Reproductive performance and quality of offsprings of parent stock of layer hens after rearing in open and closed aviary system

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ABSTRACT In this study, we analyzed the parent stock of ISA Brown hens reared in closed and open aviary (**CA** and **OA**, respectively) sections with regard to the productive performance of hens, hatchability, and quality of chicks. The flocks were reared (1,570 cocks and 17,515 hens) for 16 wk in a three-level aviary system. On the 7th wk of rearing, half of the birds (OA group of birds) were allowed to leave the section and use half of the area of the poultry house and to use all levels. The remaining half of the birds were kept in the CA section for the entire duration of rearing. After the duration of rearing, the birds were moved to 2 neighboring production poultry houses (OA = 680 cocks and 8,126 hens; CA = 685 cocks and 8,133 hens). Reproduction was performed in a litter system in accordance with the norms for parent stock of laying hens. During the production cycle (53 wk), laying performance, feed conversion ratio, water consumption, and mortality were analyzed. On 27th, 37th, and 49th wk of production, the following analysis was performed: rate of fertilization (%), rate of hatching (%), and quality of chick. In accordance with the results, birds in OA flock required less amount of feed ($P < 0.001$) and water ($P = 0.020$) to produce a laid egg, a hatching egg (respectively: $P < 0.001$; $P = 0.009$), and a chick (both $P < 0.001$) in comparison with the birds in CA flock. In addition, a lower number of litter eggs were found in the OA flock ($P < 0.001$). Mean laying production, production of hatching eggs, and number of waste eggs did not depend on the flock rearing system ($P > 0.05$); however, a combined analysis of all these parameters using multivariate analysis of variance demonstrated a better ($P < 0.001$) result for OA flock than that of CA flock. Rate of fertilization, rate of hatching, and quality of chicks did not depend on the flock rearing system ($P > 0.05$). In summary, it is possible to rear parent ISA Brown hens in open sections of aviary system without the fear of subsequent deterioration of indicators of future egg production.

Key words: closed and open aviary, parent stock laying flock, production, hatching, chick quality

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INTRODUCTION

Poultry production results depend to a large extent on proper rearing. This is of particular importance for parent stocks (**PS**) which provide eggs for the production of commercial layer hens. Relatively little is known about the relationship between welfare and production in PS flocks. On the other hand, previous studies have shown that behavioral and physiological indicators related to welfare during rearing of commercial layers are linked to their subsequent yield (de Haas et al., 2012). Similar relationships should also apply to PS.

The European Union Council Directive 1999/74/EC (European Communities, 1999), which has been in force since December 2013, prohibits husbandry of laying hens in traditional cage batteries. However, this is only applicable to commercial laying flocks (Rodengurg et al., 2012; Freire and Cowling, 2013; Heerkens et al., 2015). To date, no separate regulations have been developed for the maintenance of PS. They are maintained in accordance with the regulations for both rearing and reproduction of commercial flocks. This is probably due to the fact that the public focuses almost exclusively on the welfare of commercial layers, completely ignoring previous production levels. Parent stocks are particularly vulnerable to

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stress due to many factors, but genetic predisposition, keeping both genders together and subjecting flocks to a strict hygiene regime that strongly limits contact with humans are mentioned most often (de Haas et al., 2013). Therefore, an improvement of rearing conditions for this group of birds is particularly important issue.

At present, PS birds are reared in conventional cage batteries from first day to 16th–18th wk of life and then transferred to a litter system. However, producers are increasing their attempts to rear PS flocks in aviaries. This is primarily dictated by the welfare of the birds, possible benefits during their reproductive stage, and protection against the possible future regulatory changes with respect to the husbandry of PS birds. The choice of an aviary system as an alternative to the rearing of PS flocks in cages is based on the fact that it has proved to be best suited to the rearing of commercial flocks. More frequent manifestation of natural behaviors observed in aviary vs. cage hens (Tahamtani et al., 2014; Brantsaeter et al., 2016), reduced number of eggs laid in the litter due to reduced adaptation time to the new environment (Janczak and Riber, 2015) and less anxiety and stress (Johnsen et al., 1998) are highly desirable in PS flocks. In addition, the aviary as a multilayer system consisting of a floor and a multilevel metal structure increases the surface area for movement, thereby enabling hens to manifest behaviors such as running, wing flapping, flying up, nesting, and perching (Leyendecker et al., 2005). Therefore, this system has the greatest potential to replace cages.

However, rearing birds in the aviary system is difficult compared with rearing in a cage system because of the higher labor requirements and new hazards. First and foremost, the selection of a suitable release date and "training" all birds to return simultaneously so that they have equal chances of taking up all levels are sensitive issues to deal with. Although major companies provide instructions for the rearing of laying hens in aviaries (Hendrix-Genetics, 2014), producers who rear the first flock make the decision to release only a portion of the flock to minimize the risk of loss and to help obtain the necessary experience in new conditions.

In this study, we analyzed the changes in the indicators of reproduction of PS laying hens, which constituted the first flock reared in the aviary system of a specific farm. Production indicators, hatching rate, and chicken quality of a flock of PS hens reared in open and closed aviary (OA and CA, respectively) sections were compared. We hypothesized that improvement in the housing conditions of PS during the rearing period by releasing them from the aviary section will improve their further adaptation to litter system, without negatively affecting the reproduction results.

MATERIALS AND METHODS

Ethical Approval

Rearing, production, and mass hatching were conducted under commercial conditions. Procedures for laboratory hatching were approved by the II Local Ethical Committee for Animal Experiments in Poland (application 8 April 2019, Warsaw, Poland).

Birds and Rearing Time Conditions

The PS of ISA Brown, numbering 1,570 cocks and 17,515 hens, were purchased as 1-day-old chicks from ISA, Hendrix-Genetics (the Netherlands). The ISA Brown parent set consists of Rhode Island Red cocks and Rhode Island White hens; thus, the obtained chicks are autosexing. The birds were transported to Musielak S.A., ISA Brown Rearing Farm (Korzeniówka, PL), and were introduced into a newly assembled, three-level aviary system by Hellmann Poultry GmbH & Co. KG (Kopernikusstr, Vechta, Germany). Figure 1 present the exact dimensions of the aviary system.

