



## Production Performance and Egg Quality of Laying Hens as Influenced by Genotype and Rearing System

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### ABSTRACT

The aim of this study was to evaluate the effect of rearing systems and genotypes on production performance and egg quality. Isa Brown and New Hampshire genotypes were used in this study. These two genotypes were housed in floor and organic rearing systems. During the experimental period, which lasted one year (52 weeks), the following production performance parameters were recorded: egg production, daily egg mass, feed consumption, feed conversion efficiency, and mortality. Fifteen eggs per group were collected for analysis at 64 weeks of hen age. These samples were evaluated for external parameters (egg weight and egg shape index), internal parameters (albumen height, Haugh unit, and the proportions of albumen, yolk and shell), eggshell quality parameters (shell thickness, shell deformation and shell breaking strength), and eggs' chemical composition (dry matter, minerals, protein and lipids). Generally, Isa Brown hens had better production performance than New Hampshire hens. At the same time, organic New Hampshire layers performed better than floor-reared ones. Genotype had a significant effect on all ten egg quality parameters (external, internal and eggshell quality), rearing system independently affected only egg weight, and the interaction of the observed factors significantly influenced seven parameters. Genotype had a significant effect on three of the four chemical composition parameters, while no significant effect of the rearing system was established on the chemical composition of eggs. The rearing system x genotype interaction significantly affected the eggs' protein content.

### INTRODUCTION

Organic eggs' purchase and consumption have become particularly popular among consumers who believe that organically produced eggs are of better quality (Sokołowicz *et al.*, 2019). This stems from the perception that products obtained from "happy animals" are better and healthier for human consumption. Food produced in this way also has a functional role - not only in reducing hunger and providing basic nutrients for human consumption, but also in preventing the occurrence of diseases associated with inadequate nutrition, as well as improving the physical and mental well-being of the consumer (Siró *et al.*, 2008). Egg components can have antimicrobial, immunomodulatory, antioxidant, anticancer, and antihypersensitivity effects on human health (Abeyrathne *et al.*, 2013). It is important to note that the cheapest way, with the least environmental impact, of covering the human body's daily need for animal protein is with eggs (Molnár & Szollosi, 2020). For that reason, alternative rearing systems for laying hens have greatly expanded, especially in EU countries. The Committee for the Common Organisation of the Agricultural Markets (2021) reported that 18% of



hens in EU countries have outdoor access (free range and organic taken together).

Hybrids or native breeds can be used for rearing in alternative production systems (Sokołowicz *et al.*, 2018b). Since most hybrids are selected for intensive production, it is not entirely clear whether they can be successfully used in alternative rearing systems, especially organic ones. Namely, these birds require high levels of energy, vitamins, proteins, and especially some limiting amino acids. These needs often cannot be satisfied only through natural nutrients, i.e. without the addition of synthetic sources of these substances, the use of which is forbidden in organic production. (Rakonjac *et al.*, 2019). The mortality of hybrids reared outdoors is also often significantly higher than the established standards. For this reason, indigenous breeds are usually recommended for organic poultry production because they are easily adapted to prevailing local environments and make efficient use of paddocks (Sokołowicz *et al.*, 2019). However, the main obstacle to the use of these breeds for egg production is their poorer production performance as compared to hybrids, leading to poorer economic results.

Therefore, this study aimed at evaluating the effect of rearing systems and genotypes on production performance and egg quality.

## MATERIAL AND METHODS

The experiment was arranged in a 2 x 2 factorial design with two layer genotypes and two rearing systems (30 birds per group). Isa Brown hybrid and dual-purpose New Hampshire breed were used in this study. These two genotypes were housed in floor and organic rearing systems when hens were 18 weeks of age.

In both rearing systems, stocking density was 2.5 birds/m<sup>2</sup>. Organic layers also had about 5 m<sup>2</sup> per bird of available outdoor area covered with grass and bushes, which enabled them to supplement their diets using vegetation and small creatures living outdoors.

Floor-reared laying hens were fed a standard commercial diet *ad libitum*, the average chemical composition of which is shown in Table 1. In the organic system, feeders and drinkers were located both indoor and outdoor. It is important to note that diet for organic hens was complete, without synthetic amino acids, vitamins and minerals, with more than 80% of organic components. Its chemical composition is also shown in Table 1. Water was available *ad libitum* in all experimental groups.

