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Dynamics of occurrence of defective eggs in initial laying lines of hens

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Abstract: The aim of this study was to monitor the occurrence of abnormal eggs in five initial laying lines of the domestic chicken (*Gallus domesticus*) between 2017 and 2021. The incidence of abnormal eggs, cracks, shell-less eggs, and double-yolk eggs were examined as part of the monitoring. Also assessed was the laying intensity, which ranged from 83.7% for the Barred Plymouth Rock (BPR) B line to 96.8% for the Rhode Island Red (RIR) A line. A statistically significant relationship between the line and control year was discovered for all varieties of abnormal eggs. The highest occurrence of cracks was in the RIR B line (2.2%). The BPR A line of hens had the highest concentration of shell-less eggs (1.7%), while the RIR A line, which also had the highest laying intensity (96.8%), had the highest frequency of double-yolk eggs (1.5%). A positive trend between the intensity and the occurrence of abnormal eggs was also confirmed. The BPR B (3.4%) and BPR C (3.0%) lines, which belonged to the lines with the lowest laying intensity, had the lowest percentage of abnormal eggs. For the BPR C line, cracks (1.2%), shell-less eggs (0.9%), and double-yolk eggs (0.9%) had the lowest occurrence rates. The correlation between laying intensity and double-yolk eggs reached 0.67, and a significant positive relationship was seen. On the other hand, no association was found between the laying intensity and the prevalence of cracked or shell-less eggs. There was also a strong correlation between abnormal eggs and double-yolk eggs (0.80) and between abnormal eggs and cracks (0.73). The correlation between the total occurrence of abnormal eggs and the intensity of laying reaches a mean value of 0.41. An increase in the intensity of laying from 80% to almost 100% leads to an increase in the occurrence of abnormal eggs from 2.6% to 6.3%.

Keywords: cracks; shell-less eggs; double-yolk eggs; abnormal eggs; laying intensity

Even now, the occurrence of eggs of inferior quality is a significant cause of financial losses. Egg defects are still present in pure lines, and it is possible to anticipate that selection against their occurrence will improve the performance of commercial hybrids (Wolc et al. 2012). The frequency of defective eggs, including cracked eggs, double-yolk eggs and shell-less eggs, differs depending on the line or breed. However, Patterson et al. (2001) did not observe a marked difference in the percentage of cracked eggs between the white-egg and brown-egg hybrids (5.7% and 5.4%, respectively).

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Also, Abrahamsson and Tauson 1993 reported a different frequency of cracked eggs in two lines of White Leghorn hens.

In domestic poultry and game birds, double-yolked (DY) eggs are a rare phenomenon; usually, 1% to 2% of all eggs laid during a cycle are DY. The production of such eggs is influenced by several factors, from which the most important ones include genetics, selection for multiple ovulations, female age, light exposure and nutrition. Higher body weight is a known consequence of selection and has been linked to increased multiple ovulation (Salamon 2020).

Even young birds, just beginning to reach reproductive maturity, occasionally have double ovulations that result in the development of double-yolked eggs. These double ovulations are uncommon in hens with peak reproductive productivity and practically never result in two completely developed eggs. According to a study by Navara and Wrobel (2019), 13% of hens produced at least one double oviposition over the two weeks of observation, frequently laying a second egg 2.5 h after the first. Another study revealed a higher frequency of double-yolk eggs from heavier hens than from lighter ones (Renema et al. 2001).

Shell quality in older hens is poorer and shell damage increases (Wilson et al. 2017). Cracks, the appearance of which is related not only to the age of the hens, are a costly problem for the processing industry (Bell et al. 2001). When an effect on several qualitative measures of laying hens was shown, the influence of age and genotype on egg quality was also examined in six lines and breeds of laying hens in two age categories (Krawczyk et al. 2021). The influence of the genotype and breeding environment on the quality parameters of the eggs was similarly monitored (Sharma et al. 2022). In another study, eggshell characteristics were measured in different genotypes and different housing systems (Ketta and Tumova 2018).

