Renewable Agriculture and Food Systems

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Influence of organic and cage housing system on egg quality in laying hens

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Research Paper

Cite this article: Rodríguez-Mengod A, Domínguez-Gómez MJ, Calvo A, Raigón MD, Mínguez C (2024). Influence of organic and cage housing system on egg quality in laying hens. *Renewable Agriculture and Food Systems* **39**, e19, 1–8. https://doi.org/10.1017/S1742170524000115

Received: 14 September 2023
Revised: 7 March 2024
Accepted: 22 April 2024

Keywords:
cage system; carotenoids; egg quality; fatty acids; Haugh units; organic system; yolk color

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Abstract

Most of the eggs for consumption are produced in a conventional housing system although the demand for organic eggs is increasing because consumers assume better nutritional characteristics. This study was conducted to compare the quality of organic eggs and enriched cage eggs. A total of 409 organic eggs and 385 eggs from hens housed in enriched cages were directly collected from 15 different farms, located in Spain and were analyzed within 4 days after laying. The differences in quality by removing the time bias that can be caused by marketing time were thus determined. All the hens were of three different lines, 47–50 weeks old and consumed commercial feed with the same nutritional composition. The quality traits evaluated were egg weight (EW g), egg shape index (SI), shell thickness (ST), shell percentage (SP), Haugh units (HU), dense albumen percentage (DAP), total albumen percentage (TAP), yolk color (YC), yolk percentage (YP), Roche scale (RS), moisture (M), ash content (AC), total protein (TP), total yolk carotenoids (TYC), total fat (TF), saturated fatty acids (SFA), monounsaturated fatty acids (MFA), and polyunsaturated fatty acids (PFA). Estimates of differences were obtained by generalized least squares using housing system, genetic line and their interaction as factors. Significant differences were observed for EW (65.3 *vs* 62.9), SI (77.60 *vs* 76.10), HU (83.60 *vs* 81.80), TAP (66.5 *vs* 64.17), YC (3.11 *vs* 1.89), RS (11.79 *vs* 9.48), TP (9.99 *vs* 8.55), TYC (4.188 *vs* 2.650), SFA (32.20 *vs* 30.00) and MFA (53.40 *vs* 44.20) in favor of the enriched cage system. In the organic system, the quality parameters that had higher and significant values were ST (0.34 *vs* 0.32), SP (10.52 *vs* 9.41), YP (25.20 *vs* 24.30), AC (1.12 *vs* 0.93) and PFA (26.00 *vs* 14.00). Significant interactions between the housing system and the hen line followed the same pattern observed for fixed effects. Organic eggs were lighter, less rounded with better shell quality and therefore showed lower Haugh unit values and a lower albumen percentage. Total protein, total fat, and lipid profile were within the usual average values for commercial eggs, although the proportion of polyunsaturated fatty acids, which are beneficial for consumers, was higher in organic eggs.

Introduction

In Europe, the production system determines the commercial designation of the type of egg. Most of the eggs produced and consumed come from hens housed in a conventional farming system (enriched cages, floor, and free-range hens), 44.9% are in enriched cages compared to 6.6% that are in an organic system. The organic production of eggs has increased from 5% in 2017 to 6.6% in 2021 (EU, 2021) leading to the need for research on the nutritional value assessed for both farming systems to help consumers when choosing between organic and conventional eggs (Popa et al., 2019). The trend in production systems towards less intensive models should consider the consequences it may have on egg quality (Alig, Malheiros and Anderson, 2023a)

