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Comparison of egg production, quality and composition in three production systems for laying hens

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ABSTRACT

The increasing public concern for animal welfare has pushed the poultry sector to progressively replace conventional battery cages (CC) for laying hens with alternative systems such as enriched cages (EC) and aviaries (AV). The aim of this study was to compare laying performance, egg location, and egg quality associated with these three housing types. The experiment was conducted in twelve pilot-scale chambers fitted out with one of the three treatments. Each chamber housed 30 Lohmann LSL-Lite laying hens from 23 to 32 weeks of age. The available area was 492, 780, and 1120 cm^2/hen for CC, EC, and AV, respectively. The EC and AV chambers were equipped with nest boxes, perches, and a pecking/scratching area (PSA). In the AV chambers, hens had free access to a space arranged in three levels with a wood shaving litter on the ground level as a PSA. Hen-day production was recorded and egg quality assessment included egg cleanliness, weight and proportion of each component (albumen, yolk, and shell) but also pH, Haugh unit, and meat spots for albumen; color intensity and blood spots for yolk; thickness and resistance for shell. The laying rate and egg weight were similar for CC and EC (around 96.5% and 59.5 g; $P > 0.05$). For AV, these parameters were significantly lower (77.2% and 58.6 g; $P < 0.001$) but the differences compared to the cage systems progressively reduced across time. Nearby 70% of the eggs were laid in the nests with EC while almost all of the eggs were laid on the litter at ground level with AV. The rate of clean eggs was around 77% for both cage systems compared to 14% for AV. Most of egg quality traits were identical for the three systems ($P > 0.05$) but there was a lower yolk proportion for eggs laid in AV (25.2% versus 25.7% for cages systems; $P < 0.001$) and higher shell resistance for eggs laid in CC (40.7 N versus 39.3 N for alternative systems; $P < 0.001$). Lower laying performance observed with AV could be explained by higher animal activity and competition for facilities, but these factors were not measured in this study. The reduction of the difference in egg productivity over time compared to cage systems suggest the need for a period of training/adaptation for pullets/hens kept in such an environment. An enriched cage system seems a balanced solution that combines both laying productivity and improved animal welfare. Further research should be performed to improve acceptance and appropriate use of resources by birds in an aviary system.

1. Introduction

In the European Union, conventional battery cages (CC) for laying hens have been banned since 2012 and replaced by alternative housing systems including enriched cages (EC) and non-cages systems such as aviaries (AV), deep litter, and free-range systems (Tauson, 2005). From January 2015, in Québec, Canada, conventional cages are no longer accepted for new poultry producers (Fédération des Producteurs d'Oeufs du Québec, 2015). These regulations answered public concern about animal welfare. Indeed, conventional cages provide no or few opportunities for behaviors like nesting, perching, foraging, and wing flapping while alternative systems provide more available space and specific resources such as nest boxes, perches, pecking and scratching areas (Appleby and Hughes, 1995; Elson and Croxall, 2006). Previous experiments have demonstrated the high motivation of the hen to use these resources (Olsson and Keeling, 2000; Colson et al., 2007). Apart from the effect on animal welfare, the impact of these modifications on egg production and quality is unclear. While most studies have reported similar laying performance and egg quality for enriched cages compared with conventional cages (Elson and Croxall, 2006;

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Shimmura et al., 2007; Tactacan et al., 2009; Stojcic et al., 2012; Karcher et al., 2015), some research has shown a higher proportion of dirty or cracked eggs in enriched cages (Wall et al., 2002; Tactacan et al., 2009; Englmaierova et al., 2014). For aviaries and litter systems, the literature reports negative impacts on production traits including laying percentage, feed efficiency, mortality, and egg quality (weight, composition, strength, cleanliness, microbial contamination, and conservations), with deleterious consequences on profitability (Elson and Croxall, 2006; Englmaierova et al., 2014; Jones et al., 2015; Karcher et al., 2015; Matthews and Sumner, 2015). This partly results from the hens inappropriate use of the system resources leading to a large proportion of eggs laid outside the nest and/or presence of droppings on solid part of the cage (nest, litter or scratching area). Consequently, housing systems were modified to address these issues including refining resource placement and trialing different litter materials and floor types (Guinebretière et al., 2012; Stampfli et al., 2013; Tuytens et al., 2013; Hunniford and Widowski, 2017). Numerous other parameters like genetic line, birds' age, group size, nutrition factors, and climate conditions inside the buildings (light, temperature, ventilation, air quality) also have an impact on performance (Nimmermark et al., 2009; Guinebretière et al., 2012; Tuytens et al., 2013; Bovera et al., 2014; de Oliveira et al., 2014; Meng et al., 2015).

While conditions for laying hens are currently adapted in different part of the world to meet the societal demand for better animal welfare, some uncertainty and discrepancy remain about the influence of the housing systems on performance. Therefore, the aim of this study is to compare egg production, quality, and composition between three production systems; conventional cages (CC), enriched cages (EC), and aviary system (AV) under the Quebecer context.

2. Materials and methods

The study was conducted in the experimental farm of the IRDA located at Deschambault, Quebec, Canada. The ethical committee of the institution approved the use and treatment of animals in this study (project n° 14-AV-261).

2.1. Experimental rooms and housing conditions

The experimental rooms consisted of twelve independent and insulated chambers (1.2 m wide × 2.4 m long × 2.4 m high), arranged side by side in the same building and randomly fitted out with one of the three treatments (4 replicates per treatment). Thirty hens were allotted to each chamber. The incoming air was common for all the chambers and was pre-conditioned to maintain an optimal temperature of 23 °C throughout the experimental period. Each chamber was equipped with a variable speed exhaust fan. The lighting system provided an intensity of 5 to 10 lx at hens' level. The photoperiod was 16L:8D per day.

The conventional cage system (CC, Fig. 1) consisted of multi-deck battery cages (Farmer Automatic, Laer, Germany) with 48.55 cm wide, 50.79 cm deep, and 49.70 cm high, placed 2 × 2 on three decks for a total of six cages. Each cage housed five hens (493 cm^2 per bird). The floor was made of metallic mesh. A linear feeder was placed at the front of each cage (9.7 cm per hen) and two nipple drinkers were available per cage. The enriched cages (EC, Fig. 2) and aviary (AV, Fig. 3) systems were arranged in accordance with the European Directive 1999/74/CE. The EC chambers contained three decks of cages with 10 hens per cage. The cages were 130 cm wide, 60 cm deep, and 45 cm high. Two nests (30 cm x 30 cm) delimited by plastic curtains and lined by plastic mesh were available. A pecking and scratching area (PSA) was located above the nests with 20 cm high free space up to the cage top. Two perches of 75 cm were also installed in the cages (15 cm per hen). The total available area was 780 cm^2 per hen in each cage (excluding PSA). The linear front feeder provided 13 cm of access per hen. Three nipple drinkers were available per cage. In the AV chambers, the hens had free