Numerous authors have discussed how nutrition can affect the occurrence of abnormal eggs. In a study on Hy-Line Brown hens, the impact of vitamin C supplementation on the quality of laying hens' eggs was investigated (Delos Reyes et al. 2021). In this study, it was shown that laying hens' incidence of shell-less eggs decreased as vitamin intake rose. Egg quality, notably the proportion of cracked and shell-less eggs, was unaffected by the addition of sunflower meal to the diet of laying hens (Kocer et al. 2021). However, adding an *Enterococcus faecalis* supplement to laying hens' diets had no apparent impact on the occurrence of abnormal eggs (Zhang et al. 2019). The effect of dietary supplements on productive performance, egg physical traits and fatty acids composition of eggs was also investigated in another study (DalleZotte and Pranzo 2022).

Effective egg production also requires a reliable non-destructive system for detecting the occurrence of abnormal eggs. It is particularly important to prevent cross-contamination of intact and damaged eggs during storage. Choosing the appropriate algorithm for classifying the various types of abnormal eggs is also crucial (So et al. 2022).

A number of studies deal with the evaluation of the laying intensity. In addition to the influence of genotype (Ma et al. 2021), the influence of laying hen housing technology is also described. For example, the intensity of laying in classic cages, enriched cages and aviaries was evaluated (Philippe et al. 2020). The laying intensity was statistically substantially lower in aviaries. The value and quality of the eggs from two lines of laying hens (Lohmann Brown and Atak-S) housed in enriched cages were assessed (Denli et al. 2019). Both lines produced eggs at considerably different rates, but there was no statistically significant variation in the quality of the eggs produced by these lines. The influence of selected factors on egg production and egg quality was also evaluated for the carrier hybrid ISA Brown (Vlckova et al. 2018).

The relationship between egg production, egg quality and the age of Lohmann Brown hens was discussed (Mitrovic et al. 2010). Authors in the Czech Republic also dealt with the correlation between egg quality indicators in laying hen lines (Machal and Simeonovova 2002).

The aim of this work was to evaluate the influence of different lines of laying hen hybrids on the intensity of laying and egg quality, specifically the occurrence of cracks, shell-less eggs and double-yolk eggs. The dynamics of these parameters throughout various years were assessed concurrently.

MATERIAL AND METHODS

The experiment made use of data gathered from one breeding farm. Data from four performance evaluation cycles (2017/2018 to 2020/21) were used. The observations covered five initial laying lines:

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Barred Plymouth Rock (BPR) A, BPR B, BPR C, Rhode Island Red (RIR) A, and RIR B. Data on performance control were gathered from days 123 to 250 of hen age. Eggs were collected and recorded daily during this period; in addition to laying, data on the occurrence of cracks (%), double-yolk eggs (%) and shell-less eggs (%) were recorded. The total incidence of these defective eggs was recorded as a percentage of abnormal eggs. In addition, the laying intensity (%) was evaluated.

Hens of the BPR lines were speckled in colour, and hens of the RIR lines were coloured brown. Both lines lay brown eggs. Hens were always stocked at the end of summer at 15 weeks of age and the laying cycle started between 17 and 18 weeks of age. Two thousand six hundred eighty-seven hens (BPR A: 1 056, BPR B: 390, BPR C: 354, RIR A: 336, RIR B: 551) were stocked in 2017, 2 725 hens (BPR A: 1 047, BPR B: 584, BPR C: 233, RIR A: 572, RIR B: 289) in 2018, 2 894 hens (BPR A: 1 181, BPR B: 621, BPR C: 195, RIR A: 536, RIR B: 361) were stocked in 2019, and 2 772 hens (BPR A: 1 143, BPR B: 527, BPR C: 205, RIR A: 536, RIR B: 361) were stocked in 2020. The database, therefore, contained a total of 11 078 animals.

The hens were kept separately in individual enriched cages with grates so that the laying of each bird could be monitored and recorded. There are manure belts under the grates, which are used to remove manure from the hall. Feeding of the hens is ensured by trough feeders, into which the feed is transported using feeding chains. The water supply is provided by a nipple drinker located in each cage. The animals were given NP 100 g, a full and balanced feed mixture. The light regime was gradually increased from the beginning of laying (every eight days by half an hour) so that at the 30th week of age, the animals had 15 h of light and 9 h of darkness.