Some quality parameters in eggs such as egg weight and Haugh units, related to the albumen quality depend on environmental conditions (Lordelo et al., 2017). In the conventional systems, the intensity of light, temperature and ventilation in the farm are controlled. However, the organic production of laying hens is a regulated system where hens have free access to outdoor runs mostly covered with vegetation, with a diet based on ingredients from organic farming (EU, 2018). European legislation about organic production also requires that no more than 3000 laying hens may be housed, and that at least one third of the floor must be a solid covered construction (e.g. straw or wood shavings) (EU, 2018). Animal health is also based mainly on prevention, routine mutilations are prohibited, and priority is given to the use of autochthonous breeds, which are better adapted to local-environmental conditions (EU, 2018). Many consumers attribute organic eggs a higher nutritional quality but previous studies have been inconclusive. It is unclear if choosing an egg depending on the production system guarantees superior quality (Da Silva Pires et al., 2021).The nutritional parameters (protein, ash content and lipids) mainly depend on the genetic origin, the age of the hen and the farming production method, with particular regard to the diet (DalleZotte et al., 2021). In the case of organic hens, access to outdoors is also an influencing factor, which allows the consumption of plants and insects although it subjects them to greater environmental stress (Lordelo et al., 2017; EU, 2018).

One of the most important aspects when evaluating egg quality is the time between laying and consumption (Roberts, 2004; Hidalgo et al., 2008). Therefore, obtaining eggs from supermarkets does not allow this factor to be considered, since the time they remain in storage may differ in many cases. There is a minority of studies that compare the egg quality obtained from caged hens and organic hens at the same laying age and with the same time elapsed since the egg was laid. The aim of this study was to compare the external, internal, and nutritional quality of eggs from organic system and enriched cage-housed hens with a minimal storage time.

Materials and methods

Experimental design and egg samples

The samples came from specific and commercial farms in Eastern and Southern Spain, from semi-heavy hens belonging to Hy-Line, ISA Brown and Lohmann lines, which reach an adult weight of 2 kg and lay brown eggs. All eggs were collected in the middle phase of the hen laying cycle (47–50 weeks) (Minelli et al., 2007). Hens housed in organic and enriched cage systems consumed commercial feed with the same nutritional composition (Table 1); no raw materials of transgenic origin were used on the organic farms, as the organic feed was produced and certified by REGOE-registered companies (Real decreto, 833/2014). From 15 different farms, a total of 409 organic eggs and 385 eggs from hens housed in enriched cages were analyzed within 4 days after laying (Table 2). The enriched cages used had 756 cm^2 of living area per bird and a flock density of 450–750 cm^2 /flock; drinker with nipple tip for 6–8 birds, feeder 10–15 cm/bird, a nest with plastic mesh floor, perches with oval tube and nail clippers (EU, 1999; EU, 2008) Eggs from hens housed in enriched cages were collected from 8 farms (3 Hy- Line, 3 ISA Brown and 2 Lohmann). Organic eggs were collected from 7 organic farms (2 Hy-Line, 2 ISA Brown and 3 Lohmann).

External quality parameters

Egg weight (EW) was obtained by weighing each individual total egg on an analytical balance (CS 100 M Cobos, Barcelona, Spain) with an accuracy of ±0.001 g. Egg shape index (SI) was calculated as the equatorial diameter divided by the length of the egg multiplied by 100. Shell thickness (ST) was determined as the average of the thickness measurements of the shell's greater pole, smaller pole and equator obtained with a caliper (MITUTOYO 500–173 Comet, Sofia, Bulgaria) as described by Hammershøj and Johansen (2016). Shell percentage (SP) was expressed as a percentage of the total weight of the egg (Roberts, 2004).

Internal quality parameters

Haugh units (HU) were calculated following the method described by Haugh (1937). For dense albumen percentage (DAP), the albumen was separated from the yolk, with a domestic yolk separator, and the albumen was deposited on a 2 mm sieve for three minutes. The fluid albumen passes through the sieve and the dense albumen is retained. Both types of albumen were weighed and the value of the dense albumen is expressed as a percentage of the total egg weight. The yolk percentage (YP) was expressed as a percentage of the total egg weight and total albumen percentage (TAP) was calculated as 100-(SP + YP). Yolk color was measured using two methods, a chromameter (Konica Minolta Photo Imaging Inc., Mahwah, NJ, USA), and obtaining the color index of the yolk (CIY) (Bovšková, Mikova and Panovská, 2014). Intensity of the color was also determined using a Roche scale (DSM®) (RS), where each color is identified with a number from 1 (yellow) to 15 (red), which is a very common method in the egg industry (Galobart et al., 2004).