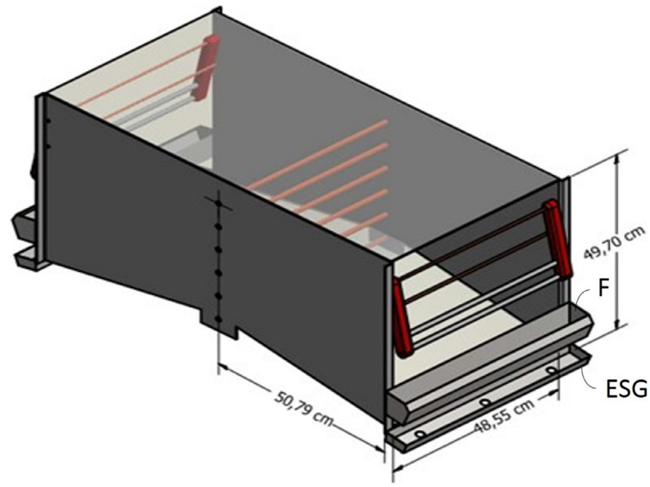

Fig. 1. Schematic view and dimensions of the conventional cage system (ESG: Egg-saver gutter; F: feeder).

access to a 3 dimensions-space of 120 cm wide, 145 deep, and 180 cm high, and arranged in three levels (Fig. 3). The available area was 1120 cm^2 per bird. The first level was covered with 10 cm of wood shavings. Levels 2 and 3 were similar, made with metallic mesh, and fitted out with two perches and three nest boxes (30 cm x 30 cm) delimited by plastic curtains and lined with plastic mesh. Inclined ramps (not illustrated) and two extra perches allowed birds to easily move from one level to the other. The total length of perch was 15 cm per hen. Three nipple drinkers and a linear feeder were installed at each level of the aviary with a total length of 10 cm per hen. In the three systems (CC, EC, and levels 2 and 3 of AV), an egg saver gutter was positioned underneath the feed trough.

2.2. Animals and feed

Lohmann LSL-Lite laying hens (n = 360) were used in this study. Birds had been beak-trimmed at one-day-old. The vaccination schedule included protection against Marek's disease, laryngotracheitis, Newcastle-bronchitis disease (B1 Type, LaSota Strain, Mass and Conn Types), infectious bursal disease, and avian encephalomyelitis virus. The birds were provided by the FPOCQ (Fédération des Producteurs d'oeufs de Consommation du Québec) and reared using a conventional battery cage system for pullets. The hens arrived in the experimental installation at the age of 22 weeks. This can be considered quite late compared to the age of transfer under commercial conditions (around 18 weeks of age) but is explained by logistical constraints linked to the experimental conditions. Before entering in the chambers, hens were individually weighted, identified by numbered wing bands, and randomly allotted to one of the three treatments. After a period of acclimation of one week, the experimental procedure begun and lasted for 70 days (from the age of 23 to 32 weeks).

The hens were fed a commercial corn-based diet (Table 1; La Coop Fédérée, Joliette, QC, Canada). The feeder was filled twice a day before it was emptied. The access to feed and water was *ad libitum* and the amounts consumed were quantified daily by chamber taking into account the weight of supplies and refusals. At the end of the experiment, the hen's body weight was measured individually.

2.3. Egg quality

Eggs were manually collected twice a day in the morning and in the afternoon, counted, and weighed by chamber. Egg cleanliness (clean or dirty) and laying location (nest, PSA/litter or other) were determined three time a week (Tuesday, Wednesday, and Friday) by the same operator throughout the experimental period. Eggs were considered as

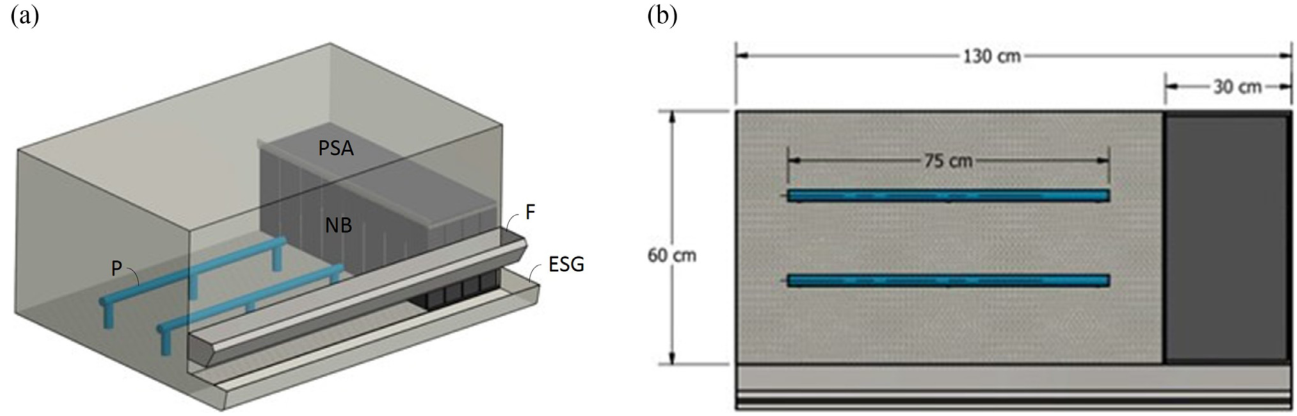

Fig. 2. Schematic view (a) and dimensions (b) of the enriched cage system (ESG: Egg-saver gutter; F: feeder; NB: nest box; P: Perch; PSA: Pecking and scratching area).

dirty if dirt was observed on more than 5% of the shell area. Every three weeks (23th, 26th, 29th, and 32th weeks of age), a sample of twenty eggs was randomly selected in each chamber to determine egg composition (10 eggs per chamber) and evaluate internal and external quality (10 eggs per chamber), representing 40 eggs per treatment for each type of analysis.

Egg quality was measured in accordance with the protocol described by Moula et al. (2013). Briefly, egg length and width were measured using digital calipers (Mastercraft, Johannesburg, South Africa; resolution 0.01 mm). Egg shape index was then deduced, as the ratio between length and width. Total egg weight was determined with an electronic balance (Metler Toledo Inc., Columbus, OH; resolution 0.01 g). The eggshell resistance was measured with a ZwickiLine testing machine Z0.5 (Zwick GmbH & Co, Ulm, Germany). Eggs were placed horizontally between two steel plates compressing them at a speed of 10 mm/min. Fmax was the force at which egg breakage occurred. After breaking, the eggs were inspected to determine the proportion of eggs with blood and meat spots. Haugh units were determined with a tripod micrometer (Haugh, 1937). Albumen was carefully separated from yolk and albumen pH was measured. The intensity of egg yolk color was measured using the DCM yolk color fan. The yolk was then rapidly weighed (Metler Toledo Inc., Columbus, OH, resolution 0.1 mg). Eggshells were dried in an oven at 90 °C for one day, eggshell weight was determined (Metler Toledo Inc., Columbus, OH, resolution 0.1 mg). Egg

Table 1
Composition of the diet.