**Table 1** – Chemical composition of laying hens' diet.

Chemical composition	Floor system	Organic system
	%	%
Dry matter	88.38	89.82
Crude proteins	16.79	16.82
Crude fats	5.15	4.31
Cellulose	4.82	4.29
Ash	12.52	12.68
Ca	3.72	3.43
Total P	0.71	0.81
Na	0.17	0.18
Lysine	0.79	0.80
Methionine+cystine	0.68	0.48
Metabolisable energy, MJ	11.5 MJ	11.3 MJ

Production performance parameters (including egg production, daily egg mass, feed consumption, feed conversion efficiency, and mortality) were recorded throughout the experimental period, which lasted one year (52 weeks), fifteen eggs per group were collected for analysis at 64 weeks of hen age. These samples (eggs were one day old) were evaluated for external, internal and eggshell quality parameters and the basic chemical composition of eggs was analyzed.

– Egg weight was measured on an electronic scale with an accuracy of 10<sup>-2</sup> g.

– Egg shape index, or short-axis to long-axis length ratio (%), was determined using a special device (B.V. Apparatenfabriek van Doorn, Holland).

– Albumen, yolk, and shell weights were measured on an electronic scale with an accuracy of 10<sup>-2</sup> g, and then their proportions were calculated in relation to the whole egg weight.

– Albumen height was determined by a tripod micrometer (AMES, USA)

– Haugh units were calculated according to the following formula:

$$HU=100\log(H+7.57-1.7M^{0.37})$$

where H = albumen height, mm. M = egg weight, g.

– Shell deformation was measured using a special device (Marius, Holland).

– Shell strength was tested with an Egg Crusher made by Pavlovski & Vitorović (1996)

– Shell thickness was measured on shell fragments sampled from the equatorial circumference (SOMET, USA)

The analysis of the chemical composition of eggs was performed based on AOAC procedures (AOAC, 1990).

Production performance data were analysed by the non-parametric Wilcoxon test. Egg quality data were analysed by ANOVA and LSD test (Stat Soft Inc Statistica for Windows. Version 7.0., 2006).



## RESULTS AND DISCUSSION

Egg production parameters are presented in Table 2.

As expected, dual-purpose New Hampshire hens achieved lower values for egg production, daily egg mass and feed conversion efficiency ( $p \leq 0.05$ ) as compared to Isa Brown hybrid because of their genetic origin that brings together meat characteristics to egg laying capability. Rizzi & Chiericato (2005) also recorded significantly higher egg production for hybrids in the

organic production system (Hy-Line Brown - 94.1%, Hy-Line White - 88.7%) as compared to two Italian breeds (Robusta Maculata - 63%, Ermellinata of Rovigo - 56.8%) in 32-week old hens. Similarly to the results of this study, Mostert *et al.* (1995) reported that the New Hampshire breed had worse feed conversion (3.19 g feed / g eggs in the system with outdoor access and 3.49 g feed / g eggs in the floor rearing system) as compared to the hybrid used in this experiment (2.13 g feed / g eggs in the floor system, and 2.40 g feed / g eggs in the rearing system with outdoor access).

**Table 2** – Effect of rearing systems and genotypes on the production performance of laying hens.

Rearing system	Floor		Organic	
	Isa Brown	New Hampshire	Isa Brown	New Hampshire
Egg production (%)	75.91 <sup>a</sup>	40.56 <sup>c</sup>	77.88 <sup>a</sup>	55.98 <sup>b</sup>
Egg mass (g egg hen day <sup>-1</sup> )	47.98 <sup>a</sup>	24.98 <sup>c</sup>	47.57 <sup>a</sup>	35.32 <sup>b</sup>
Feed consumption (g day <sup>-1</sup> )	125.46 <sup>b</sup>	124.33 <sup>b</sup>	125.54 <sup>b</sup>	129.43 <sup>a</sup>
Feed conversion (g feed per g egg)	2.92 <sup>a</sup>	6.93 <sup>c</sup>	3.03 <sup>a</sup>	5.55 <sup>b</sup>

a–c: Values within rows with different superscripts are significantly different ( $p \leq 0.05$ )