Nutritional quality

Nutritional analyses were performed in triplicate. Moisture (M) was calculated using the gravimetric method, introducing the beaten egg with washed and dried sea sand in a forced air oven (P-select Digitronic) at 100°C for 24 h or until a constant weight was reached. Ash content (AS) was determined with the gravimetric method, pre-dried for 30 min at 100°C and introduced in the muffle (Carbolite, Hope Valley, UK), at 500°C for 5 h (AOAC, 2000). Quantitative determination of nitrogen was used to express total protein (TP) using the Kjeldhal Foss Tecator 2006 (Foss, Hilleroed, Denmark). Determination of total yolk carotenoids (TYC) was done with a UV/Visible spectrophotometer (Jenway 6305, Staffordshire, UK) applying a standard method (Karadas et al., 2006). A Sohxlet semiautomatic device (Foss 2050 Soxtectm, Hilleroed, Denmark) was used for the total fat (TF) determination following the Soxhlet method. Quantitative and qualitative determination of methyl esters of fatty acids for the fatty acid profile (FAP) was carried out using gas chromatography following the official method (AOAC, 2000). The equipment used was a gas chromatograph (Varian Star 3400cx, Palo Alto, CA, USA) consisting of a Combipal CTC automatic injector and an FID detector (flame detector). The column used was an RTX 2330 model (10% cyanopropylphenylpolyoxylan) (Restek; Bellefonte, United States) and was programmed at an initial temperature of 70°C, which was maintained for three minutes and then increased to 260°C (10°C.min^{-1}). The trawl gas was helium; the temperature of the injector was 230°C and the temperature of

Table 1. Chemical composition of the diet in organic and enriched cage system (%)[a,b]

Dry matter (% as fed)	Crude fiber	Crude protein	Ether extract	Ca	P	Na	K	Fe	ME (kcal/kg)
89%	3.5	17	6	3.5	0.8	0.16	0.9	0.04	2900

[a]Value based on the information by manufacturer's label.
[b]Both diets had the same nutritional composition and energy content, the only difference being that the raw materials used for the organic diet were of organic origin and not from genetically modified organisms.

Table 2. Descriptive statistics of egg quality traits

Trait	*N*	Mean	SD	Minimum	Maximum
Egg weight (EW) (g)	794	63.69	7.51	41.70	84.40
Egg shape index (SI)	653	77	4.10	57	95.26
Shell thickness (ST) (mm)	570	0.32	0.07	0.14	0.612
Shell percentage (SP)	576	9.79	1.18	5.05	15.25
Haugh units (HU)	690	83.13	11.81	30.83	110.78
Dense albumen percentage (DAP)	562	59.48	5.55	31.62	88.36
Total albumen percentage (TAP)	543	65.93	2.97	55.55	76.43
Yolk percentage (YP)	558	24.38	2.64	14.40	37.73
Yolk color (YC)	688	2.47	2.07	−3.27	11.02
Roche scale (RS)	600	10.87	2.59	1	15
Total protein (TP) (%)	433	9.39	1.26	6.45	14.91
Moisture (M) (%)	447	76.41	1.93	66.52	82.27
Ash content (AS) (%)	274	1.00	0.27	0.08	2.264
Total fat (TF) (%)	222	7.45	2.05	1.59	11.28
Total yolk carotenoids (TYC) (μg/g)	149	3713.6	1556.22	523.6	8442.9
Saturated fatty acids (SFA) (%)	155	31.83	3.83	22.98	47.31
Monounsaturated fatty acids (MFA) (%)	155	51.40	5.71	32.34	60.58
Polyunsaturated fatty acids (PFA) (%)	155	15.39	5.74	5.18	34.84

N, Total eggs analyzed for each trait; SD, standard deviation.

the detector 260°C. The internal standard used was a mixture of fatty acid methyl esters Custom FAME mix (Restek, ref 35077).