Ingredients (%)	
Corn	55.30
Soybean seed, extruded	10.00
Calcium oxide	9.71
Soybean meal	9.63
DGS[a]	7.50
Meat and bone meal	5.00
Gluten feed	1.49
Minerals-Vitamins complex	0.57
Dicalcium phosphate	0.38
Natrium chloride	0.22
Animal or vegetal fat	0.20
Chemical composition (%)	
Dry matter	88.80
Crude protein	17.08
Starch	36.70
Sugars	2.57
Crude fat	5.09
Crude fibre	2.92
Crude ash	14.58
Calcium	4.30
Metabolizable energy (kJ kg^{-1})	**11.52**

[a] Distillers grains with solubles.

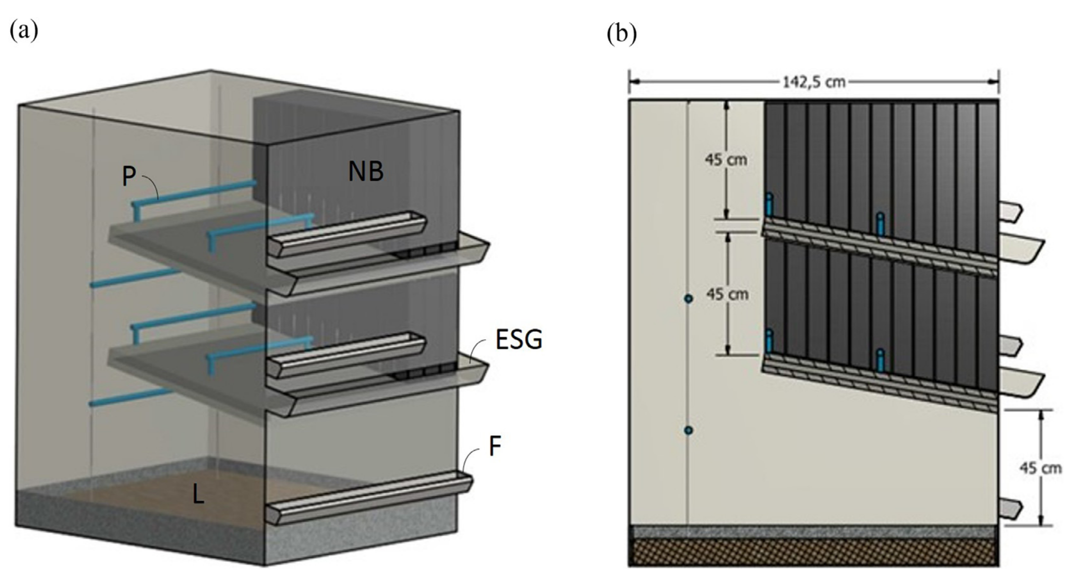

Fig. 3. Schematic view (a) and dimensions (b) of the aviary system (ESG: Egg-saver gutter; F: feeder; L: Litter; NB: nest box; P: Perch; PSA: Pecking and scratching area).

shell thickness was measured at three different random points around the equatorial shell zone using an electronic micrometer (Accusize Co. Ltd, Richmond Hill, ON, Canada, resolution 0.01 mm). Finally, albumen weight was deducted by subtraction.

Chemical composition was measured for the aggregated ten eggs selected by chamber but separately for internal (yolk and albumen) and external content (eggshell). The dry matter (oven drying at 105 °C) and nitrogen content (kjeldahl method) were determined. Mineral composition using the EPA-3050 method (US Environmental Protection Agency, 1996) included analyses for Ca, P, K, and Mg content.

2.4. Statistical analysis

The initial body weights and the weight gains were tested using a generalized linear model for the analysis of the variance with two factors: the housing system (2 dl) and the chamber nested within housing system (9 df; proc GLM, SAS 9.3, SAS Institute Inc., Cary, NC).

Feed intake, egg quality, and egg composition data were tested using a mixed model including housing system (2 df), week of measurements (9 and 3 df, respectively, for laying performance, laying location, and dietary consumption on one hand; and egg quality and composition on the other hand), and the interaction between the housing system and the week of measurement (18 and 6 df respectively) as fixed effects, and the chamber as a random effect, with 10 and 4 successive measurements per chamber respectively (proc MIXED, SAS 9.3, SAS Institute Inc., Cary, NC). Correlation between successive measurements was modeled using a type1-autoregressive structure. For blood and meat spots, the statistical analyses were performed on arcsine square root transformed data according to Snedecor and Cochran (1989), but back-transformed values are presented. In this way, residuals were normally distributed with a null expectation for all the parameters (proc UNIVARIATE, SAS 9.3, SAS Institute Inc., Cary, NC).

3. Results

3.1. Growth, consumption and laying performance

Table 2 presents the data related to hen's weight, feed consumption, and laying performance. The evolution of laying performance and egg weight throughout the experimental period is presented on Figs. 4 and 5, respectively.

While the initial body weight was equivalent for the three treatments (around 1.5 kg; $P > 0.05$), the growth rates associated with EC and AV were significantly lower compared to CC ($P < 0.001$). In parallel, feed intakes tended to be lower for AV compared to CC with an intermediate value for EC ($P = 0.07$).

Laying rate was identical in CC and EC (around 96.5%; $P > 0.05$)

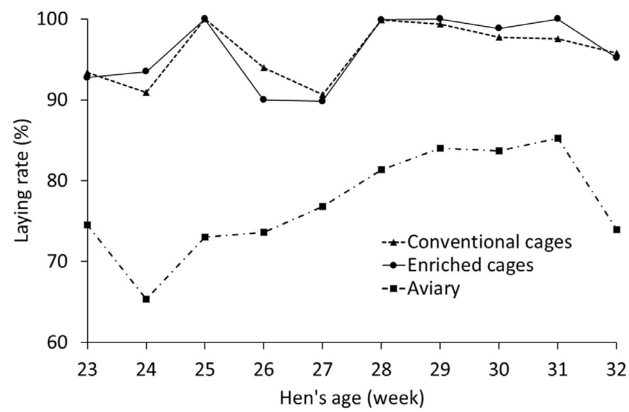

Fig. 4. Evolution of the laying rate of hens kept under three different housing systems.

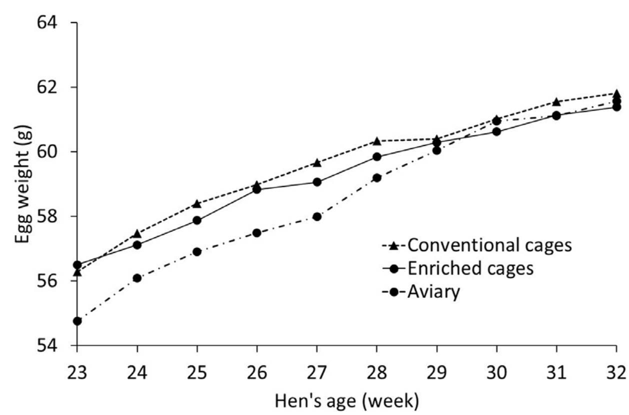

Fig. 5. â€“ Evolution of the egg weight for hens kept under three different housing systems Apologies for the inconvenience.

but was significantly reduced in AV at 77.2% ($P < 0.001$). Similarly, the egg weight presented no statistical difference between CC and EC (around 59.5 g), but was lower in AV at 58.6 g. As a consequence of these figures, feed conversion was also worse with the AV system, expressed per dozen eggs as well as per kg eggs (Table 2).