When stocking the rearing facility, approximately 105 cocks or 113 hens were introduced to a single section of the aviary. The 1-day-old chicks (males and females separately) were all placed in the middle level of the cage of each section of the aviary. At 10 d of age, half of the chickens were placed in the lower level to meet the growing need for more space. Until 7 wk, all chicks were reared under similar conditions, separately pullets and cockerels, in closed sections, where they were unable to move between the levels and did not have access to the floor area. From 7 wk onward, chicks from half of rearing facility were released and were allowed to use the floor area and all levels, together pullets and cockerels. The birds were trained to return to the aviaries through systematic switching on and off of LED in the sections so that they are distributed equally in all 3 levels. The time spent by the chicks (in hours) outside the aviary depended on the light:dark (**L:D**) program. To facilitate the movement of the birds on different levels, every third balcony was opened to form stairs. The return to their sections was precisely monitored for the first 10 d. Those birds which stayed on the floor were manually introduced into the sections. The number of birds in each individual section and on specific levels was controlled before switching the lights off, and the numbers were offset.

Apart from the constant maintenance of birds in CA and OA sections, the remaining rearing conditions were kept constant. The following 2 feed based on wheat, corn, and soybean meal were provided *ad libitum*: "OT1CED0" from first day to 7th wk of age (18.5% crude protein, 2,880 ME kcal/kg) and "OT2CED0" from 8th to 16th wk of age (15.5% crude protein, 2,790 ME kcal/kg). The feed was distributed by a chain feed line running centrally through each section. The feeder space per chicken was about 2.2 cm. At each level of every section, 4 nipple drinkers were installed. Water was available *ad libitum*. Day length during the first week was maintained up to 22 h. Subsequently, the day was systematically shortened to the 14L:10D until the age of 16 wk. The temperature was systematically reduced from approximately 33.5°C on first day to 20.5°C in the middle of the 7th wk, which was maintained until the end of

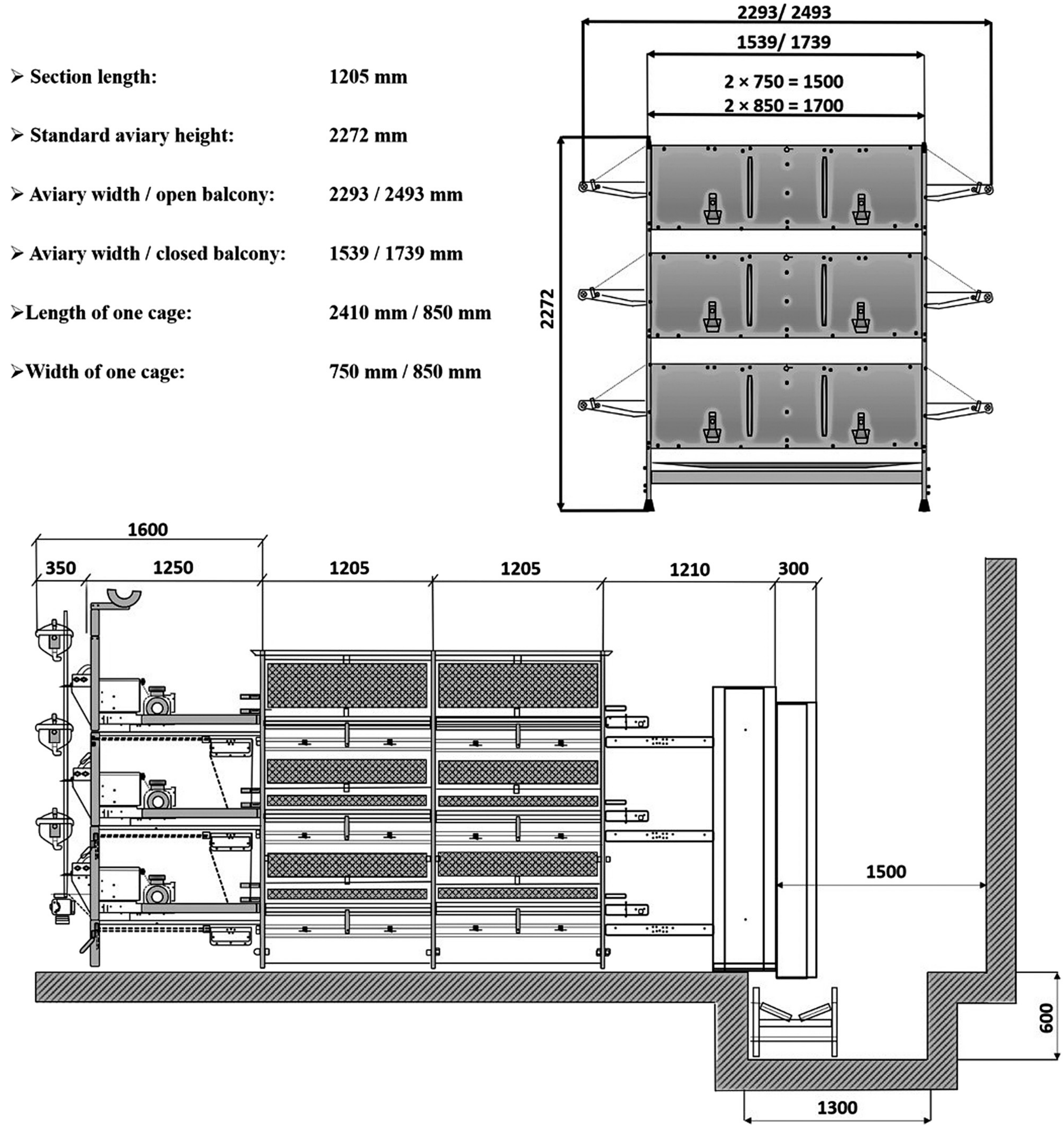

Figure 1. The scheme of aviary system construction.

rearing. During the entire rearing period, a full set of preventive vaccinations were administered in-line with the Hendrix-Genetics recommendation (2014). Rearing continued for up to 16 wk of age.

Production Time Conditions

After 16 wk, both flocks were transported approximately 40 km to ISA Brown Reproduction Farm and Hatchery (Niedabyl 49, PL) and were introduced into the 2 identical and neighboring poultry houses (OA and CA flock separately). Considering the mortalities and rejections during rearing and rejections after the transport, the following number of chickens was introduced into the poultry house: 680 cocks and 8,126 hens from flock OA and 685 cocks and 8,133 hens from flock CA. The density was 8 birds/m^2. Flocks were housed using floor housing with partly slatted floors (about 1/3 areas near nest). The floor was covered with a litter of finely chopped straw. The poultry house was equipped with central automatic egg nests (1 m^2/120 hens), 2 automatic droplet drinker lines, and 2 feeder lines (Big Dutchman, Germany). The poultry house was illuminated for up to 15.0–16.5 h per day and the light intensity ranged from 1.3 to 42.1 lx (average: 25.6 lx). Cocks and hens were fed with a feed based on corn, wheat,

Figure 2. Eggs troyller with marked (arrow, line) hatching baskets for analysis in commercial hatchery.

dehulled sunflower seeds, triticale, and postextraction soybean meal (OG4CED0). The nutritional value of the meal was as follows: 17.0% crude protein, 2,820 ME kcal/kg, 4.69% crude fiber, 3.45% crude fat, and 11.63% crude ash. Feed and water were available to birds *ad libitum*.