Statistical analysis

Data was analysed using the Statistica v14 statistical program (TIBCO Software, Inc., Palo Alto, CA, USA). Two-way analyses of variance (ANOVA) with interaction was used to assess the impact of line and laying year. Post hoc analysis was performed using Duncan's test. In the case of effects and post hoc analysis, the null hypothesis was always rejected at the $\alpha = 0.05$ significance level. The equation for the analysis of the variance model had the following form:

$$y_{ijk} = \mu + \text{year}_j + \text{line}_k + \text{int}_{jk} + e_{ijk} \quad (1)$$

where:
y – dependent variable (laying intensity, abnormal eggs, cracks, shell-less eggs, double-yolk eggs);
μ – general intercept;
year – effect of laying year j ($j = 4$);
line – effect of hen line k ($k = 5$);
int – interaction of laying year and line;
e – random residual error.

Pearson's correlation coefficients were used to evaluate the relationship between individual egg defects.

RESULTS

Table 1 shows the laying intensity and the incidence of individual egg defects for the interaction of line and year of laying. All parameters observed were significantly affected ($P < 0.01$) by the effects of line and laying year. The interaction of line and laying year was significant only in the case of the total occurrence of abnormal eggs ($P < 0.05$) and in the case of the frequency of shell-less eggs ($P < 0.01$). For all lines, there is no discernible upward or downward trend in the frequency of abnormal eggs and shell-less eggs with the control year. The BPR A line had the highest percentage of abnormal eggs in 2020/2021 (6.3%) and then in the same line in 2018/2019 (6.1%). Statistical analysis showed these values were statistically distinct from those of other lines and laying years. Contrarily, the BPR C line recorded the lowest incidence of abnormal eggs in 2019/2020 (2.6%) and 2018/2019 in the BPR B and BPR C lines, 2.7%.

The RIR A line experienced the lowest occurrence of shell-less eggs in 2018/2019, with a value of just 0.3%, which was statistically different from other values for shell-less eggs. Both the BPR B line and the BPR C line experienced similarly low results for shell-less eggs in 2018/2019. In both cases, the occurrence level of shell-less eggs was 0.5%. Conversely, the highest percentage occurrence of shell-less eggs was for the BPR A line in 2020/2021 (2.1%) and then for the RIR A line in 2017/2018 (1.9%). The BPR A line exhibits the

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Table 1. Incidence of defects in different lines for each year

Line	Year	n	Laying intensity (%)	Abnormal eggs (%)	Cracks (%)	Shell-less eggs (%)	Double-yolk eggs (%)
BPR A	2017/2018	1 056	92.8	3.6^{f}	1.0	1.5^{c}	1.14
	2018/2019	1 047	98.2	6.1^{a}	1.5	1.6^{b}	1.52
	2019/2020	1 181	95.0	4.0^{e}	1.1	1.7^{b}	1.16
	2020/2021	1 143	94.7	6.3^{a}	2.4	2.1^{a}	1.86
BPR B	2017/2018	390	80.4	3.5^{f}	0.8	1.6^{b}	1.2
	2018/2019	584	87.6	2.7^{g}	1.4	0.5^{f}	0.9
	2019/2020	621	81.0	2.8^{g}	0.9	1.1^{de}	0.8
	2020/2021	527	86.1	4.7^{d}	2.1	1.2^{d}	1.3
BPR C	2017/2018	354	86.5	2.9^{g}	0.8	1.2^{d}	0.9
	2018/2019	233	86.5	2.7^{g}	1.5	0.5^{f}	0.7
	2019/2020	195	85.4	2.6^{g}	0.8	1.0^{e}	0.8
	2020/2021	205	85.2	3.8^{e}	1.8	0.9^{e}	1.0
RIR A	2017/2018	336	95.6	5.6^{b}	2.1	1.9^{ab}	1.6
	2018/2019	572	99.7	3.2^{f}	1.6	0.3^{g}	1.4
	2019/2020	536	95.8	4.0^{e}	1.7	1.1^{e}	1.3
	2020/2021	536	96.3	5.2^{c}	2.2	1.1^{e}	1.9
RIR B	2017/2018	551	82.2	4.8^{d}	2.2	1.6^{b}	1.0
	2018/2019	289	89.1	4.1^{e}	1.9	1.2^{d}	1.0
	2019/2020	361	86.5	3.9^{e}	2.0	1.2^{d}	0.7
	2020/2021	361	85.8	5.5^{b}	2.8	1.4^{c}	1.3
Line	–	–	0.001	0.001	0.001	0.001	0.001
Year	–	–	0.001	0.001	0.001	0.001	0.001
Line × year	–	–	0.252	0.025	0.141	0.001	0.749

BPR = Barred Plymouth Rock; RIR = Rhode Island Red

$^{a-g}$Different superscripts indicate statistically significant differences between means (rejecting H0 at $P < 0.05$)

highest rates for abnormal and shell-less eggs. The lowest values of the percentage occurrence of abnormal eggs and shell-less eggs occur for the BPR C line (3.0% and 0.9%, respectively).