The laying rate was significantly influenced by the week of measurement. In CC and EC, it fluctuated between 90% and 100% from a week to another. In AV, it increased steadily between week 24 and week 31 of age, from 65% to 85% respectively. In the three systems, the egg weight increased regularly across time. In CC and EC, it raised from 56.4 g in week 23 to 61.6 g in week 32, with no statistical difference

Table 2
Growth, consumption and laying performance of laying hens kept in three different housing systems (least square means).

	Housing systems			SEM	Level of significance		
	CC	EC	AV		H	W	H x W
Initial weight (kg)	1.516	1.524	1.519	0.010	0.8638	–	–
Weight gain (kg)	175.3^{a}	78.7^{b}	64.6^{b}	7.2	<0.001	–	–
Laying rate (%)	96.3^{a}	96.6^{a}	77.2^{b}	0.01	<0.001	<0.001	0.6849
Egg weight (g)	59.6^{a}	59.3^{a}	58.6^{b}	0.2	0.0100	<0.001	<0.001
Feed intake (g day^{-1})	123.4^{a}	119.9^{ab}	117.8a^{b}	1.7	0.0741	<0.001	0.4338
Feed conversion							
(kg feed dz^{-1} eggs)	1.61^{a}	1.60^{a}	2.12^{b}	0.07	<0.001	<0.001	0.0018
(kg feed kg^{-1} eggs)	2.26^{a}	2.24^{a}	3.03^{b}	0.10	<0.001	<0.001	0.0057
Water intake							
(mL day^{-1})	188.9	177.8	189.7	4.4	0.1073	<0.001	<0.001
(L kg^{-1} feed)	1.65^{a}	1.65^{a}	1.79^{b}	0.05	0.0695	<0.001	<0.001

CC: conventional cages; EC : enriched cages; AV : aviary; SEM : standard error of the means; H : housing type; W: week.
[a,b,c]Values with different superscripts across a row differ statistically ($P < 0.05$).

Table 3
Laying location and proportion of clean eggs for laying hens kept in three different housing systems (least square means).

	Housing systems			SEM	Level of significance		
	CC	EC	AV		H	W	H x W
Laying location (%)							
Nest	–	68.5^a	3.7^b	2.3	< 0.001	0.3780	0.1575
Scratching area/ Litter	–	9.9^a	95.7^b	2.0	< 0.001	0.0059	< 0.001
Other	–	21.7^a	0.6^b	3.2	< 0.001	0.3602	0.0160
Egg cleanliness (%)							
Nest	–	83.7	89.5	2.2	0.0715	< 0.001	< 0.001
Scratching area/ Litter	–	59.2^a	8.2^b	4.3	< 0.001	< 0.001	< 0.001
Other	–	68.2	63.5	11.5	0.4819	< 0.001	0.3156
Overall	77.7^a	76.7^a	13.9^b	2.0	< 0.001	< 0.001	< 0.001

CC: conventional cages; EC : enriched cages; AV : aviary; SEM : standard error of the means; H : housing type; W: week.
[a, b]Values with different superscripts across a row differ statistically ($P < 0.05$).

between the two systems. The trend was similar for eggs from AV, but the weight was significantly lower compared to CC and EC until week 28 ($P < 0.05$), thereafter no difference was observed between all the systems.

The laying location differed significantly between the two alternative systems (Table 3), with nearby 70% of the eggs laid in the nests with EC while almost all of the eggs were laid on the litter at ground level with AV. Taken into account the low cleanliness level of eggs laid on the litter area, this resulted in a low overall proportion of clean eggs in AV (13.9%) compared to the cage systems (around 77%). The eggs cleanliness remained low over the time in AV and roughly fluctuated between 0% and 40%. In the two cages systems, the cleanliness regularly improved over time from 60% to nearly 100%.

3.2. Egg quality

The quality of eggs laid by hens in the three housing systems is presented in Tables 4 to 7 for external quality, albumen, yolk, and eggshell characteristics, respectively. Table 8 shows the mineral composition of eggshells and inside content (yolk and albumen together).

The egg weights were similar in CC and EC for the four selected weeks of measurement ($P < 0.05$). The eggs from AV were always lighter but the difference was only significant at the beginning of the experiment ($P < 0.05$). The egg weights steadily increased over time in the three treatments, with a gain of 5.4, 5.2, and 7.8 g for CC, EC, and AV respectively, from the age of 23 to 32 weeks. The same findings were observed for the eggs length and width in relation with the effect of the housing system and the time. The eggs shape value was the lowest in EC ($P < 0.05$), and the evolution of the egg shape over time did not show a specific trend.

The overall weight of albumen was not significantly influenced by the housing systems with an average value of 37.5 g ($P > 0.05$). While albumen weight increased steadily with the age of bird, albumen proportion declined concurrently for the three treatments ($P < 0.001$). Overall, albumen proportion was higher for AV, with 64.5% compared to 63.9 for both CC and EC ($P < 0.05$). Albumen pH was the lowest in CC compared to the two other treatments ($P < 0.05$); it was influenced by the week of measurement and achieved the highest value at the end of the experiment in the three systems. Haugh units, as freshness indicator, did not differ between the treatments ($P > 0.05$) but fluctuated significantly with the course of time ($P < 0.001$) with an initial increase from week 23 to week 26 followed by a regular decrease until week 32 of age. The proportion of eggs with meat spots detected on the albumen was similar over time for the three housing systems, involving about 1% of eggs ($P > 0.05$).

Table 4
External egg characteristics as affected by the housing systems and the age of the hens (least square means).

