housing system was found out in all internal parameters of eggs in the first experiment. Egg weight was not significantly affected by housing or genotype (Table 1). Eggs from cages were heavier than those from litter. The heaviest eggs in cages were laid by Hisex Brown and the lightest by Moravia BSL. However, there was a significant interaction ($P \leq 0.001$) between strain and housing system: the heaviest eggs were laid by Hisex Brown in cages while the same strain produced the lightest eggs on

Table 1. Mean egg weight and internal quality measurements of eggs from three laying strains housed in cages or on litter (Experiment 1)

Housing	Genotype	Egg weight (g)	Yolk		Albumen weight (g)	Haugh units	Yolk/albumen ratio (%)
			weight (g)	colour (%)			
Cage	ISA Brown	59.9^{c}	15.9^{c}	6.8^{ab}	36.2^{c}	86.5^{c}	44.0
	Hisex Brown	60.4^{a}	15.8^{c}	6.9^{a}	37.2^{a}	88.4^{a}	42.7
	Moravia BSL	58.9^{e}	16.4^{b}	7.0^{a}	35.7^{d}	86.9^{c}	46.1
Litter	ISA Brown	59.2^{d}	15.8^{c}	6.8^{b}	35.9^{d}	83.9^{d}	44.2
	Hisex Brown	58.9^{e}	15.2^{d}	5.5^{c}	36.4^{b}	87.6^{b}	41.9
	Moravia BSL	60.1^{b}	16.8^{a}	6.8^{a}	36.5^{b}	86.8^{c}	46.3
Significance							
Housing		n.s.	n.s.	0.001	n.s.	0.011	n.s.
Genotype		n.s.	0.001	0.001	0.001	0.001	0.001
Housing × genotype		0.001	0.001	0.002	0.001	0.050	n.s.

[a–d]statistically significant differences ($P \leq 0.05$) in columns are indicated by different superscripts; n.s. = not significant

Table 2. External egg quality measurements of three egg laying strains housed in cages or on litter (Experiment 1)

Housing	Genotype	Egg shell weight (g)	Egg shell thickness (mm)	Egg shell strength (g/cm^2)	Egg shell surface (cm^2)	Egg shell colour (%)	Shell index (g/100 cm^2)
Cage	ISA Brown	6.3	0.376	4872	71.4^a	34.3^b	8.8^a
	Hisex Brown	6.1	0.412	4883	71.8^a	29.7^c	8.4^b
	Moravia BSL	5.5	0.326	4479	70.3^b	46.6^a	7.8^c
Litter	ISA Brown	6.3	0.375	4835	70.8^b	31.6^c	8.8^a
	Hisex Brown	6.0	0.361	4847	70.7^b	30.2^c	8.5^b
	Moravia BSL	5.5	0.324	4271	71.6^a	45.1^a	7.3^d
Significance							
Housing		n.s.	n.s.	0.004	n.s.	0.001	n.s.
Genotype		0.001	n.s.	0.001	0.023	0.001	0.001
Housing × genotype		n.s.	n.s.	n.s.	0.001	0.001	0.010

$^{a–d}$statistically significant differences ($P \leq 0.05$) on columns are indicated by different superscripts; n.s. = not significant

litter, whereas, in cages, eggs with the lowest weight were laid by hens of the Moravia BSL strain which produced the heaviest eggs on litter. Significant differences ($P \leq 0.001$) in egg weight were also found in ISA Brown hybrid, which laid heavier eggs in cages than on litter. Yolk weight was affected mainly by genotype, with the largest yolks being produced by Moravia BSL in both housing systems. Significant interactions ($P \leq 0.002$) were also observed in yolk colour. In ISA Brown and Hisex Brown, yolks were significantly lighter on litter in comparison with cages. In both housing systems, the significantly

Table 3. Mean egg weight and internal egg quality measurements of three egg laying strains housed in cages, on litter and in enriched cages (Experiment 2)