The interaction of line and year of laying was inconclusive for the other monitored parameters, therefore, no statistically significant differences between individual averages were found in the post hoc analysis.

Table 2 shows the values for individual measured parameters according to each individual line of hens. The line effect was statistically highly significant in all cases ($P < 0.01$). The RIR A line reached a laying intensity of 96.8%. The lowest val-

Table 2. Incidence of defects in differents lines

Line	n	Laying intensity (%)	Abnormal eggs (%)	Cracks (%)	Shell-less eggs (%)	Double-yolk eggs (%)
BPR A	4 427	95.2^{b}	5.0^{a}	1.5^{c}	1.7^{a}	1.4^{a}
BPR B	2 122	83.7^{d}	3.4^{c}	1.3^{d}	1.1^{c}	1.0^{b}
BPR C	987	85.9^{c}	3.0^{c}	1.2^{d}	0.9^{d}	0.9^{c}
RIR A	1 980	96.8^{a}	4.5^{b}	1.9^{b}	1.1^{c}	1.5^{a}
RIR B	1 562	85.9^{c}	4.6^{b}	2.2^{a}	1.4^{b}	1.0^{b}
Significant	–	0.001	0.001	0.001	0.001	0.001

BPR = Barred Plymouth Rock; RIR = Rhode Island Red

$^{a-d}$Different superscripts indicate statistically significant differences between means (rejecting H0 at $P < 0.05$)

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Table 3. Correlation coefficients between eggs defects (n = 20)

Traits	Laying intensity	Abnormal eggs	Cracks	Shell-less eggs	Double-yolk eggs
Laying intensity	1	–	–	–	–
Abnormal eggs	0.41	1	–	–	–
Cracks	0.18	0.73^{++}	1	–	–
Shell-less eggs	0.05	0.50^{+}	0.2	1	–
Double-yolk eggs	0.67^{++}	0.80^{++}	0.50^{+}	0.45	1

$^{+}$Statistically significantly non-zeros correlation coefficients (rejecting H0 at $P < 0.05$); $^{++}$statistically significantly non-zeros correlation coefficients (rejecting H0 at $P < 0.01$)

ue of laying intensity was measured by line BPR B (83.7%). The hens of the BPR A line showed a laying intensity of 95.2%. The BPR C and RIR B lines achieved a laying intensity of 85.9%.

The BPR A line (5.0%) had the highest incidence of abnormal eggs, which was statistically distinct from the other lines. Lines RIR A, and RIR B reached an average incidence of abnormal eggs of 4.5%, respectively 4.6%; these means were not statistically significantly different. Also, there were no statistically significant differences between the rates of abnormal eggs in the BPR B and BPR C lines. The occurrence of abnormal eggs was 3.4% in BPR B and 3.0% in BPR C.

The RIR B line (2.2%) had the highest crack incidence, whereas the BPR B line (1.3%) and the BPR C line (1.2%) had the lowest. The difference between BPR B and BPR C was not statistically significant. The BPR A line had the highest prevalence of shell-less eggs (1.7%), followed by the RIR B line (1.4%). The lowest was, similarly to the occurrence of cracks, for the BPR C line (0.9%). Also, in the occurrence of double-yolk eggs, the BPR C line showed the best parameters when this abnormality occurred in 0.9% of cases. Conversely, the highest incidence of double-yolk eggs was recorded in the RIR A line (1.5%).

The Pearson correlation coefficients between the observed parameters are displayed in Table 3. There is a positive relationship between all parameters. There is a demonstrably non-zero correlation coefficient between the total occurrence of abnormal eggs and cracks, shell-less eggs and double-yolk eggs. The intensity of egg laying was correlated with double-yolk eggs at 0.67. Moreover, a fairly significant connection (0.50) between cracks and double-yolk eggs is seen. The correlation coefficient between abnormal eggs and double-yolk eggs, which is 0.80, and between abnormal eggs and cracks, which was 0.73, show the strongest association.