Statistical analysis

The parameters studied were Egg weight (EW), Egg shape index (SI), Shell thickness (ST), Shell percentage (SP), Haugh units (HU), Dense albumen percentage (DAP), Total albumen percentage (TAP), Yolk percentage (YP), Yolk color (YC), Roche scale (RS), Total protein (TP), Moisture (M), Ash content (AC), Total fat (TF), Total yolk carotenoids (TYC), Saturated fatty acids (SFA), Monounsaturated fatty acids (MFA) and Polyunsaturated fatty acids (PFA).

The estimates of the differences between organic *vs* conventional eggs were obtained by generalized least squares, using the R Project program (R Core Team., 2021). The model used in this analysis was:

$$Y_{kl} = P_k + B_l + PxB_{kl} + \varepsilon_{kl}$$

where Y_{kl} is the character register; P_k is the effect of the production system (two levels; organic and conventional); B_l is the effect of the hen breed (three levels; Hy-Line, ISA Brown, and Lohmann), PxB_{kl} is the interaction between rearing system and hen line and ϵ_{kl} is the residual effect. Tukey's post hoc test was used for difference comparison between groups. A level of significance was established at $\alpha = 0.05$.

Results

Summary statistics for egg quality traits are shown in Table 2. In Table 3, the least squares means between the housing systems for the studied traits can be observed. Significantly higher values in EW, SI, HU, TAP, YC, RS, TP, TF, TYC, SFA, and MFA traits were observed in conventional eggs and ST, SP, YP, AC, and PFA were superior in organic eggs. No significant differences were observed for the traits DAP and M.

Results of the different hen lines are presented in Table 4. For EW, the eggs laid by the Lohmann line were heavier than the eggs of the ISA Brown line, these were heavier than those of the Hy-Line (significant among all of them). For SP, higher values were observed for eggs from the Hy-Line and ISA Brown lines (significant with Lohmann). For HU and TYC, higher values were found for eggs from the Hy-Line and Lohmann lines (significant with ISA Brown). For trait M, Hy-Line showed a significant and higher YP in eggs compared to Lohmann (no significant differences were found between eggs from Hy-Line *vs* ISA Brown and ISA Brown *vs* Lohmann). For trait, M, SFA and PFA differences were observed for eggs from Hy-Line (no significant differences were found between Lohmann *vs* ISA Brown), with M and PFA being higher in eggs from Lohmann and ISA Brown, and SFA higher in Hy-Line. For the traits SI, ST, DAP, TAP, RS, TP, M, TF, and MFA no significant differences were observed.

In Table 5, the interactions between the hen line and the housing system are shown. Significant interactions were observed in the egg quality parameters of EW, ST, HU, YP, and AS. For EW, similar values were observed in Lohmann hens for conventional and organic eggs. However, EW was significantly lower in Hy-Line and ISA Brown organic eggs. For ST, ISA Brown hens showed similar values in both housing systems. However, the interaction showed lower values of ST for organic Hy-Line hens and higher values of ST for conventional Lohmann. Contrary to what can be observed in Table 3, lower HU values were found in eggs from conventional ISA Brown hens. For YP,

https://doi.org/10.1017/S1742170524000115 Published online by Cambridge University Press

Table 3. Least squares means (± standard error) of egg quality traits across egg housing system