Monitoring of Production Results

Laying performance was inspected every day in the flocks, including all laid eggs, eggs laid on the litter, hatching eggs, and waste eggs. A hatching egg was an egg intended for hatching, which met the following criteria: eggs weight 52–75 g, clean shell without any damage and deformations. Waste consisted of eggs that did not meet the above criteria. Daily feed (kg) and water (L) uptake were controlled and mortalities and rejections were documented. During the week of flock combining (19th wk of age), initial body weight (**BW**) was assessed based on the weighed hen (100) and cock sample (15). The repeated BW control was performed during the last week of production (71st wk of age).

Table 1. Curve parameter estimates and SE of Yang model used to fit weekly egg production rates of parental laying stock after rearing in opened and closed aviary.

Treatment	OA[1]		CA[2]	
	Parameter	SE	Parameter	SE
a	0.00035	0.00014	0.00032	0.00009
b	1.779	0.091	1.777	0.062
c	1.782	0.091	1.780	0.062
d	4.471	0.034	4.504	0.023

a = asymptotic value of egg production at the peak of egg-laying; b = rate of production decrease after the peak (eggs/hen-day decrease per week); c = reciprocal indicator of the variation in week of production of first egg; d = mean week of egg production at sexual maturity.

Abbreviations: CA, closed aviary; OA, open aviary; PS, parent stocks.

[1]OA = PS flock rearing in opened aviary cages.

[2]CA = PS flock rearing in closed aviary cages.

Based on the obtained results, laying performance curves were developed, and the following was calculated: mean laying percentage, mortality, feed conversion ratio (**FCR**; g), and water (mL) uptake per egg laid, hatching egg, and female chicks.

Hatching Parameter and Quality of Chicks

The hatching analysis of both flocks was performed 3 times: on 27th, 37th, and 49th wk of production. Results of commercial and experimental hatching were obtained at the same time.

Commercial Hatchery Hatching eggs from the daily collection were laid on the trays with the large end up, were disinfected by spraying with Virkon S (1:100), and were placed in transport trolleys. One tray contained 150 eggs and one trolley had 32 trays. After the collection, the eggs were transported to the egg storehouse located in the hatchery. The transport time did not exceed 10 min. The eggs were stored for 4–7 d under controlled microclimatic conditions (15°C–18°C and 65–75% RH). The turning of eggs during the storage consisted of setting the angle of trays inclination by 90° every 12 h, so the eggs were always in the 45° inclination from the vertical plane, but with the change of the side plane (up-down). After 4 d, the eggs were placed in the setter (Petersime 576, Zulte, Belgium) with a capacity of 57,600 eggs. The eggs were incubated at 37.5°C–38.5°C and with 50–60% RH. Every 2 h, the eggs were turned (by 90°) and the CO_2 level was monitored from 5th d of incubation (3.5–4.5 ppm). On 18th d of incubation, the eggs were candled and unfertilized eggs were discarded; the apparent rate of fertilization was calculated based on the number of fertilized eggs. During candling, random samples were selected from the discarded eggs to identify the infertile eggs or early dead embryos. Breakout examination was performed on a total of 1,462 eggs from OA flock and 1,491 eggs from CA flock. Failure in fertilization was identified based on the changes in the area of germinal disc (prematurely dead embryos) and the presence of dead embryos. The diagnosis of early death was made on the basis of the stages of chicken embryogenesis described and illustrated by Hamburger and Hamilton (1951). After candling the eggs, they were placed in breeding baskets and placed in hatcher (Petersime AirStreamer 12S, Zulte, Belgium). The eggs were incubated in the horizontal position at 37.6°C and 65% RH.

Four trays per hatching trolleys were selected for hatching analysis. To keep the conditions of incubation constant, the trays were selected identically: the 5th tray from the top and 5th tray from the bottom in both trolleys columns (Figure 2). The number of trays selected for analysis depended on the number of trolleys per given set. In the first one, 22 and 32 trays for OA and CA flocks, respectively, were analyzed. In the second and third set, 21 and 26 trays for OA and CA flocks,