Housing	Genotype	Egg weight (g)	Yolk weight (g)	Yolk colour (%)	Albumen weight (g)	Haugh units	Yolk/albumen ratio (%)
Cage	ISA Brown	61.6^d	15.6^{bc}	5.3^b	38.5^e	82.6^f	41.1^b
	Bovans Brown	64.1^a	15.5^{bc}	5.2^{bc}	40.9^a	87.7^b	38.4^e
	Moravia BSL	63.1^b	16.5^a	5.3^b	39.4^d	85.6^b	42.2^a
Litter	ISA Brown	62.6^c	15.3^c	5.3^b	39.9^b	82.7^f	38.6^e
	Bovans Brown	63.1^b	15.3^c	5.3^{bc}	39.6^c	87.5^b	39.4^d
	Moravia BSL	63.2^b	16.3^a	5.5^a	39.8^{bc}	86.9^c	40.9^b
Enriched cages	ISA Brown	59.9^e	14.7^d	5.2^{bc}	38.1^f	84.6^e	39.0^d
	Bovans Brown	63.3^b	15.8^b	5.2^c	39.7^c	85.8^d	40.2^c
	Moravia BSL	62.0^c	15.9^b	5.2^c	38.9^b	88.1^a	41.1^b
Significance							
Housing		0.001	0.001	0.001	0.001	0.016	0.001
Genotype		0.001	0.001	0.014	0.001	0.001	0.001
Housing × genotype		0.001	0.001	0.001	0.001	0.001	0.001

$^{a–f}$statistically significant differences ($P \leq 0.05$) on columns are indicated by different superscripts; n.s. = not significant highest ($P \leq 0.001$) Haugh unit scores were measured in eggs of Hisex Brown. There was no significant interaction in the yolk/albumen ratio and this parameter was influenced by genotype.

As shown in Table 2, no significant interactions between housing and genotype were found out for eggshell weight, thickness or strength. Eggshell thickness was not affected by housing or genotype. Eggshell weight depended on strain and eggshell strength was influenced by both factors. In contrast with the main eggshell indicators, interactions for eggshell index, surface and colour were significant ($P \leq 0.001$). The lowest shell index was in Moravia BSL eggs in both housing systems. This strain also produced eggs with the lowest shell weight, thickness and strength. The shell colour was highly significantly ($P \leq 0.001$) affected by strain and housing, and the lightest egg shells were produced by Moravia BSL in both housing systems. ISA Brown produced eggs with significantly lighter shells in cages in comparison with those from litter. However, there were no significant differences in eggshell colour in Hisex Brown.

In the second experiment, like in the first, there was a significant interaction ($P \leq 0.001$) between housing and genotype in internal measurements (Table 3). Egg weight was the highest in Bovans Brown in conventional cages followed by enriched cages. The heaviest eggs on litter were produced by Moravia BSL, this genotype producing the heaviest eggs on litter also in the first experiment. Yolks were significantly heavier ($P \leq 0.001$) in eggs from Moravia BSL in all housing systems whereas eggs with the significantly smallest yolks were produced by ISA in enriched cages. The yolk colour was less affected by genotype than by housing and the darkest was in Moravia BSL on litter. The lightest yolks were produced in enriched cages. The significantly highest Haugh unit scores ($P \leq 0.001$) were measured in enriched cages in the Moravia BSL strain, and the lowest in ISA Brown in all housing systems. In contrast with experiment 1, a significant interaction ($P \leq 0.001$) was also found out in the yolk/albumen ratio. The highest values were in Moravia BSL in all housing systems.

Eggshell thickness was the only eggshell quality parameter to show a non-significant interaction (Table 4). Birds kept on litter produced eggs with thicker shells compared with those from cages, but it turned out that these shells had the lowest breaking strength. The lowest eggshell quality parameters were found out in the Moravia BSL genotype, corresponding with findings in the first

Table 4. External egg quality measurements of three egg laying strains housed in cages, on litter and in enriched cages (Experiment 2)

Housing	Genotype	Egg shell					Shell index ($g/100\ cm^2$)
		weight (g)	thickness (mm)	strength (g/cm^2)	surface (cm^2)	colour (%)	
Cage	ISA Brown	6.1^{b}	0.357	4863^{b}	72.7^{f}	30.4^{e}	10.2^{b}
	Bovans Brown	6.3^{ab}	0.359	4688^{d}	74.7^{a}	31.2^{cd}	10.1^{b}
	Moravia BSL	5.8^{c}	0.329	4423^{f}	73.9^{b}	38.8^{b}	9.7^{c}
Litter	ISA Brown	6.2^{b}	0.353	4583^{e}	73.6^{c}	31.8^{c}	9.9^{bc}
	Bovans Brown	6.4^{a}	0.374	4975^{a}	73.9^{b}	31.1^{d}	10.5^{a}
	Moravia BSL	5.8^{cd}	0.327	4273^{g}	74.0^{b}	44.0^{a}	9.6^{cd}
Enriched cages	ISA Brown	5.9^{c}	0.372	4684^{d}	71.4^{e}	31.5^{c}	9.8^{bc}
	Bovans Brown	6.5^{a}	0.374	4761^{e}	74.1^{b}	28.9^{f}	10.5^{a}
	Moravia BSL	5.7^{d}	0.332	4449^{f}	73.1^{d}	44.1^{a}	9.6^{c}
Significance							
Housing		0.026	0.065	0.015	0.001	0.001	n.s.
Genotype		0.001	0.001	0.001	0.001	0.001	0.001
Housing × genotype		0.001	n.s.	0.001	0.001	0.001	0.001