However, the data in Table 2 suggest that there was a significant interaction between the rearing systems and genotypes for all production parameters studied. Namely, there was no significant difference in egg production, daily egg mass, and feed conversion between Isa Brown layers in the organic system and those in the floor rearing system ( $p \geq 0.05$ ). Similar results were reported by Turker & Alkan (2018), who did not find a significant difference in egg production, feed consumption, and feed conversion between deep-litter and free range Lohman Brown hens; as well as by Ferrante *et al.* (2009), who analyzed egg production differences between barn and organic Hy-Line Brown layers. In contrast, New Hampshire hens in the organic system achieved significantly higher egg production and egg mass, as well as better feed conversion ( $p \leq 0.05$ ) than those reared on the floor, and significantly lower values ( $p \leq 0.05$ ) when compared to both Isa Brown experimental groups. These results suggest that some genotypes respond better to fresh air and freedom of movement, showing better production performance in a rearing system with outdoor access than in an indoor system. Kucukyilmaz *et al.* (2012) confirmed that hen genotypes significantly differed in their response to different management procedures. Namely, in their research, White Lohmann LSL layers had a higher egg production rate and higher daily egg mass in the cage system (89.8%; 59.01 g) than in the organic system (87.2%; 57 g), while at the same time ATAK-S hens showed lower values of egg production rate and

egg mass production in the cage (80.4%; 50.99 g) when compared with the organic production system (82.5%; 53.35 g) (all four groups significantly differed,  $p \leq 0.05$ ). Also, feed conversion rate was significantly affected by the interaction of investigated factors - cage White Lohmann LSL layers (1.87 g feed / g eggs), organic (2.65 g feed / g eggs), cage ATAK-S (2.32 g feed / g eggs) and organic ATAK-S (2.43 g feed / g eggs).

Organic New Hampshire hens had significantly higher ( $p \leq 0.05$ ) average daily feed consumption when compared with the other three experimental groups, which did not vary significantly from each other ( $p \geq 0.05$ ). The reason why floor-reared New Hampshire hens had significantly lower feed consumption when compared with organic hens lies in their significantly lower productive needs because of much lower egg production. In contrast, organic Isa Brown hens had higher energy requirements than floor reared layers due to higher locomotor activity, which they compensated through outdoor food; therefore, there was no difference between the two Isa Brown groups in terms of feed consumption ( $p \geq 0.05$ ). This is in agreement with the results published by Henry (2002), who reported that hens raised outdoors can satisfy even 20% of their food needs by consuming grass, insects and various invertebrates. Mugnai *et al.* (2013) found no significant difference in feed consumption between caged (109.8 g) and organic (110.4 g) Ancona laying hens.

The mortality of laying hens is presented in Table 3.



**Table 3** – Effect of rearing system and genotype on the mortality of laying hens.

Rearing system	Floor		Organic	
	Isa Brown	New Hampshire	Isa Brown	New Hampshire
Genotype				
Mortality (%)	6%	0%	6%	3%

The effect of the rearing system on the mortality of laying hens was determined by a large number of authors (Mugnai *et al.*, 2009; Gerzilov *et al.*, 2012), but there is also an interaction between rearing system and genotype when considering this parameter (The Humane Society of the United States, 2010). A significant effect of genotype on the mortality of laying hens was also found by Sørensen (2001), who determined different mortality rates for four genotypes in the free-range rearing system - 19.9% for Isa Brown hens, 13.8% for New Hampshire, 6.7% for White Leghorn, and 3.9% for New Hampshire x White Leghorn.

Egg quality parameters are presented in Table 4.

Organic Isa Brown hens had a significantly lower ( $p \leq 0.05$ ) egg weight compared with all other experimental groups, which did not differ significantly from each other ( $p \geq 0.05$ ).

The main reason for these results was the lower level of methionine and cystine in organic feed (0.48%) as compared to conventional feed (0.68%). A similar conclusion was reached by Koreleski & Świątkiewicz (2009) and Rakonjac *et al.* (2018a), that is, a limited level of methionine in the feed for organic laying hens may, *inter alia*, reduce average egg weight. The main reason why organic New Hampshire hens did not respond by decreasing their egg weight was probably their lower egg production rate, which causes reduced levels of methionine in their feed to be sufficient to meet their production needs.