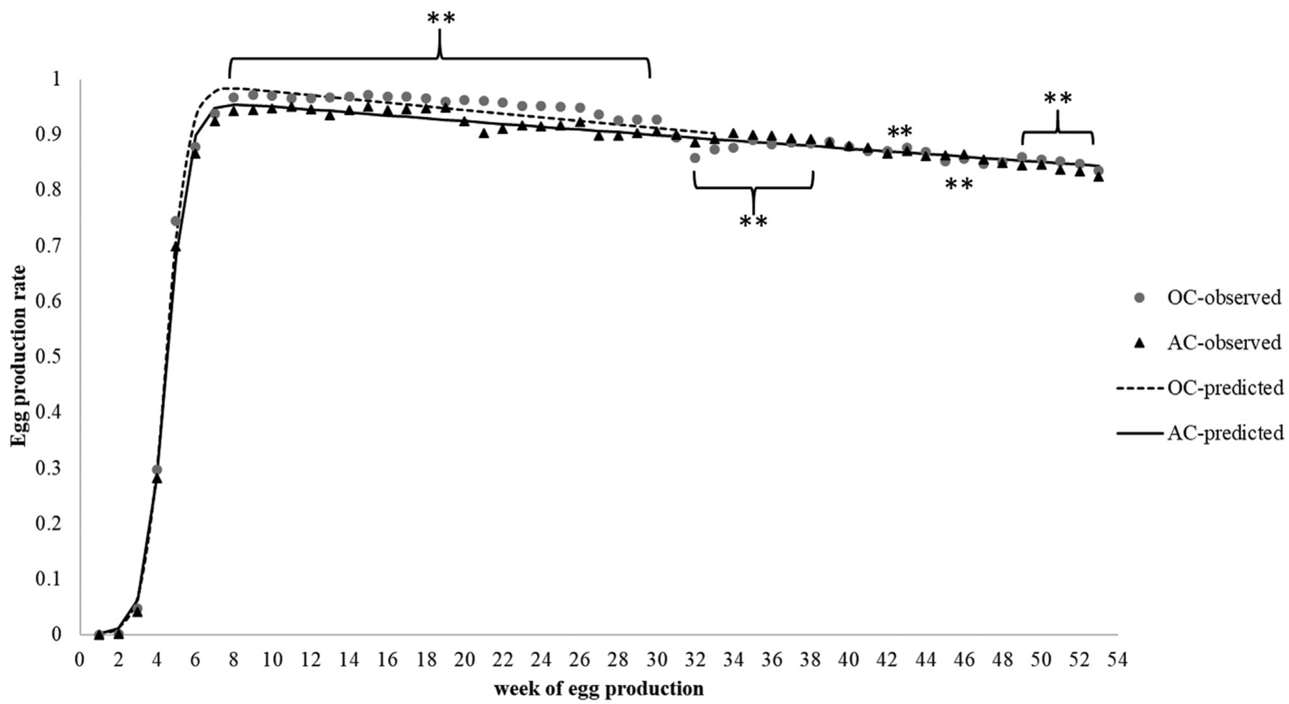

Figure 3. Curve of Yang model used to fit weekly egg production rates of parental laying stock after rearing in opened and closed aviary; OA = PS flock rearing in opened aviary cages. CA = PS flock rearing in closed aviary cages. **Main effect—significantly different at $P \leq 0.05$. Abbreviations: CA, closed aviary; OA, open aviary; PS, parent stocks.

respectively, were analyzed. A total number of 10,350 and 11,850 eggs were analyzed from OA and CA flocks, respectively. After completing the incubation for up to 21 d, rate of hatching was analyzed. After moving the trolleys from the hatchery, selected hatching trays were separated from the others. Female chicks, male chicks, and unhatched eggs were counted in each tray. Based on the results, hatching of all chicks from the laid eggs, seemingly fertilized eggs, and hatching of female chicks from the laid eggs were calculated.

Laboratory Hatching In the same terms (27th, 37th, and 49th wk of hens production), additional 100 hatching eggs from each group OA and CA, collected from transport trolleys from daily egg harvest, were provided for experimental hatching (a total of 300 hatching eggs per flock). The eggs were transported to the laboratory of the Institute of Animal Sciences, Warsaw University of Life Science (Poland). The egg transport duration was 1.5 h. Eggs were transported by a specifically adapted transport system. After the transport, the eggs were stored for 3 d under conditions similar to the hatchery storehouse. Before the eggs were placed in setter (OvaEasy 380, Brinsea, Weston, UK), the egg weight was determined (±0.1 g). The eggs were incubated at 37.6°C–38.0°C with a 50–65% RH, but without the possibility of controlling CO_2 level. The eggs were automatically turned by 90° after every 2 h. The eggs were candled and again weighed on the 18th d of incubation. Breakout examination was performed for all eggs without a live fetus and analyzed similar to the waste in the hatchery. The obtained results were used to calculate egg weight loss up to 18th d and fertilization (%). The remaining eggs were placed individually in hatcher (OvaEasy 380, Brinsea, Weston, UK). After the completion of hatching on 21st d of incubation, individual BW of the chicks (±0.1 g) was determined and the ratio of chick BW to egg weight was calculated. Subsequently, the hatching rate (%) of all chicks from laid and fertilized eggs, as well as hatching rate of female chicks from all laid eggs and the contribution (%) of unhatched eggs in relation to laid eggs was calculated. All remaining eggs were cracked open and the possible causes for the lack of hatching were determined, considering the sex, live/dead, abnormal hatching position, genetic defects, and others. Supplementary Figure 1 presents examples of observed defects.

The quality of chicks hatched in the laboratory was determined in accordance with the simplified methodology described by Tona et al. (2003). Seven chick traits were assessed. For activity, navel area, remaining yolk and legs 0—20 points were awarded, for eye appearance 0—10 points, for fluff appearance and remaining membrane 0—5 points. The maximum score of a chick was 100. The ratio of chicks with a score of 100 (%), an average score of all chicks and the average score of chicks with a score <100 was calculated. The average score for the given trait for both flocks was also determined. Supplementary Figure 2 presents the examples of defects resulting in reduced scores.

Statistical Analysis

The results are presented as mean ± SD or as percentages (fractions). Data of OA and CA groups were compared using *t*-test for means and chi-square test for fractions. Multivariate comparisons were performed using a one-way multivariate analysis of variance

Table 2. Production results of parental laying stock after rearing in opened and closed aviary.

Parameter	OA[1] Means ± SD	CA[2] Means ± SD	*P*-value
N[3]			
Cocks	680	685	—
Hens	8,126	8,133	—
Average eggs production (%)	85.3 ± 21.5	84.1 ± 21.1	0.412
Hatching eggs production (%)[4]	94.6 ± 4.6	93.8 ± 6.1	0.071
Litter eggs production (%)[5]	3.10 ± 0.71	3.30 ± 0.44	<0.001
Waste eggs (%)[6]	5.40 ± 4.59	6.15 ± 6.06	0.072
Together: Average eggs production (%); Hatching eggs production (%); Waste eggs (%): MANOVA-based F ratio = 8.16			<0.001
Feed conversion ratio (g) for:			
One laid egg	143.3 ± 12.6	160.9 ± 17.3	<0.001
One hatching egg	152.0 ± 17.2	172.5 ± 24.3	<0.001
One hatching female	389.8 ± 44.2	450.3 ± 63.5	<0.001
Together feed conversion ratio (g) for: one laid egg; one hatching egg; one hatching female: MANOVA-based F ratio = 14,201			<0.001
Water used (mL) for:			
One laid egg	252.8 ± 30.0	258.7 ± 33.3	0.020
One hatching egg	268.8 ± 41.0	277.8 ± 47.1	0.009
One hatching female	689.3 ± 105.2	725.3 ± 123.0	<0.001
Together water used (mL) for: one laid egg; one hatching egg; one hatching female: MANOVA-based F ratio = 8,627			<0.001
Mortality			
Cocks			
(wk)[7]	0.128 ± 0.178	0.132 ± 0.207	0.871
(%)[8]	6.78	7.02	0.860
Hens			
(wk)[7]	0.266 ± 0.143	0.251 ± 114	0.410
(%)[8]	14.10	13.40	0.139
Initial BW (g)			
Cocks	1,840 ± 260	1,738 ± 211	0.349
Hens	1,325 ± 103	1,322 ± 131	0.830
Final BW (g)			
Cocks	2,771 ± 137	2,692 ± 112	0.086
Hens	1,741 ± 123	1,690 ± 115	0.003

Main effect—significantly different at $P \leq 0.05$.
Abbreviations: BW, body weight; CA, closed aviary; OA, open aviary; PS, parent stocks.
[1]OA = PS flock rearing in opened aviary cages.
[2]CA = PS flock rearing in closed aviary cages.
[3]Initial number of reproduction roosters and hens.
[4]Eggs intended for hatching (quality standards of hatching eggs).
[5]Litter eggs intended for hatching (quality standards of hatching eggs).
[6]Eggs not intended for hatching (without hatching standard).
[7]Weekly average mortality.
[8]Total mortality for 53 wk of production.