Figure 1 shows the course of the dependence between the laying intensity and the occurrence of abnormal eggs. The aforementioned linear regression function explained almost 17% of the vari-

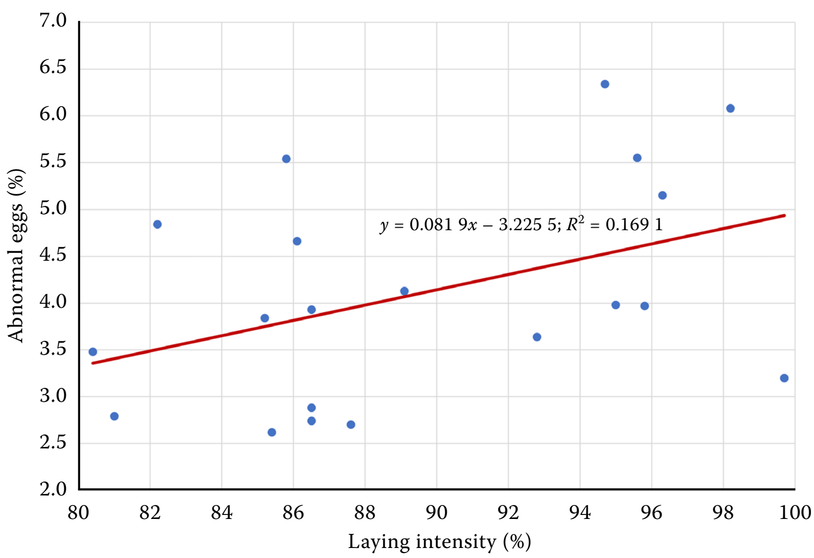

Figure 1. Relationship between laying intensity (%) and abnormal eggs (%)

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ability, corresponding to a correlation coefficient between abnormal eggs and laying intensity of 0.41. With the increasing laying intensity, the probability of the occurrence of abnormal eggs increases. The regression coefficient, which reaches a value of 0.08, represents this growth. Thus, with an increase in the laying intensity by 1%, an increase in the occurrence of abnormal eggs can be expected by an average of 0.1%. With a laying intensity of about 80%, it is predicted that the incidence of abnormal eggs would be around 2.5%; however, at a laying intensity of about 100%, it can be assumed that the incidence of abnormal eggs would be close to 6.5%.

DISCUSSION

The occurrence of abnormal eggs is one of the important indicators related to efficient egg production. For example, the occurrence of cracks is significant in terms of quality and price in the market (Patterson et al. 2001). The authors state that cracks develop on average between 5.4% and 5.7% in starting lines, which is much more than what we discovered for the analysed starting lines. In contrast, in a study of 11 000 brown laying hens, an average incidence of cracks of 0.7% was observed (Wolc et al. 2012), which is less than the rate attained by the laying hen lines in our study. Similar incidence values (0.8%) were only seen for the BPR B and BPR C lines in the control year 2017/2018. In the research mentioned above (Wolc et al. 2012), the total incidence of abnormal eggs (3.9%), shell-less eggs (0.2%) and double-yolk eggs (0.6%) was also monitored. The percentage of cracks is also reported by the authors of the study on Lohmann Brown (Denli et al. 2019), with values varying from 2.1% to 4.8% depending on the phase of the laying cycle. In our study, lower incidence rates of all abnormal eggs were seen for the BPR B (3.4%) and BPR C (3.0%) lines. The data we obtained were consistently and significantly greater for double-yolk and shell-less eggs across all lines.

The statistically proven influence of different lines on the occurrence of abnormal eggs, cracks and other defects is also described by other authors, e.g. for two lines of White Leghorn hens (Abrahamsson and Tauson 1993) or six egg-laying breed lines in Poland (Krawczyk et al. 2021). An effect on egg quality was also reported between the Hy-Line Brown and White Leghorn W-36 lines (Sharma et al. 2022). Double-yolk eggs are common in 1–2% of cases (Salamon 2020). The occurrence of double-yolk eggs is caused by double ovulation, which can reach a frequency of up to 13% in laying hens (Navara and Wrobel 2019) and is higher in high-yield hybrids of laying hens, where it can lead to an incidence of double-yolk eggs of up to 3%. The incidence of double-yolk eggs in our study is within the range of the above values, where the lowest incidence was 0.9% for the BPR C line and the highest at 1.5% for the RIR A line.