Trait	Enriched cage system	Organic system
Egg weight (EW) (g)	65.30 (±0.37)[a] (*N* = 385)	62.90 (±0.37)[b] (*N* = 409)
Egg shape index (SI)	77.60 (±0.20)[a] (*N* = 333)	76.10 (±0.25)[b] (*N* = 320)
Shell thickness (ST) (mm)	0.32 (±0.00)[b] (*N* = 290)	0.34 (±0.00)[a] (*N* = 280)
Shell percentage (SP)	9.41 (±0.05)[b] (*N* = 290)	10.52 (±0.07)[a] (*N* = 286)
Haugh units (HU)	83.60 (±0.59)[a] (*N* = 354)	81.80 (±0.66)[b] (*N* = 336)
Dense albumen percentage (DAP)	59.40 (±0.29)[a] (*N* = 296)	59.30(±0.42)[a] (*N* = 266)
Total albumen percentage (TAP)	66.55 (±0.14)[a] (*N* = 280)	64.17 (±0.22)[b] (*N* = 263)
Yolk percentage (YP)	24.30 (±0.13)[b] (*N* = 283)	25.20 (±0.19)[a] (*N* = 275)
Yolk color (YC)	3.11 (±0.10)[a] (*N* = 349)	1.89 (±0.11)[b] (*N* = 339)
Roche scale (RS)	11.79 (±0.12)[a] (*N* = 309)	9.48 (±0.16)[b] (*N* = 291)
Total protein (TP) (%)	9.99 (±0.07)[a] (*N* = 219)	8.55 (±0.08)[b] (*N* = 214)
Moisture (M) (%)	76.38 (±0.12)[a] (*N* = 233)	76.00 (±0.15)[a] (*N* = 214)
Ash content (AS) (%)	0.93 (±0.02)[b] (*N* = 140)	1.12 (±0.02)[a] (*N* = 134)
Total fat (TF) (%)	8.63 (±0.15)[a] (*N* = 117)	6.04 (±0.17)[b] (*N* = 105)
Total yolk carotenoids (TYC) (μg/g)	4188 (±131)[a] (*N* = 83)	2650 (±212)[b] (*N* = 66)
Saturated fatty acids (SFA) (%)	32.20 (±0.32)[a] (*N* = 83)	30.00 (±0.63)[b] (*N* = 72)
Monounsaturated fatty acids (MFA) (%)	53.40 (±0.40)[a] (*N* = 83)	44.20 (±0.79)[b] (*N* = 72)
Polyunsaturated fatty acids (PFA) (%)	14.00 (±0.45)[b] (*N* = 83)	20.60 (±0.82)[a] (*N* = 72)

Means in the same row with the same superscript do not differ significantly (significant difference at $\alpha = 0.05$).
N, number of eggs.

a higher percentage was found in organic eggs from Lohmann hens, and there was no difference in the values of AS for eggs from Hy-Line hens across the two housing systems.

For the traits SI, SP, DAP, TAP, YC, RS, TP, M, TF, TYC, SFA, MFA, and PFA the interaction was no significant and followed the same pattern observed for fixed effects presented in Table 3.

Discussion

Consumers choose organic products for reasons such as animal welfare, development of rural areas, respect for the environment and better food quality (Popa et al., 2019). In order to evaluate and compare the quality of organic and cage eggs, it is necessary to analyze the internal, external, and nutritional quality parameters in detail and to consider the factors that can influence them such as genetic line and housing system (Da Silva Pires et al., 2021).