(**MANOVA**). Yang model was applied to fit weekly egg production rates for hens in each group (Yang et al., 1989):

$$y_t = \frac{ae^{-bt}}{1+e^{-c(t-d)}}$$

where y_t = egg production rate at t weeks of laying; a = asymptotic value of egg production at the peak of egg-laying; b = rate of production decrease after the peak (eggs/hen-day decrease per week); = reciprocal indicator of the variation in week of production of first egg; d = mean week of egg production at sexual maturity.

The data were analyzed using Statistica 13 software. For all the analyses, the significance level was set at 0.05 (Statsoft, 2014). The original raw data set is available in S1 Dataset.

RESULTS

Egg Production, FCR, and Mortality

Both PS started egg production during a similar period (parameter c and d, Table 1). In both flocks, the first eggs (0.01% of lay) were laid in the middle of 19 wk of life, and the collection of eggs for hatching began at the end of 24 wk of life (S1 Dataset). The lack of differences in egg production from the first to seventh week of laying period (Supplementary Table 1) evidenced that both flocks were characterized by a similar laying rate (Figure 3 and Supplementary Figure 3). As a result, throughout the 53rd wk of laying, the mean egg production did not depend ($P = 0.412$) on the rearing system, similar to the eggs ($P = 0.071$), classified as hatching eggs (Table 2). Hens from OA flock laid

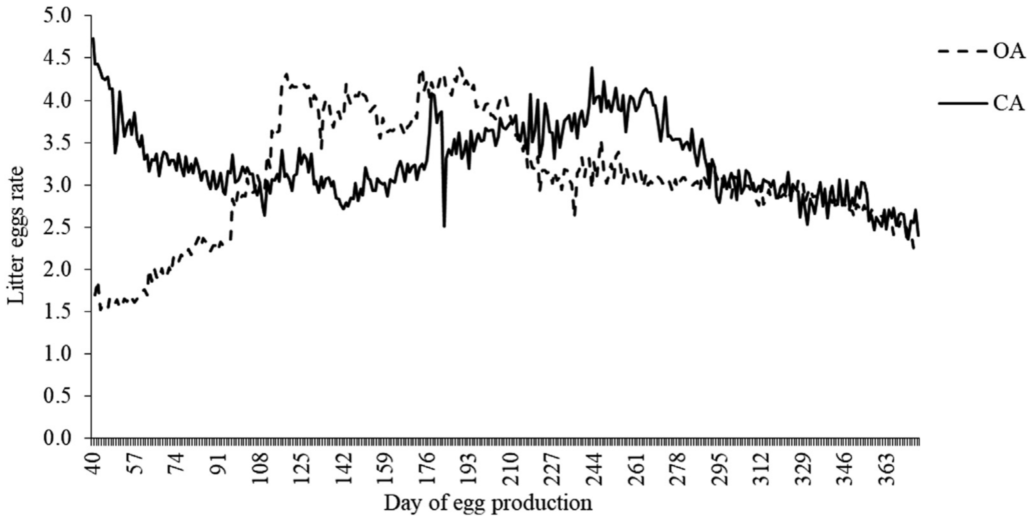

Figure 4. Curve of litter eggs production rate of parental laying stock after rearing in opened and closed aviary. OA = PS flock rearing in opened aviary cages. CA = PS flock rearing in closed aviary cages. Abbreviations: CA, closed aviary; OA, open aviary; PS, parent stocks.

($P < 0.001$) less number of eggs on the litter (Table 2) particularly in the early laying period. During the laying peak (from 17th–30th wk), lower number of litter-laid eggs were observed in the CA flock (Figure 4, Supplementary Table 2). The combined analysis of the mean production of all eggs, hatching eggs, and waste eggs demonstrated considerable ($P < 0.001$) positive effect of OA vs. CA rearing system. This is due to the fact that although the differences in particular indicators were insignificant, they were all better in the OA flock.

The OA flock required 17.6 g of feed and 5.9 mL of water less (respectively: $P < 0.001$; $P = 0.020$) for the production of a single laid egg, and 20.5 g feed and 9.0 mL water less to produce one hatching egg (respectively: $P < 0.001$; $P = 0.009$), and 60.5 g feed and 63.0 mL water less to produce one chicken (both $P < 0.001$) compared with the CA flock (Table 2). As a result, the combined analysis of obtain indices showed that hens from OA flock demonstrated a significantly better FCR and water intake than that of hens from CA flock ($P < 0.001$).

The hens of OA and CA flocks did not differ in the mortality of cocks and hens throughout the production period (Table 2 and Figure 5). No differences in initial BW could be determined for both sexes (respectively: $P = 0.349$; $P = 0.830$). Similarly, the final BW of cocks was almost same in both flocks ($P = 0.086$), but the final BW of OA hens was higher ($P = 0.003$) than that of CA hens (Table 2).