Rearing systems did not cause differences in the egg shape index, which is in agreement with the findings

reported by Ahammed *et al.* (2014), Dikmen *et al.* (2017), Sokolowicz *et al.* (2018b, 2019), Rakonjac *et al.* (2018a, 2018b), and Popova *et al.* (2020). Isa Brown hens produced rounder eggs than New Hampshire ( $p \leq 0.01$ ). Škrbić *et al.* (2011) also found that native breeds produced “pointier” eggs as compared to hybrid hens. A significant effect of genotype on the egg shape index was also determined by Zita *et al.* (2009), Ledvinka *et al.* (2012), and Kraus & Zita (2019).

Rearing systems had no significant effect on the proportions of the main components of the egg ( $p \geq 0.05$ ), but the rearing system x genotype interaction significantly affected the proportions of albumen and shell ( $p \leq 0.01$ ). Generally, New Hampshire eggs had a higher content of yolk and a smaller content of albumen when compared with Isa Brown eggs ( $p \leq 0.05$ ), which is in agreement with the results published by Rakonjac *et al.* (2017), who found 2.78% more yolk and 2.23% less albumen in New Hampshire than in Isa Brown eggs. Suk & Park (2001) also confirmed that eggs from native breeds have a higher content of yolk and a smaller content of albumen when compared with eggs from hybrid hens - they found 6.07% more yolk and 5.38% less albumen in KNC, Korean native breeds, as compared to the Isa Brown hybrid. There was no significant difference in shell proportion between the examined genotypes in the floor rearing system ( $p \geq 0.05$ ), while Isa Brown eggs had a significantly higher proportion of the shell compared with New Hampshire eggs ( $p \leq 0.01$ ) in the organic system. Similar results were reported by Kucukyilmaz *et al.* (2012), who found a significantly higher ( $p \leq 0.05$ ) proportion of

**Table 4** – Effect of rearing system and genotype of laying hens on egg quality.

Rearing system (RS)	Floor		Organic		ANOVA	RS	G	RS x G
	Isa Brown	New Hampshire	Isa Brown	New Hampshire				
Genotype (G)								
Egg weight (g)	69.43 <sup>a</sup>	69.67 <sup>a</sup>	63.92 <sup>b</sup>	68.67 <sup>a</sup>		*	*	*
Egg shape index	76.60 <sup>a</sup>	74.47 <sup>b</sup>	76.20 <sup>a</sup>	73.80 <sup>b</sup>		NS	**	NS
Albumen proportion (%)	60.27 <sup>a</sup>	56.14 <sup>c</sup>	58.86 <sup>ab</sup>	58.42 <sup>b</sup>		NS	**	**
Yolk proportion (%)	27.30 <sup>c</sup>	31.45 <sup>a</sup>	27.67 <sup>c</sup>	29.87 <sup>b</sup>		NS	**	NS
Shell proportion (%)	12.43 <sup>b</sup>	12.41 <sup>b</sup>	13.47 <sup>a</sup>	11.71 <sup>c</sup>		NS	**	**
Albumen height (mm)	5.93 <sup>b</sup>	7.69 <sup>a</sup>	6.65 <sup>b</sup>	6.80 <sup>ab</sup>		NS	**	*
Haugh unit	70.93 <sup>b</sup>	84.40 <sup>a</sup>	78.60 <sup>a</sup>	78.80 <sup>a</sup>		NS	**	*
Shell thickness (mm)	0.330 <sup>a</sup>	0.303 <sup>b</sup>	0.333 <sup>a</sup>	0.280 <sup>c</sup>		NS	**	*
Shell deformation (µm)	21.53 <sup>b</sup>	25.73 <sup>a</sup>	20.47 <sup>b</sup>	28.20 <sup>a</sup>		NS	**	NS
Shell strength (N)	38.26 <sup>a</sup>	39.58 <sup>a</sup>	42.38 <sup>a</sup>	32.72 <sup>b</sup>		NS	*	**

a–c: Values within rows with different superscripts are significantly different ( $p \leq 0.05$ )

\* –  $p \leq 0.05$ , \*\* –  $p \leq 0.01$ , NS – non-significant



the shell in Lohmann LSL organic eggs (10.58%) than in cage eggs of the same genotype (10.36%), while there was no significant difference in shell proportion between organic and cage ATA-S eggs (9.77%: 9.63%,  $p \geq 0.05$ ). A significant effect of the rearing system x genotype interaction on shell proportion was determined by Svobodova *et al.* (2014).