	Housing systems			SEM	Level of significance		
	CC	EC	AV		H	W	H x W
Weight (g)							
Week 23	56.0^{Aa}	55.6^{Aa}	53.5^{Ba}	0.5	0.0397	< 0.0001	0.2157
Week 26	58.1^b	57.2^b	56.9^b	0.5			
Week 29	60.4^c	59.9^c	59.6^c	0.5			
Week 32	61.4^c	61.8^d	61.3^d	0.5			
Overall	59.0^A	58.6^{AB}	57.8^B	0.3			
Length (mm)							
Week 23	55.7^{Aa}	55.6^{Aa}	54.6^{Ba}	0.3	0.0112	< 0.0001	0.2864
Week 26	56.2^a	56.4^b	55.9^b	0.3			
Week 29	57.4^b	57.3^c	57.0^c	0.3			
Week 32	57.8^b	58.4^d	57.8^d	0.3			
Overall	56.8^A	56.9^A	56.3^B	0.2			
Width (mm)							
Week 23	42.2^{Aa}	42.2^{Aa}	41.7^{Ba}	0.2	0.0490	< 0.0001	0.1316
Week 26	42.9^{Ab}	42.4^{Ba}	42.4^{Bb}	0.2			
Week 29	43.2^{bc}	43.1^b	43.0^c	0.2			
Week 32	43.4^c	43.3^b	43.4^d	0.2			
Overall	42.9^A	42.7^{AB}	42.6^B	0.1			
Shape index							
Week 23	75.8^{ab}	75.8^a	76.3^a	0.3	0.0223	< 0.0001	0.3404
Week 26	76.5^{Ab}	75.2^{Ba}	76.0^{ABa}	0.3			
Week 29	75.3^a	75.3^a	75.4^{ab}	0.3			
Week 32	75.1^a	74.2^b	75.1^b	0.3			
Overall	75.7^A	75.1^B	75.7^A	0.2			

CC: conventional cages; EC : enriched cages; AV : aviary; SEM : standard error of the means; H : housing type; W: week.
[A,B,C:] Values with different superscripts across a row differ statistically ($P < 0.05$).
[a,b,c,d]: Values with different superscripts across a column differ statistically ($P < 0.05$).

Yolk characteristics of eggs laid in AV differed significantly from those laid in CC and EC, with a reduced weight (expressed in g or in percentage) and increased color intensity ($P < 0.05$). Across all the housing treatments, yolk weight and proportion increased with the hen's age, while color intensity was not significantly impacted over time ($P > 0.05$). Globally, the rate of blood spots was not affected by the treatment or the week of measurement ($P > 0.05$).

On average, the eggshell weight was the highest in CC, the lowest in AV and intermediate in EC. Eggshell proportion and thickness were statistically similar for the three treatments representing around 10.4% of the total egg weight, and measuring 380 µm of thickness ($P > 0.05$). The eggshell strength was higher in CC compared to EC and AV ($P < 0.05$). Increasing hen's age was associated with increased weight but decreased proportion and strength of the shell ($P < 0.05$), while the effect of time on thickness was less pronounced ($P > 0.05$).

The housing conditions had no significant impact on the calcium and phosphorus contents of the egg shells (around 340–345 g Ca kg^{-1} and 925 g P kg^{-1}, $P > 0.05$). Eggs from AV showed higher DM and Mg contents but lower K and Mg contents in their shells ($P < 0.05$). The inside content of the eggs (yolk and albumen together) showed similar mineral composition for potassium, magnesium, nitrogen, and sodium. Eggs from CC had significantly more calcium ($P < 0.05$) while eggs from AV had significantly less DM and phosphorus, compared to the other housing systems ($P < 0.05$).

4. Discussion

This study aimed to compare laying traits for hens kept in CC, EC, or AV. The laying rate and egg weight were significantly reduced for AV compared to CC and EC. Nearby 70% of the eggs were laid in the nests with EC while almost all of the eggs were laid on the litter at ground level with AV. The rate of clean eggs was reduced with AV. Most of egg

Table 5
Albumen characteristics as affected by the housing systems and the age of the hens (least square means).

	Housing systems			SEM	Level of significance		
	CC	EC	AV		H	W	H x W
Albumen weight (g)							
Week 23	36.9^{Aa}	36.5^{Aa}	35.2^{Ba}	0.5	0.6097	< 0.0001	0.1798
Week 26	37.3^{ab}	36.9^{ab}	36.8^{b}	0.5			
Week 29	38.0^{ab}	37.9^{bc}	38.3^{c}	0.5			
Week 32	38.5^{b}	38.5^{c}	38.9^{c}	0.5			
Overall	37.7	37.5	37.3	0.3			
Albumen (%)							
Week 23	65.9^{a}	65.6^{a}	65.8^{a}	0.3	0.0317	< 0.0001	0.4171
Week 26	64.2^{b}	64.5^{b}	64.6^{b}	0.3			
Week 29	63.0^{Ac}	63.3^{ABc}	64.1^{Bbc}	0.3			
Week 32	62.5^{ABc}	62.4^{Ad}	63.3^{Bc}	0.3			
Overall	63.9^{A}	63.9^{A}	64.5^{B}	0.1			
Albumen pH							
Week 23	8.61^{Aa}	8.75^{Ba}	8.77^{Ba}	0.04	0.0032	< 0.0001	0.0133
Week 26	8.54^{Aa}	8.60^{Ab}	8.74^{Ba}	0.04			
Week 29	8.60^{Aa}	8.73^{Ba}	8.61^{Ab}	0.04			
Week 32	8.81^{b}	8.81^{a}	8.80^{a}	0.04			
Overall	8.64^{A}	8.72^{B}	8.73^{B}	0.02			
Haugh units							
Week 23	90.0^{Aab}	87.5^{Ba}	88.3^{ABa}	0.6	0.5018	0.0001	0.1717
Week 26	90.9^{a}	90.6^{b}	89.9^{b}	0.6			
Week 29	90.1^{ab}	89.5^{bc}	89.8^{b}	0.6			
Week 32	88.6^{b}	88.5^{ac}	89.5^{ab}	0.6			
Overall	89.0	89.9	89.4	0.3			
Meat spots (%)							
Week 23	0.65^{ab}	2.44	4.67	0.65	0.9534	0.2737	0.5249
Week 26	0.00^{a}	0.00	0.65	0.65			
Week 29	0.65^{ab}	2.44	0.65	0.65			
Week 32	5.54^{b}	0.59	0.59	0.65			
Overall	0.99	0.95	1.29	0.16			

CC: conventional cages; EC : enriched cages; AV : aviary; SEM : standard error of the means; H : housing type; W: week.
A, B, C: Values with different superscripts across a row differ statistically ($P < 0.05$).
a,b, c, d: Values with different superscripts across a column differ statistically ($P < 0.05$).

Table 6
Yolk characteristics as affected by the housing systems and the age of the hens (least square means).