Hatching Results

The rearing system of the PS did not affect the egg fertilization. This was confirmed in controls of the apparent fertilization at the hatchery ($P = 150$; Table 3) as well as fertilization control in laboratory

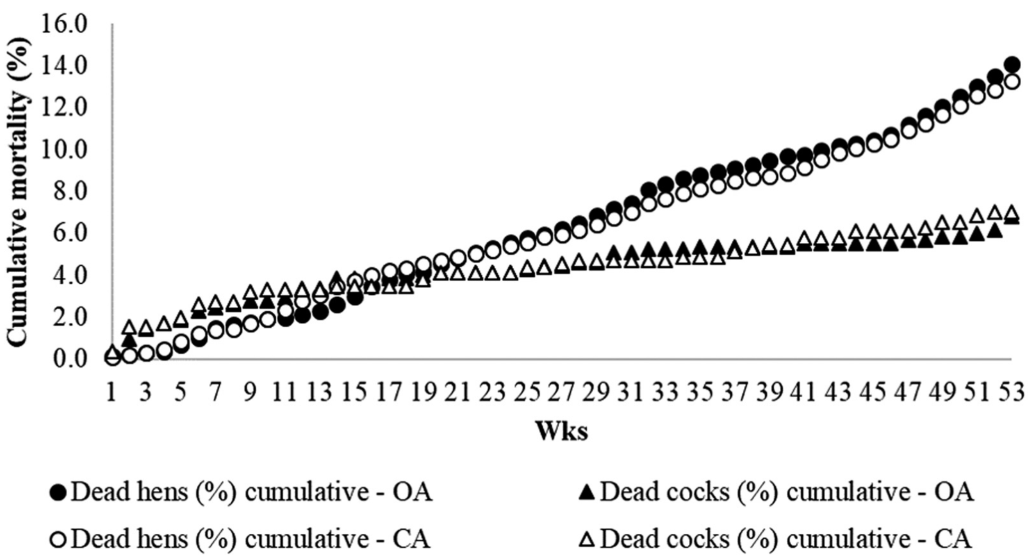

Figure 5. Cumulative mortality of parental laying stock after rearing in opened and closed aviary. OA = PS flock rearing in opened aviary cages. CA = PS flock rearing in closed aviary cages. Abbreviations: CA, closed aviary; OA, open aviary; PS, parent stocks.

Table 3. Commercial hatching results of parental laying stock after rearing in opened and closed aviary.

Parameter	OA[1] Means ± SD	CA[2] Means ± SD	P-value
Set eggs (N)	10,350	11,850	—
Apparent fertility (%)[3]	88.6 ± 2.6	87.9 ± 2.9	0.150
Unfertilized eggs (%)[4]	36.3 ± 6.6	36.5 ± 6.4	0.925
Dead embryos (%)[4]	63.7 ± 6.6	63.5 ± 6.4	0.925
Hatchability of apparent fertile eggs (%)[3]	89.4 ± 3.2	89.8 ± 3.3	0.422
Hatchability of set eggs (%)[3]	79.2 ± 3.9	78.9 ± 3.8	0.733
Hatching females (%)[3]	39.0 ± 3.5	38.3 ± 3.6	0.238
No hatched chicks (%)[3]	10.0 ± 3.2	9.0 ± 2.9	0.053

Main effect—significantly different at $P \leq 0.05$.
Abbreviations: CA, closed aviary; OA, open aviary; PS, parent stocks.
[1]OA = PS flock rearing in opened aviary cages.
[2]CA = PS flock rearing in closed aviary cages.
[3]For all set eggs.
[4]For selected eggs sample: CA=1,491 eggs; OA=1,462 eggs.

conditions ($P = 670$; Table 4). Breakout examination of the rejected eggs at the hatchery also demonstrated that the ~~ration~~ of unfertilized eggs and eggs containing dead embryos was similar between OA and CA flocks (for both $P = 0.925$). OA and CA flocks did not differ in terms of hatching from laid and fertilized eggs (Tables 3 and 4). In OA flock, the hatching of chicks in hatchery and laboratory conditions was higher by 0.7 and 8.8%, respectively, but the difference was not confirmed (respectively: $P = 0.238$; $P = 0.062$).

The difference in female BW and female BW ratio to eggs of both OA and CA flocks was not confirmed ($P > 0.05$). Body weight and BW ratio of male was higher (for both $P = 0.003$) in OA flock than that in CA flock (Table 4).

The percentage of unhatched eggs was higher in CA flock than that in OA flock by 6.2%, yet the difference was insignificant ($P = 0.239$; Table 4). In CA flock, at least 50% of the unhatched chicks were females, 33.9% were cocks, and sex for 16.1% of the fetus could not be discerned. The number of unhatched male and female chicks was similar in OA flock (37.8 and 35.1%, respectively) (Table 5), but sex could not be confirmed in 27.1% of the cases. The most common reason for chicks not hatching in OA and CA flock were abnormal positions (56.8 and 60.7%, respectively), with the lower number of genetic defects confirmed (16.2 and 7.1% respectively). The other reasons, which included nongenetic inborn defects, limb tangled in blood vessels, and so on (S1 Dataset) constituted 13.5% in OA flock and 10.7% in CA flock. The reason could not be determined in 13.5% of the cases of unhatched eggs from OA flock and 10.7% from CA flock. Most of the fetuses from both flocks were dead at the time of analysis, but 27% OA eggs and 16.1% CA eggs contained live fetuses. The number of unhatched eggs, sex of unhatched fetuses, and reasons for the lack of hatching not depended ($P > 0.05$) on the rearing system of PS (Table 5).

Table 4. Laboratory hatching results of parental laying stock after rearing in opened and closed aviary.

Parameter	OA[1] Means ± SD	CA[2] Means ± SD	P-value
Set eggs (N)	300	300	—
Egg weight (g)	61.5 ± 3.3	61.3 ± 3.7	0.566
Eggs weight loss for 18 d of incubation (g)	15.1 ± 3.0	15.4 ± 3.4	0.232
Fertility (%)	97.8 ± 2.2	98.5 ± 1.7	0.670
Hatchability of fertile eggs (%)	78.4 ± 7.0	70.7 ± 10.9	0.356
Hatchability of set eggs (%)	76.7 ± 6.8	69.6 ± 10.9	0.396
Hatching females			
%	40.6 ± 2.7	31.8 ± 5.4	0.062
Chicks BW (g)			
Female	40.5 ± 3.2	40.3 ± 3.5	0.672
Male	41.3 ± 3.1	40.0 ± 3.2	0.003
Chicks BW ratio (%)[3]			
Female	66.0 ± 3.8	65.2 ± 3.2	0.096
Male	67.0 ± 3.3	65.7 ± 3.2	0.003
No hatched fetus (%)	12.0 ± 3.1	18.2 ± 7.1	0.239

Main effect—significantly different at $P \leq 0.05$.
Abbreviations: BW, body weight; CA, closed aviary; OA, open aviary; PS, parent stocks.
[1]OA = PS flock rearing in opened aviary cages.
[2]CA = PS flock rearing in closed aviary cages.
[3]Chicks BW ratio in weight of set eggs.

Table 5. Analysis of no hatched fetus of parental laying stock after rearing in opened and closed aviary.