[a–f]statistically significant differences ($P \leq 0.05$) on columns are indicated by different superscripts; n.s. = not significant

Table 5. Pore density of the egg shell (pore number/cm^2) in three egg laying strains housed in cages and on litter (Experiment 2)

Housing	Genotype	Small-end	Large-end	Equator
Cage	ISA Brown	65.9	165.6	119.2^b
	Bovans Brown	67.9	140.0	106.5^c
	Moravia BSL	67.0	155.5	108.6^c
Litter	ISA Brown	50.2	158.5	116.7^b
	Bovans Brown	50.6	161.5	127.5^a
	Moravia BSL	45.0	172.7	127.6^a
Significance				
Housing		0.022	n.s.	0.020
Genotype		n.s.	n.s.	n.s.
Housing × genotype		n.s.	n.s.	0.014

$^{a-c}$statistically significant differences ($P \leq 0.05$) on columns are indicated by different superscripts; n.s. = not significant

experiment. High eggshell quality indicators were measured in the Bovans Brown strain, which produced eggs with the darkest shell.

Complementing eggshell quality measurements, pore density was evaluated in eggs from the two most different housing systems, namely conventional cages and litter (Table 5). Pore density was not affected by genotype but housing system did have an influence on this parameter. A higher pore density was measured on the small end and in the equatorial area in eggs from hens on litter. In addition, in the equatorial area a significant interaction between genotype and housing was revealed. This result seems to be valuable because of the high correlation between pore density on the large end of the egg and the equator (Table 6). The majority of eggshell quality indicators were found to be slightly correlated with pore density.

DISCUSSION

The results of both experiments revealed a significant interaction between housing system and genotype in the majority of internal quality parameters of eggs, which is consistent with findings re-

Table 6. Correlations between pore density and selected characteristics (Experiment 2)

Characteristics	Small end		Large end		Equatorial region	
	correlation	significance	correlation	significance	correlation	significance
Housing	–0.29	0.018	–0.09	0.449	–0.27	0.025
Genotype	0.06	0.624	0.01	0.911	0.08	0.517
Egg weight	–0.17	0.179	–0.11	0.939	–0.09	0.444
Egg shell strength	–0.05	0.659	0.08	0.493	–0.15	0.205
Egg shell thickness	–0.08	0.493	0.03	0.824	–0.11	0.354
Egg shell weight	–0.21	0.095	–0.01	0.941	–0.18	0.150
Egg surface	–0.17	0.177	0.01	0.942	–0.09	0.488
Egg shell index	–0.08	0.502	0.01	0.935	–0.13	0.277
Small-end			–0.03	0.776	0.19	0.118
Large-end					0.42	0.001

ported by Mostert et al. (1995), Leyendecker et al. (2001a,b), Wall and Tauson (2002), Vits et al. (2005) and Singh et al. (2009). In the literature, the interaction between housing and genotype is described in both white and brown hybrids. Both types of strains vary in many quality parameters but brown hybrids should be more similar. Leyendecker et al. (2001a) pointed out that white and brown layer lines also differed in their ability to perform in alternative housing systems.

Egg weight is one of the most important economic parameters of egg production and the effect of different factors on egg weight would therefore influence the economics of egg production on a farm. In both experiments, the heaviest eggs were laid on litter by Moravia BSL, the heaviest hybrid which was used in the experiments. ISA Brown produced lighter eggs than Hisex Brown or Bovans Brown, the latter strain producing larger eggs in both cage systems. Eggs from hens on litter were heavier and this could have correlated with live weight and egg production. Singh et al. (2009) described mainly the relationship between egg weight and live weight of hens.