	Housing systems			SEM	Level of significance		
	CC	EC	AV		H	W	H x W
Yolk weight (g)							
Week 23	13.1^{ABa}	13.2^{Aa}	12.7^{Ba}	0.2	< 0.0001	< 0.0001	0.2380
Week 26	14.7^{Ab}	14.4^{ABb}	14.1^{Bb}	0.2			
Week 29	15.9^{Ac}	15.8^{Ac}	15.2^{Bc}	0.2			
Week 32	16.7^{ABd}	17.1^{Ad}	16.2^{Bd}	0.2			
Overall	15.1^{A}	15.1^{A}	14.6^{B}	0.1			
Yolk (%)							
Week 23	23.5^{a}	23.8^{a}	23.8^{a}	0.2	0.0140	< 0.0001	0.0955
Week 26	25.4^{b}	25.1^{b}	24.9^{b}	0.2			
Week 29	26.4^{Ac}	26.4^{Ac}	25.5^{Bb}	0.3			
Week 32	27.1^{ABc}	27.7^{Ad}	26.5^{Bc}	0.3			
Overall	25.6^{A}	25.7^{A}	25.2^{B}	0.1			
Yolk color intensity							
Week 23	6.82^{A}	6.93^{Aa}	7.16^{B}	0.07	< 0.0001	0.1353	0.6515
Week 26	6.86^{AB}	6.68^{Ab}	6.98^{B}	0.07			
Week 29	6.80^{A}	6.80^{Aab}	7.02^{B}	0.07			
Week 32	6.88^{AB}	6.80^{Aab}	7.08^{B}	0.07			
Overall	6.84^{A}	6.80^{A}	7.06^{B}	0.04			
Blood spots (%)							
Week 23	3.59^{AB}	14.37^{Aa}	0.65^{B}	1.06	0.5874	0.7460	0.2478
Week 26	0.59	5.28^{ab}	3.27	1.06			
Week 29	3.81	3.59^{ab}	0.59	1.06			
Week 32	5.54	0.00^{b}	2.44	1.06			
Overall	3.04	4.06	1.53	0.29			

CC: conventional cages; EC : enriched cages; AV : aviary; SEM : standard error of the means; H : housing type; W: week.
$^{A,\ B,\ C}$: Values with different superscripts across a row differ statistically ($P < 0.05$).
$^{a,\ b,\ c,\ d}$: Values with different superscripts across a column differ statistically ($P < 0.05$).

quality traits were identical for the three systems at the exception of yolk proportion (lower with AV) and shell resistance (higher with CC).

Similar productivity for conventional and enriched cage systems as reported here is in accordance with most previous experiments (Elson and Croxall, 2006; Shimmura et al., 2007; Tactacan et al., 2009; Englmaierova et al., 2014; Yilmaz-Dikmen et al., 2017). However, impairment of some performance factors in enriched cages compared with conventional cages was also observed in the literature, such as in increased feed conversion ratio reported by Englmaierova et al. (2014) or reduced laying rate by Stojcic et al. (2012). Performance observed in the AV in the current study was reduced compared to the two cage systems, with lower laying rate, lower egg weight and higher feed conversion ratio. In addition, feed intake and weight gain were also lower with this alternative system. These findings confirm the results obtained by several authors (Elson and Croxall, 2006; Englmaierova et al., 2014; Karcher et al., 2015; Samiullah et al., 2017). In the experiment of Englmaierova et al. (2014), the laying rate were about 80% with aviaries and litter systems compared to about 92% with both conventional and enriched cages systems. Samiullah et al. (2017) reported egg weight was reduced by 2 g with aviaries compared to conventional cage systems (58.6 versus 60.7 g, respectively). A higher feed conversion ratio and lower body weight were also observed by Elson and Croxall (2006) when comparing non-cage with cage systems. In contrast, Taylor and Hurnic (1996) and Shimmura et al. (2010) observed similar laying performance for aviaries, conventional cages, or enriched cages but higher feed intake with the aviaries.

In alternative systems, extra space area and resources such as nest boxes, perches, and scratching areas as provided to the hens to meet their behavioural needs. This leads to higher bird activity and potential competition between hens for facilities resulting in greater energy loss and poorer productivity (Michel and Huonnic, 2003; Shimmura et al., 2007b). The lower feed intake and feed efficiency observed for hens kept in AV also contributed to their poorer performance. The consumption of litter could partly counterbalance this effect, but the nutritional and energetic values of the substrate are rather low. In addition, direct observations have shown the higher attractiveness of the litter for the hens that preferentially occupy this area with high animal density as a result. This crowding could lead to a higher proportion of cracked/broken eggs that can be eaten by the birds and thus uncounted.

This high use of the litter area was confirmed by the records of laying location showing that in AV most of the eggs were laid at ground level in the litter (95.7%) while only 3.6% of the eggs were laid in the nest. This rate of misplaced eggs is much higher than those found in the literature for aviaries. Abrahamsson et al. (1998) reported the percentage of misplaced eggs varying from 1% to 18% depending of the batch. Nest use around 90–95% was measured by Colson et al. (2008) and Villanueva et al. (2017). For hens kept in EC, most of the eggs were laid in the nest (nearby 70%) while the laying rates for the PSA and elsewhere in the cage were around 20% and 10%, respectively. These results are in accordance with Tuytens et al. (2013), reporting a nest laying rate of 70.8% for enriched cages. Higher rates of nest eggs, exceeding 95%, were reported by numerous other authors (Appleby et al., 2002; Huneau-Salaün et al., 2011; Bovera et al., 2014). Guesdon and Faure (2004) reported a lower proportion of eggs laid in the nest, ranging between 43% and 68% dependent on different animal densities.

Misplaced eggs is an important factor that impairs sector profitability because it is associated with higher dirtiness, bacterial contamination, higher rate of broken eggs, and work overload due to

Table 7
Eggshell characteristics as affected by the housing systems and the age of the hens (least square means).

	Housing systems			SEM	Level of significance		
	CC	EC	AV		H	W	H x W
Eggshell weight (g)							
Week 23	5.95[Aa]	5.87[Aa]	5.54[Ba]	0.11	0.0524	< 0.0001	0.5121
Week 26	6.04[ab]	5.95[a]	5.97[b]	0.11			
Week 29	6.35[b]	6.18[a]	6.22[b]	0.11			
Week 32	6.34[b]	6.13[a]	6.21[b]	0.11			
Overall	6.17[A]	6.03[AB]	6.00[B]	0.05			
Eggshell (%)							
Week 23	10.7	10.6[a]	10.4	0.2	0.3844	0.0489	0.8567
Week 26	10.4	10.4[ab]	10.6	0.2			
Week 29	10.6	10.3[ab]	10.5	0.2			
Week 32	10.4	10.0[b]	10.1	0.2			
Overall	10.5	10.3	10.4	0.1			
Shell thickness (μm)							
Week 23	398.1	396.6[a]	381.2	12.2	0.6903	0.0820	0.9674
Week 26	380.2	378.0[ab]	383.8	12.2			
Week 29	384.8	375.6[ab]	379.9	12.2			
Week 32	373.0	360.6[b]	365.0	12.2			
Overall	384.0	377.7	377.5	6.1			
F_{max} (N)							
Week 23	42.7[a]	42.9[a]	40.5	0.9	0.0295	< 0.0001	0.0825
Week 26	40.4[ab]	40.5[b]	40.0	0.9			
Week 29	40.6[ab]	38.4[b]	38.2	0.9			
Week 32	39.1[Ab]	35.5[Bc]	38.3[A]	0.9			
Overall	40.7[A]	39.3[B]	39.3[B]	0.4			

CC: conventional cages; EC : enriched cages; AV : aviary; SEM : standard error of the means; H : housing type; W: week.
[A, B]: Values with different superscripts across a row differ statistically ($P < 0.05$).
[a, b, c]: Values with different superscripts across a column differ statistically ($P < 0.05$).

manual egg collection (Tuytens et al., 2013; Bovera et al., 2014; Englemaierova et al., 2014). In the current study, 41% of eggs laid on PSA (EC) were soiled. This rate reached 92% for eggs laid on the litter (AV). Appropriate housing conditions and management to increase the attractiveness of the nest is thus needed to respect animal behavior and ensure productivity. For this, numerous managements, housing designs, and materials were previously tested to enhance nest laying.