	OA[1]	CA[2]	
Parameter	N and %	N and %	P-value
No hatched fetus (N)	37	56	—
Including:			
Females	14 (37.8%)	28 (50.0%)	0.249
Males	13 (35.1%)	19 (33.9%)	0.905
Causes			
Abnormal hatching position	21 (56.8%)	34 (60.7%)	0.704
Genetics defects	6 (16.2%)	4 (7.1%)	0.167
Others	5 (13.5%)	6 (10.7%)	0.682
No visible defects	5 (13.5%)	12 (22.0%)	0.259
Fetus			
Alive	10 (27.0%)	9 (16.1%)	0.200
Dead	27 (73.0%)	47 (83.9%)	0.200

Main effect—significantly different at $P \leq 0.05$.
Abbreviations: CA, closed aviary; OA, open aviary; PS, parent stocks.
[1]OA = PS flock rearing in opened aviary cages.
[2]CA = PS flock rearing in closed aviary cages.

Quality of the Chicks

The rearing system of PS did not affect any of the 7 assessed traits in chicks (Figure 6). The ratio (%) of chicks with a maximum score of 100, mean score of all chicks, and mean score of all chicks assessed at <100 points were similar for both OA and CA flocks ($P > 0.05$) (Table 6).

DISCUSSION

In this study, we aimed to verify whether opening the sections of the aviary system and enabling ISA Brown PS flocks' to move on a larger area of the poultry house and different construction levels has an effect on their reproductive results. The analysis of production parameters, and hatching efficiency clearly demonstrated that, as assumed in the hypothesis, releasing chickens outside of the section area from the 7th wk of rearing did not cause these indicators to deteriorate. On the contrary, lower number of litter eggs, more favorable FCR, and lower amount of water intake per one egg laid, per one hatching egg, and per one hatched female chick in OA flock indicates a positive effect. It may be supposed that the improvement of conditions of hen husbandry during the rearing period influences the future improved economic indexes of PS.

The number of studies on the evaluation of chicken PS production depending on their rearing conditions is very limited. However, previous studies have proved that adult birds are able to adapt to new maintenance conditions in a production poultry house, but the time of adaptation depends on their housing conditions during the rearing period (Wichman and Keeling, 2009; Nicol et al., 2011). In this study, we observed that OA hens had higher laying performance than that of CA hens, which was recorded from the onset of production until 30th wk, although the difference was insignificant during the first 7 wk. The hens of OA flock learned to use the nests quicker than CA hens, which is proven by the considerably lower number of eggs laid on the litter (Table 2), particularly in the early laying period (from 7th–15th wk) and after laying peak (from 32nd–41st wk). Gunnarsson et al. (1999) observed that access to perches from not later than the 4th wk of age decreased the prevalence of floor eggs during the period from start-of-lay until 35 wk of age. Roll et al. (2009) obtained contrasting results. They showed that hen reared outside the cage resulted in an increased number of dirty and cracked litter eggs. In our study, dirty and cracked eggs were considered as waste eggs, that is eggs unfit for hatching. In the case of both hatching and waste

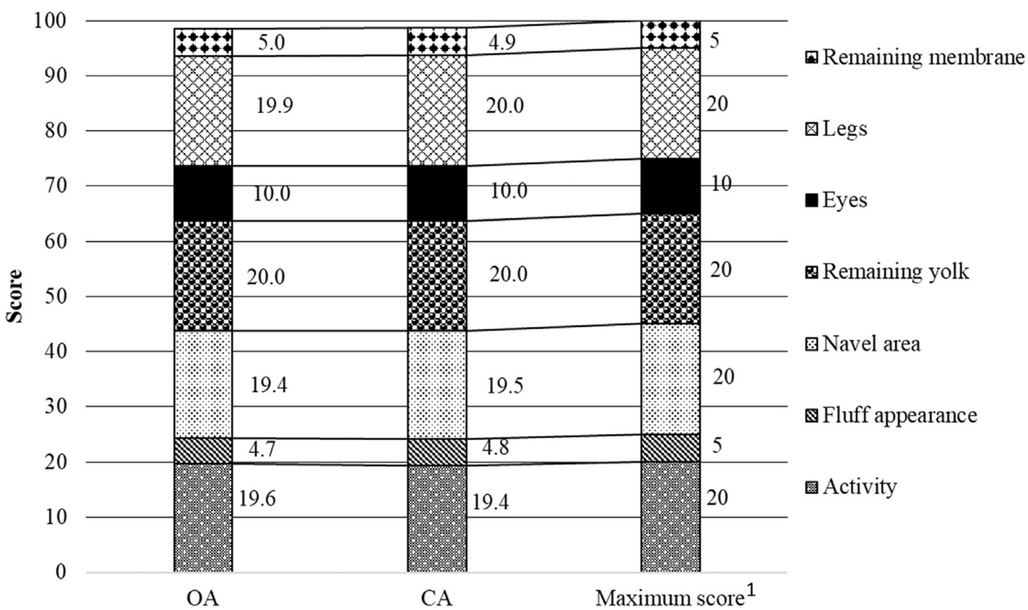

Figure 6. Chicks quality scores of parental laying stock after rearing in opened and closed aviary. OA = PS flock rearing in opened aviary cages. CA = PS flock rearing in closed aviary cages. [1]Maximum score = maximum score for a given trait. The quality of chicks was determined in accordance with the simplified methodology described by Tona et al. (2003). Abbreviations: CA, closed aviary; OA, open aviary; PS, parent stocks.

Table 6. Chicks quality of parental laying stock after rearing in opened and closed aviary.

Parameter	OA[1] Means ± SD	CA[2] Means ± SD	P-value
Chicks with score 100 (%)	73.5	80.1	0.103
Average score of all chicks	98.56 ± 4.44	98.64 ± 4.51	0.861
Average score of chicks with score <100	94.57 ± 7.29	93.15 ± 8.09	0.356

Main effect—significantly different at $P \leq 0.05$.
Abbreviations: CA, closed aviary; OA, open aviary; PS, parent stocks.
[1]OA = PS flock rearing in opened aviary cages.
[2]CA = PS flock rearing in closed aviary cages.

eggs, no significant differences were observed between the flocks. However, higher number of hatching eggs (by 0.80%) and lower number of waste eggs (by 0.75%) were found in the OA flock than that in the CA flock, which is in-line with the results reported by Gunnarsson et al. (1999) and contradictory to those reported by Roll et al. (2009).