The eggs of New Hampshire breeds in the floor rearing system had a significantly higher albumen height and Haugh units as compared to the organic eggs of this genotype ( $p \leq 0.05$ ), while no differences were recorded for the Isa Brown hybrid ( $p \geq 0.05$ ). Kucukyilmaz *et al.* (2012) also established a significant effect of the rearing system x genotype interaction on albumen height and Haugh units in the eggs. Namely, Lohmann LSL conventional system hybrid eggs (6.90 mm; 82.13) and those from the organic production system (7.01 mm; 81.15) showed no significant differences in albumen height and Haugh units ( $p \geq 0.05$ ). Conversely, ATA-S hybrids' eggs from the organic system (6.35 mm; 77.73) had significantly higher ( $p \leq 0.05$ ) values of the investigated parameters than eggs of this genotype reared in the floor rearing system (6.10 mm; 75.50). A significant effect of the rearing system x genotype interaction on albumen height and Haugh units was also found by Sokołowicz *et al.* (2018a, 2018b).

Isa Brown hens generally had better eggshell quality as compared to New Hampshire hens, but the genotype x rearing system interaction had a strong effect on two of the three eggshell quality traits examined. New Hampshire hens from the floor rearing system had significantly higher ( $p \leq 0.05$ ) eggshell thickness when compared with organic hens of the same genotype, while the experimental Isa Brown groups were not different from each other ( $p \geq 0.05$ ), but had a significantly higher ( $p \leq 0.01$ ) value of this parameter when compared with the New Hampshire genotype. Mostert *et al.* (1995) also found significantly lower ( $p \leq 0.05$ ) eggshell thickness in the New Hampshire breed (0.311 mm) when compared with eggs from three commercial hybrids (0.332 mm, 0.329 mm and

0.333 mm) reared in cage, floor and free-range systems, respectively. A significant effect of the rearing system x genotype interaction on eggshell thickness was also observed by Ledvinka *et al.* (2012) in Isa Brown, Hisex Brown and Moravia BSL genotypes, in the floor and cage production systems, as well as by Sokołowicz *et al.* (2018a) in Green-legged Partridge, Rhode Island Red, and Hy-Line Brown in litter barn, free-range, and organic rearing systems. New Hampshire layers had higher eggshell deformation when compared with Isa Brown hybrid's ( $p \leq 0.01$ ). Svobodova *et al.* (2014) also determined a crucial effect of genotype on this trait: in both systems (cage and floor), both genotypes had identical eggshell deformation - Lohmann white 0.29 mm and Czech hen 0.31 mm. Organic New Hampshire hens had significantly lower ( $p \leq 0.05$ ) eggshell strength when compared with all three experimental groups, which did not differ significantly from each other ( $p \geq 0.05$ ). These results can be explained by the interaction of numerous factors affecting eggshell quality, including genotype, hen age, mating, nutrition, stress, some diseases, climatic factors, and rearing system (Roberts, 2004), and in the present study they probably caused reduced eggshell quality in organic New Hampshire hens. A significant effect of the rearing system x genotype interaction on shell thickness and shell strength was also determined by Sokołowicz *et al.* (2018b).

Table 5 showed that there was no significant effect of the rearing system on these traits, which is in agreement with the results published by Minelli *et al.* (2007), Nistor *et al.* (2014) and Kiczorowska *et al.* (2015). New Hampshire eggs had a higher dry matter ( $p \leq 0.01$ ) and minerals ( $p \leq 0.01$ ) content when compared with Isa Brown eggs. Similarly, Pavlovski *et al.* (2011) determined higher dry matter (25.59%) and minerals (0.93%) contents in breed eggs (Naked Neck) when compared with hybrid (Hy-Line) hens (23.04% and 0.88%, respectively).