Yolk weight is related mainly to genotype and in both experiments Moravia BSL hens laid eggs with the largest yolks in all housing systems. The effect of genotype on yolk weight was described by Leyendecker et al. (2001b), Singh et al. (2009) and Tůmová et al. (2009). The lower impact of housing on yolk weight and a higher fluctuation in yolk weight in enriched cages might have been responsible for the large variation in egg weight, which was most obvious in the ISA Brown line, which laid the lightest eggs with the smallest yolks in the enriched cages.

Contradictory results were obtained in yolk colour. In the first experiment darker yolks were produced in cages while in the second these were from hens on litter. The results of the second experiment, where darker yolk colour was in eggs from litter, are in agreement with those of Sűto et al. (1997), Pištěková et al. (2006) and Singh et al. (2009). The yolk colour depends mainly on pigments in feed but the same feed mixtures were used in both experiments. On the other hand, significant differences among hybrids in this characteristic and interactions between housing and genotype indicate other effects on this parameter. Similar relationships were described by Singh et al. (2009), who pointed out that this could possibly be due to the dilution effect of higher egg production by commercial layers and genetic variation unrelated to productivity (Hocking et al., 2003).

The housing system affected albumen quality, which was higher in cages. Hidalgo et al. (2008) also found out significant differences in albumen quality, mainly in Haugh units, between housing systems. The highest values were in eggs from cages while organic eggs presented the lowest. Higher Haugh unit scores were measured in conventional cages in both experiments. In addition, in the second experiment, Haugh unit scores were higher in enriched cages compared to conventional cages. One explanation for lower albumen quality in eggs from litter could be connected with the hypothesis of Benton and Brake (2000) and Singh et al. (2009), who stated that eggs from a litter system are more exposed to ammonia from litter, which would reduce the Haugh unit score. Generally, Haugh units were dependent on genotype in all housing systems, which corresponds with the results of Leyendecker et al. (2001b) and Singh et al. (2009).

The results of this study document that eggshell quality characteristics were more affected by genotype than by housing system, which is consistent with Heil and Hartmann (1997), Tůmová et al. (2007), Singh et al. (2009) and Zita et al. (2009). The poorest eggshell quality indicators (eggshell weight, eggshell thickness and strength) were in eggs from the Moravia BSL strain, which also produced the lightest shells. Similar results were reported by Campo et al. (2007), who stated that the incidence of cracked eggs was higher in the breeds laying white eggs than in those laying tinted or brown and dark brown eggs.

Eggshell thickness, in contrast with eggshell strength or eggshell weight, was not affected by a housing system, and no significant interaction between housing and genotype was found out. These results disagree with those of van den Brand et al. (2004), who recorded greater eggshell thickness and strength in eggs from outdoor layers. However, Lichovníková and Zeman (2008) reported higher eggshell strength in eggs from cages. Also Hidalgo et al. (2008) showed the effect of housing on eggshell thickness and strength. They stated that shell thickness was the lowest in eggs produced in cages, while free-range and barn eggs presented the highest values. In contrast, the thinner egg shells of eggs laid in cages in these trials resulted in higher shell strength, which corresponds with results of Hidalgo et al. (2008). The shells from eggs produced in cages seem to have ultrastructural features which support the eggshell strength. The rates of calcium deposition in shells of eggs produced in the two systems are possibly different. Lichovníková and Zeman (2008) showed that calcium content in the shell and calcium intake were higher in cages than on litter. Structural differences in the eggshell formation according to a housing system may be the result of variable pore density in eggs from cages and litter. In eggs from hens on litter, fewer pores were determined mainly on the large end and equator. Egg surface area is highly correlated with egg weight and the results of both experiments showed larger surface areas in eggs from cages as well as a significant interaction ($P \leq 0.001$) between genotype and housing system. On the other hand, there was not a direct connection between this parameter and the number of pores in spite of the negative correlation between them.

The results of this study have demonstrated that there exist differences in egg quality not only between white and brown strains of laying hens but also within brown strains. Significant interactions between housing system and genotype in relation to internal egg quality parameters and eggshell characteristics were also identified. Therefore it is important to select an appropriate genotype for a particular housing system in order to produce eggs with the highest quality parameters as these may affect subsequent safety and storage.

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Corresponding Author

Prof. Ing. Eva Tůmová, CSc., Czech University of Life Sciences Prague, Faculty of Agrobiology, Food and Natural Resources, Department of Animal Husbandry, Kamýcká 129, 165 21 Prague 6-Suchdol, Czech Republic
Tel. +420 224 383 048, fax +420 224 383 065, e-mail: tumova@af.czu.cz