However, the most important results of this study was the lower FCR and water intake in OA flock than that of CA flock. Despite the fact that the mean laying performance, production of hatching eggs, and production of waste eggs did not differ significantly between the flocks, these parameters had more favorable values for OA hens than for CA hens. As a result, their combined analysis confirmed differences between the flocks. Aviary rearing, compared with cage rearing, has a more pronounced stimulating effect on their reproductive system, which is confirmed by the elevated concentration of steroid hormones in the blood (Janczak et al., 2009).

However, whether these factors are significant for the entire production cycle, depends on the duration of the effect of rearing in the given flock. It has been proven that positive effect of aviary rearing of hens decreases with production time (Tahamtani et al., 2014; Brantsaeter et al., 2016). They recorded positive benefits of aviary system on the expression of natural behavior of hens during the first few weeks of their transfer to the new environment. It can be assumed on the basis of their study that the current living environment of the hens will have more effect at a later stage. Although Tahamtani et al. (2014) and Brantsaeter et al. (2016) investigated the impact of transferring commercial laying hens from aviary to furnished cages, our study indicates that the same mechanisms may have worked for PS flocks transferred from aviary to litter, which was reflected in the results. Analysis of the laying curve (Figure 3) and the number of eggs laid on the litter (Figure 4) also showed that the advantage of OA hens over CA hens decreased. However, CA hens were characterized by lower laying persistence than that of OA hens, and at the end of production, the laying performance of CA hens was lower than that of OA hens. These results suggest for possibility of longer efficient maintenance of OA hens. In this study, production was finished simultaneously, but in the future, we recommend examining reproduction of PS birds reared in different environmental conditions for a longer duration.

The total mortality of hens and cocks in the OA flock was similar to the CA flock. However, analyzing the course of cumulative mortality (Figure 5) a tendency confirming earlier observations can be observed of Tahamtani et al. (2014) and Brantsaeter et al. (2016). These authors found a higher mortality rate in hens that were reared in aviaries compared with those reared in cages.

In this study, we could not confirm the effect of releasing PS hens from the aviary section during rearing on the hatching rate and chick quality, but this result shall be considered positive. In general, the reproductive capacity of laying hens is high, and it is difficult to further stimulate their improvement. However, during the study, we expected that the aviary rearing system may have a positive impact on the activity of cocks. A long-term reaction was expected, analogous to the one observed after the application of interspiking in meat-type cocks (Chung et al., 2012). The fertilization rate of 97.8 and 98.5% (Table 4), respectively, in CA and OA indicates that rearing PS flocks in CA and OA sections resulted in equally high sexual activity of birds. The mortality of cocks in both studied flocks was also comparable, which showed similar adaptation after transferring to litter conditions in production poultry house.

Another parameter was the effect of the PS rearing system of flocks on the quality of hatched chicks. Earlier research has demonstrated that not only genetic factors but also environmental factors of the mother may influence the physiology and behavior of the offspring (Lickliter, 2005; Henriksen et al., 2011). All these aspects may change depending on the rearing method of PS. However, our results clearly indicate that the application of OA sections in the rearing of PS of chicken does not affect the survivability of embryos and morphological quality of chicks in the first day of life. This result is positive, although for several reasons better hatching results and quality of chicks in OA vs. CA flocks could be expected. This is due to the fact that OA hens after moving to the poultry house where reproduction started had already established a hierarchy in the flock, were accustomed to the presence of roosters, had a better orientation over a large area of the poultry house and felt much less fear of humans. All these factors could reduce the stress of the hens during the production of hatching eggs. Schmidt et al. (2009) demonstrated that if stress in hens during egg formation is not avoided, there may be negative consequences for fertilization, hatching, and early and late embryo mortality. Elevated levels of corticosterone in the blood of reproductive birds also contribute to prolonging the incubation time of the eggs and causes desynchronization of hatching, resulting in a deterioration of chicks quality (Schmidt et al., 2009). In addition, the study by de Haas et al. (2013), which first addressed the relationship between stress and production rates of PS hens, showed that the management of such flocks should take into account the human–bird relationship and flock size. Limited relations with humans (greater fear) and keeping in small flocks negatively affects the production performance of PS hens. Such conditions are created primarily in case of caged hens. In aviary management, birds stay in large flocks and contact with humans is more frequent. This particularly concerns the rearing period when birds are released from their segments and taught to return at night by manual catching. This labor-intensive procedure plays a major role in creating a stress-free, permanent human–bird relationship.

The only exception to the difference in the quality of chicks between OA and CA flocks that was confirmed in this study was a higher BW and the ratio of BW to egg weight of males from the OA flock. This result is insignificant during the production of adult laying birds because F1 males are not intended for production; however, it is interesting to know why the difference is present in only one sex. It can be assumed that this outcome was accidental because, in this study, the effect of rearing system on PS of hens on the BW of the offsprings was examined for the first time. However, the lack of comparative information and the heavily restricted knowledge on the effect of rearing parent flock on the weight of hatched chicks (Dixon et al., 2016) suggests the need to confirm this result in future studies.

In summary, the most important result of this study is that OA hens get fewer litter-laid eggs and a more favorable FCR. The lower number of litter-laid eggs facilitates collection, reduces dirt and shell damage. Lower FCR results in better economic performance of flocks. At the same time, it is important that all other reproduction results of OA flocks were not deteriorated compared with CA flocks. Therefore, there are no restrictions for hatching egg producers to keep PS flocks reared in the open aviary system. The current rapid tightening of the regulations on the housing conditions for commercial laying hens makes it possible to expect that regulations will also be introduced for PS flocks in the near future. The best alternative to caged rearing will then be the use of an aviary system. This may be limited by the higher labor input and consequently the higher cost of PS flocks rearing by opening individual sections of the aviary. This requires constant monitoring of the birds' behavior during the first weeks after release and teaching them how to return before the light is turned off evenly at all levels of the aviary. Therefore, a study is needed in the future which will analyse the results of the rearing period of PS flocks in the aviary and cage system.

CONCLUSION

Our results confirmed the hypothesis that releasing PS chickens to outside sections of the aviary from the seventh wk of rearing what enables them to use a larger area do not have a negative effect on future egg production, hatching results, and chick quality. The smaller number of litter-laid eggs in the PS OA flock, especially at the beginning of laying, indicates better adaptation to the new environment. At the same time, it can be expected that FCR and water intake per egg produced, per hatching egg, per hatched female chick, and lower number of litter-laid eggs can be improved. This study constitutes a practical basis for the producers of PS of laying hens, who consider installation of aviary systems to enhance their welfare during rearing period.

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DISCLOSURES

The authors declare no conflicts of interest.

SUPPLEMENTARY DATA

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