Rearing systems had no significant effect on the protein content of eggs ( $p \geq 0.05$ ), which is consistent with the findings published by Krawczyk & Gornowicz

**Table 5** – Effect of laying hens' rearing systems and genotypes on the chemical composition of eggs.

Rearing system (RS)	Floor		Organic		ANOVA	RS	G	RS x G
	Isa Brown	New Hampshire	Isa Brown	New Hampshire				
Genotype (G)								
Dry matter (%)	23.65 <sup>c</sup>	25.42 <sup>a</sup>	24.16 <sup>bc</sup>	25.13 <sup>ab</sup>		NS	**	NS
Minerals (%)	0.89 <sup>ab</sup>	0.93 <sup>a</sup>	0.87 <sup>b</sup>	0.91 <sup>ab</sup>		NS	*	NS
Protein (%)	12.14 <sup>b</sup>	12.71 <sup>a</sup>	12.38 <sup>ab</sup>	12.14 <sup>b</sup>		NS	NS	**
Lipids (%)	9.29 <sup>b</sup>	10.33 <sup>a</sup>	9.13 <sup>b</sup>	10.29 <sup>a</sup>		NS	**	NS

a–c: Values within rows with different superscripts are significantly different ( $p \leq 0.05$ )

\* –  $p \leq 0.05$ , \*\* –  $p \leq 0.01$ , NS – non-significant



(2010) and Radu-Rusu *et al.* (2014). Also, Rakonjac *et al.* (2018b) found no difference in the protein content between floor and organic eggs. However, there was a strong interaction between the examined factors ( $p \leq 0.01$ ), and therefore floor-reared New Hampshire hens had a significantly higher egg protein content as compared to organic New Hampshire and floor-reared Isa Brown layers (which had identical egg protein contents). Organic Isa Brown hens had an intermediate value of this parameter and did not differ from any of the other three experimental groups ( $p \geq 0.05$ ). Similarly to our results, Kucukyilmaz *et al.* (2012) observed no significant difference in the protein content of eggs between organic and caged ATA-S hens (both groups at 13.32%). However, in the same experiment, organic Lohmann LSL layers displayed a higher ( $p \leq 0.05$ ) protein content (13.19%) as compared to caged hens of the same genotype (12.85%), which showed that some genotypes can respond differently in rearing systems with outdoor access and thus cause differences in eggs' protein content. A significant effect of the rearing system on protein content in eggs was also determined by Perić *et al.* (2016) and Yenice *et al.* (2016).

There was no significant effect of the rearing systems on the lipid content of eggs, which is in agreement with the findings published by Rakonjac *et al.* (2018b), who found no difference in the lipid content between floor and organic eggs, while cage eggs had a higher lipid content when compared with the previous two groups. The absence of a significant effect of rearing system on this characteristic was also determined by Minnelli *et al.* (2007), Krawczyk & Gornowicz (2010), Pavlovski *et al.* (2011) and Filipiak-Florkiewicz *et al.* (2017).

New Hampshire hens had a significantly higher lipid content in eggs ( $p \leq 0.01$ ) when compared to Isa Brown. The significantly higher content ( $p \leq 0.01$ ) of lipids in the yolk of the breed (Araucana - 27%) compared with the hybrid (Isa Brown - 20%) was also established by Pintea *et al.* (2012).

## CONCLUSION

Generally, Isa Brown hens had better production performance when compared with the New Hampshire breed. At the same time, organic New Hampshire layers were dominant when compared with floor-reared ones.

Genotype had a significant effect on all ten egg quality parameters (external, internal and eggshell quality), while rearing system independently affected only egg weight. However, the interaction of the

observed factors significantly influenced seven tested parameters. Genotype similarly had a significant effect on three of the four chemical composition parameters of chemical composition, while there was no significant effect of the rearing system on the chemical composition of eggs. The rearing system x genotype interaction significantly influenced the protein content of eggs.

These results indicate that in alternative rearing systems, especially organic ones, special attention must be given to the choice of genotype, because most of the examined properties were significantly affected by the breeding system x genotype interaction.

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