Replacing wire mesh floor of the nest by artificial turf increases its attractiveness, and also maintains egg cleanliness due to manipulation of nesting materials by the birds that remove dirt (Wall and Tauson, 2002b; Guinebetière et al., 2012).

Tuytens (2013) highlighted the hen's preference for non-sloping floor in the nest arguing comfort reasons and inclination of the birds to prevent egg lost out of the nest. However, the slope of the commercial nests ought to be sufficient so that the eggs will roll away to the egg cradle for collection.

Since hens prefer dark and secluded areas for oviposition, nest boxes with low light intensity and closed by plastic curtains appears to be successful strategies to minimize mislaid eggs (Taylor and Hurnik, 1996). Works of Huber-Eicher (2004) showed higher attractiveness by hens for yellow nests rather than red, green, or blue ones. Additionally, it was noticed that allowing hens to differentiate individual nests by color permits them to establish nest preferences and contributes to reduce bird's competition and proportion of mislaid eggs (Huber-Eicher, 2004). In the current experiment, nests in EC and AV were characterized by lined plastic mesh on the floor with a 10%-slope and were delimited by black plastic curtains. This allowed a good occupation rate of the nest for laying in EC, but it failed for AV.

The group size also impacts nest competition and percentage of eggs laid outside the nest with a higher rate of mislaid eggs associated with smaller groups, as observed in enriched cages by Huneau-Salaün et al. (2011) with groups of 20 or 40 hens, or by Bovera et al. (2014) with groups of 25 or 40 hens. Whereas the nesting area per hen was the same, the overall area of the nest in the cage increased with the number of birds per cage. This resulted in less competition for the nest in larger groups suggesting that the ratio of nest space per bird needed to avoid crowding declines with group size. In the current experiment, the group size was higher in AV than in EC (30 vs 10 birds) but this failed to guarantee an elevate number of eggs laid in the nest.

The presence of a PSA in enriched cages is also proposed by Tuytens et al. (2013) to explain the high proportion of mislaid eggs as it attracts hens away from the nest and toward the PSA. Litter provision in the PSA could accentuate the phenomenon making the PSA even more attractive to the hens, as noticed by Guinebretière et al. (2012). Recently, Hunniford and Widowski (2017) observed that a simple wire partition added in the scratch area lead to more eggs laid outside the nest. The authors hypothesized that the partition would increase the perception of enclosure by hens, and provide an alternative attractive site to lay their eggs. In EC designed for this experiment, the PSA was located above the nest and could have brought a feeling of enclosure that may have contributed to its use as laying area.

In aviary systems, Stampfli et al. (2013) investigated the effect of a nest access platform to achieve good nest acceptance and prevent

Table 8
Mineral composition of eggs as affected by the housing systems (least square means).

	Housing systems			SEM	Level of significance		
	CC	EC	AV		H	W	H x W
Eggshell composition							
Dry matter (%)	72.5[a]	74.2[b]	77.5[c]	0.6	< 0.0001	0.0030	0.1745
Ca (g kg^{-1})	342.9	342.5	344.7	1.5	0.5633	< 0.0001	0.0166
K (mg kg^{-1})	1041.4[a]	1003.9[a]	868.4[b]	28.1	0.0004	0.0003	0.1148
Mg (mg kg^{-1})	2769[a]	2815[a]	2942[b]	34	0.0035	0.2825	0.1324
Na (mg kg^{-1})	1557[a]	1509[a]	1391[b]	28	0.0008	< 0.0001	0.0587
P (mg kg^{-1})	913.3	917.4	944.8	13	0.1971	0.0002	0.4427
Inside composition							
Dry matter (%)	23.7[a]	23.5[a]	23.0[b]	0.1	0.0001	< 0.0001	0.6016
Ca (mg kg^{-1})	615.4[a]	589.4[b]	582.8[b]	5.6	0.0008	< 0.0001	0.2524
K (mg kg^{-1})	1465	1455	1451	9	0.4986	< 0.0001	0.5629
Mg (mg kg^{-1})	117.0	116.2	117.9	1.0	0.4424	0.0006	0.0969
N (g kg^{-1})	19.4	19.0	19.1	0.3	0.4275	0.0044	0.6690
Na (mg kg^{-1})	1480	1490	1497	14	0.7000	< 0.0001	0.6709
P (mg kg^{-1})	1942[a]	1941[a]	1897[b]	14	0.0606	< 0.0001	0.4855

CC: conventional cages; EC : enriched cages; AV : aviary; SEM : standard error of the means; H : housing type; W: week.
[a, b, c]: Values with different superscripts across a row differ statistically ($P < 0.05$).

mislaid eggs. From their work, they recommended a continuous plastic grid rather than wooden perches that provided reduced space in front of the nest, restricting nest inspection with a higher number of eggs laid outside the nest as a consequence. The floor in front of the nest in AV was made of wire mesh, but unfortunately this did not ensure proper occupation rate.

The location of other equipment also influences the rate of mislaid eggs. Comparing different types of aviaries, Abrahamsson and Tauson (1998) observed more eggs laid on the litter when feed and water were provided on the floor rather than on raised platforms. In the current study, hens had access to feed and water at each level, including the littered floor. This may not encourage hens to move vertically and to find the nests. Given the great attractiveness of litter for hens (Campbell et al., 2016), and because the nesting pattern is highly conservative and difficult to reverse (Zupan et al., 2008), hens may have needed more and earlier experience with an aviary environment (Shinmura et al., 2006).

Indeed, it was previously found that the rearing environment of birds during the pre-laying period impacts the space use and the laying location. Colson et al. (2008) confirmed higher use of vertical levels and fewer floor eggs for pullets already reared in an aviary compared to cage systems. Otherwise, adjustment to the new environment after introduction to aviary could take up to 2 weeks for full use of the tiered wire floor (Tanaka and Hurnik, 1992; Shinmura et al., 2006). In enriched cages, Wall and Tauson (2002) also observed an increasing proportion of eggs laid in the nest with bird age, roughly from 80% to 95% between week 24 and week 79 of age. A common procedure to discourage oviposition in the litter is to keep the pullets enclosed in the laying system upon arrival until they begin to lay or reach peak lay (Tauson, 2005; Lay et al., 2011). In the current study, hens originated from battery cages before entering in experimental installation, and had access to the entire space of the systems. Throughout the experimental period (from week 23 to week 32 of age), laying location remained quite stable over the time with an average of 70% and 4% of eggs laid in the nests for EC and AV respectively. However, the difference of egg productivity between AV and cage systems did reduce over time. Additionally, no difference in egg weight were observed from week 29. This could reflect a normalization of performance between the different housing systems in the course of time, and confirm the need for an adaptive period for hens moved from cages to alternative housing systems (or the need to rear pullets in a system to match the layer system) (Janczak and Riber, 2015).