The proportion of abnormal eggs was also investigated in broiler breeder hens in Canada (Renema et al. 2001). Depending on the growth curve and photostimulation, the authors estimate that the overall incidence of defective eggs ranges from 0.6% to 5.2%. The proportion of shell-less eggs increased from 0.1% to 0.5%. Furthermore, when the incidence range ranged from 0.03% to 0.3%, the occurrence of double-yolk eggs would be recorded. While broiler breeds were included in the study mentioned above, the numbers presented here are noticeably lower than our findings. As a result, egg production was reduced, which is consistent with our study's finding that there is a positive association between egg production and abnormality (0.41).

The occurrence of shell-less eggs in the hybrids we monitored ranged from 0.9% to 1.7%, which is substantially more than what some publications report. For example, a study on Hy-Line Brown laying hens (Delos Reyes et al. 2021) examined the effect of vitamin C supplementation on egg production and found that the proportion of shell-less eggs varied between 0.01% to 0.2% (with no vitamin C supplementation). In contrast, research on white-egg hybrids in Turkey (Kocer et al. 2021) describes the percentage of shell-less eggs in the range of 1.3% to 1.6%, which corresponds to our results (0.9% to 1.7%). This study evaluated the occurrence of cracks, which ranged from 0.3% to 0.4%, values that were much lower than those observed in our group of hens. Another study dealing with egg production in Hy-Line Brown (Zhang et al. 2019) describes the incidence of cracks at the level of 0.5% to 0.7%, i.e. lower values again. The laying intensity is reported by the authors to be 79.4% to 84.1% for this hybrid. This lower laying intensity may also lead to a lower occurrence of cracks compared to our results.

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The laying intensity reached the highest level in the RIR A (96.8%) and BPR A (95.2%) lines. This is comparable to the laying intensity of Lohmann laying hens in Canada (Philippe et al. 2020), where the laying intensity in conventional and enriched cages reached 96.3%, respectively 96.6%. The other lines in our experiment had lower laying intensity results. However, compared to all the lines in our research, the laying intensity was lower in a study on Hy-Line Brown (Zhang et al. 2019). In our study, a positive relationship was observed between the laying intensity and the frequency of abnormal eggs (Table 3). However, among laying lines, there are large differences between the laying intensity and the frequency of abnormal eggs (Table 1). The differences between the lines are also described in the work by Machal et al. (2004) and also Machal and Simeonovova (2002). The differences are due to the fact that there is a greater difference in traits between lines than between individual breeds. The frequency of abnormal eggs is the reason for strict negative selection within the line.

CONCLUSION

When analyzing the incidence of abnormal eggs in the initial laying lines (Rhode Island Red and Bar Plymouth Rock), a statistically significant difference was found. This applies to all evaluated lines. At the same time, a difference was observed within the individual years 2017 to 2021, when the BPR A line, in particular, had the highest incidence of cracks (2.4%), shell-less eggs (2.1%) and double-yolk eggs (1.86%) in the last control year. The average laying intensity increased in the BPR A and BPR B lines for each of the individual control years, rising from 92.8% to 94.7% for the BPR A line and from 80.4% to 86.1% for the BPR B line. The trend for each of the individual control years varies for the other lines. The interaction of control year and line is evident for abnormal eggs and shell-less eggs. The BPR C line had the lowest incidence of all abnormal egg types among the individual lines (3.0%). However, it belonged to the lines with lower egg-laying intensity (85.9%), which is also supported by the positive correlation between egg-laying intensity and the overall incidence of abnormal eggs throughout the lines. The findings indicate differences in the incidence of abnormal eggs for different initial lines of laying hybrids. In order to increase the effectiveness of egg production of final laying hybrids, it is important to pay attention to the occurrence of cracks, shell-less eggs, and double-yolk eggs in the populations of these lines during breeding.

Conflict of interest

The authors declare no conflict of interest.

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