The shape index, defined as the ratio between egg width and length, was higher for eggs from CC and AV compared to EC. Similar shape index for conventional and enriched cages was reported by Yilmaz-Dikmen et al. (2017). Lewko et al. (2011) noticed more elongate eggs from cages than littered systems. This trait may seem irrelevant but can affect the proportion of cracked eggs since globular eggs (i.e. high shape index) were found more resistant to breakage (Altuntas and Sekeroglu, 2008) whereas elongation increases the speed of eggs rolling out of the nest. This could be especially relevant in large housing systems where eggs must travel a longer distance from the nest to the collection cradle.

Most of the albumen characteristics did not differ among the treatments, except for the albumen proportion that was higher for AV, and albumen pH that was lower for CC ($P < 0.05$). These results confirm previous studies that have reported similar albumen properties for both cages systems and aviaries (Shimmura et al., 2007 and 2010; Stojcis et al., 2012; Samiullah et al., 2017; Lordelo et al., 2016; Yilmaz-Dikmen et al., 2017). In contrast, Tumova et al. (2011) and Englmaierova et al. (2014) observed that conventional cages are associated with lower albumen percentage, but higher HU compared to enriched cages and aviaries. In the current experiment, higher albumen proportion for AV was linked to lower egg weight combined with similar albumen weight. Albumen pH and Haugh unit are reliable indicators of the freshness of the eggs which reflects a series of chemical changes. As the egg ages, albumen protein is degraded, and eggs loses water and carbon dioxide, which leads to a decrease of albumen height and an increase in albumen pH. Many factors affect albumen quality, like hens' strain and age, storage time and conditions, and feed composition (Lordelo et al., 2016). The time of oviposition and egg collection could also play a role as suggested by Bovera et al. (2014) who reported lower HU for eggs laid and collected in the morning compared to the afternoon. Singh et al. (2009) hypothesized that eggs from a litter system are more exposed to ammonia from litter, which would contribute to reduce the Haugh unit score. Nevertheless, even though HU is an important measure of egg quality, it may be difficult to assess HU by the housing system alone.

Parameters related to yolk quality were statistically identical for CC and EC ($P > 0.05$). Contrarily, yolks from AV had lower weight, lower contribution to total weight but higher color intensity compared to the two cage systems ($P < 0.05$). Yolk quality is significant for the egg processing industry, as yolk has a greater market value, and darker yolk color is highly desirable by consumers in many countries (Samiullah et al., 2017; Lordelo et al., 2016). Yolk color is strongly affected by the feed, mainly by addition of synthetic xanthophyll in the diet. Some authors have also reported darker yolk colors from hens kept in free-range systems because they have access to feedstuffs rich in carotenoid pigments such as grass and herbs (Lordelo et al., 2016). In the current study, the same feed was used for the three treatments but in the AV system, foraging and potential eating of litter substrate by hens could explain darker yolk color. As suggested by Singh et al. (2009), yolk color intensity could also be impacted by the egg production level, with paler yolk related to higher productivity. This dilution effect is confirmed in the current experiment since the cage systems were associated with both a higher laying rate but lighter yolk color.

Eggshell quality is a trait of major economic importance related to the incidence of cracked eggs that could spoil commercial gains. Indeed, a desirable shell should be thick enough to resist transportation and handling shock. In the literature, many authors did not detect significant differences in most shell characteristics regarding housing conditions (Shimmura et al., 2007 and 2010; Stojcic et al., 2012; Samiullah et al., 2017; Lordelo et al., 2016; Yilmaz-Dikmen et al., 2017). Additionally, some reported diverse findings with better breaking strength for either conventional (Valkonen et al., 2008; Tumova et al., 2011; Englmaierova et al., 2014), or alternative systems (Pavlovski et al., 2001; Ahammed et al., 2014). In the current study, Fmax was higher for CC compared to EC and AV whereas other shell traits (thickness, weight, percentage) were quite similar between treatments. Karcher et al. (2015) demonstrated that a decrease of nutrient intakes, especially energy and protein, was associated with a decrease in shell strength force. Lichovnikova and Zeman (2008) showed that calcium intake and calcium content in the shells were higher in cages than litter systems. In the current study, feed intake was lower for hens kept in AV, but calcium content of the shell was identical for the three housing systems. For hens kept in aviaries, Scholz et al. (2008) observed lower eggshell breaking strength but higher bone strength compared to cage systems. They postulated that systems that provided more space area and resources to promote animal activity and so calcium might be preferentially used for bone remodeling and conservation rather than for egg shell composition. The eggs shape also impacts the shell resistance, with greater force needed to rupture more globular eggs (Altuntas and Sekeroglu, 2008).

As expected, the age of the hens affected the egg quality with similar trends across all housing systems. Typically, the weight of the eggs (and of each of their components) increased over the time, but changes in the proportion of the components were observed. Thus, the percentage contribution made by the yolk increased throughout the laying period, but the proportion of albumen and eggshell was reduced. This finding agrees with results from the literature (Bovera et al., 2014; Samiullah et al., 2017; Yilmaz-Dikmen et al., 2017). The decrease in shell thickness with increasing hens age may indicate either less calcium accumulation during each shell formation cycle or same calcium distribution over a relatively larger surface area of the shell (Samiullah et al., 2017). This contribute to justify the reduction of eggshell strength recorded during the trial.

5. Conclusion

Enriched cages and aviaries are alternative housing systems that were developed to enhance animal welfare by providing extra space area and additional resources allowing hens to perform specific behavior like nesting, perching or scratching. While productivity parameters were quite similar for EC and CC, a deterioration of performance was noticed for AV, with lower FCR, laying rate, egg weight, and impairment of some egg quality traits. Moreover, the percentage of eggs laid outside the nest was substantially higher for hens kept in AV, which further impairs profitability. Higher animal activity and competition for facilities with alternative systems were proposed to explain these results. The attractiveness and usage of the nests could be enhanced by some adaptations to the equipment (e.g. floor type, nest access, and facilities location) and the management procedure (e.g. rearing environment of the pullets, habituation periods, and temporarily restricted access to the litter). The difference of egg productivity between AV and cages systems was reduced over time. This reflects the need for an adaptive period for hens kept in such an enriched environment.

From this research, it can be concluded that enriched cages seem better for both laying productivity and animal welfare compared to conventional cages and aviary systems. However, further investigations should be conducted to improve the aviary systems with higher acceptance and appropriate use of the resources by the hens. Additionally, a crucial attention must be paid to the rearing conditions to better match layer system.

Declaration of Competing Interest

The authors declare that there is no conflict of interest for this study.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.livsci.2020.103917.

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