The means of the egg weights were within the range of commercial weights in the European Union (EU, 2008). Therefore, all the eggs studied could have been marketed. Egg weight has been the most parameter studied in quality studies because it is correlated with surface area, diameter, and height (Da Silva Pires et al., 2021). For EW, Minelli et al. (2007) showed that conventional eggs were heavier than the organic ones (which have a higher commercial value). However, Jones et al. (2010) obtained a higher EW in the organic system. This discrepancy may be because the eggs were retail purchased in Jones et al. (2010) and they did not have information available about genetic lines (they used the line of white and brown shells) and the age of the flocks. Mugnai, Dal Bosco and Castellini (2009) found no significant differences between organic and conventional eggs for this trait. SI results were within the acceptable values between 72 and 76 g (Duman et al., 2016). SI influences the commercialization, as excessively long or round eggs are more likely to break. In our study, the SI of organic eggs was slightly higher than conventional eggs, but for both systems, the results were within acceptable values. SP and ST are related to shell strength, which should be considered as they are important to reduce the percentage of broken eggs in the marketing process. Both traits were higher in eggs from organic hens, in line with the results obtained by Rizzi et al. (2006). Alig, Malheiros and Anderson (2023a) concluded that access to pasture seemed to provide free-range hens with different nutritional advantages such that eggs from free-range hens had better shell quality than those from enriched cages. A better shell quality may be due to higher physical activity which has a positive impact on bone strength and calcium resorption to egg shell mineralization (Van Den Brand, Parmentier and Kemp, 2004, Hammershøj, Kristiansen and Steenfeldt, 2021) and to a higher synthesis of vitamin D_3 as a result of a greater exposure to sunlight (Mugnai, Dal Bosco and Castellini, 2009).

The HU are used to assess the quality of the albumen and relate the weight of the egg to the height of the albumen (Haugh, 1937). In the present study, HU were higher in the conventional eggs, contrary to that found by Minelli et al. (2007), where cages were not enriched and could result in a high concentration of ammonia, high enough to affect the structure of the albumen (Da Silva Pires et al., 2021). The EU Council Directive 1999/74/EC, which requires the use of enriched cages, was not mandatory until January 2012 (EU, 1999). Hidalgo et al. (2008), in a study carried out in the USA, found that eggs produced by hens in conventional cages had statistically higher HU than those of organic production; with the most probable cause of these results being the time elapsed in the distribution of the organic eggs, so that the eggs were not as fresh and HU decrease with storage time (Roberts, 2004). In this study, all eggs were analyzed within 4 days of collection, which may explain the differences in our results compared to other studies that did not take in to account the time since egg laying.

Consumers associate a color of the yolk, that varies from golden yellow to orange, with a good total egg quality (Wall, Jonsson and Johansson, 2010). In this sense, there are also preferences for population groups and geographical areas, so US consumers prefer yolks with a score between 7 and 10 on the Roche

Table 4. Least squares means (± standard error) of egg quality traits for the different hen lines

Trait	Hy-Line	ISA Brown	Lohmann
Egg weight (EW) (g)	62.40 (±0.40)[a] (*N* = 271)	64.10 (±0.48)[b] (*N* = 259)	65.90 (±0.49)[c] (*N* = 246)
Egg shape index (SI)	76.50 (±0.25)[a] (*N* = 227)	77.30 (±0.28)[a] (*N* = 219)	76.70 (±0.29)[a] (*N* = 207)
Shell thickness (ST) (mm)	0.32(±0.00)[a] (*N* = 195)	0.34 (±0.00)[a] (*N* = 190)	0.32 (±0.01)[a] (*N* = 185)
Shell percentage (SP)	10.01 (±0.07)[a] (*N* = 197)	10.20 (±0.08)[a] (*N* = 192)	9.66 (±0.09)[b] (*N* = 187)
Haugh units (HU)	84.20 (±0.67)[a] (*N* = 243)	80.40 (±0.82)[b] (*N* = 228)	83.40 (±0.87)[a] (*N* = 219)
Dense albumen percentage (DAP)	59.80 (±0.39)[a] (*N* = 190)	59.00(±0.44)[a] (*N* = 188)	59.30 (±0.49)[a] (*N* = 184)
Total albumen percentage (TAP)	65.60 (±0.19)[a] (*N* = 186)	65.20 (±0.22)[a] (*N* = 181)	65.30 (±0.26)[a] (*N* = 176)
Yolk percentage (YP)	24.30 (±0.21)[b] (*N* = 199)	24.70 (±0.20)[ab] (*N* = 183)	25.20 (±0.22)[a] (*N* = 176)
Yolk color (YC)	2.55 (±0.11)[a] (*N* = 235)	2.11 (±0.13)[b] (*N* = 231)	2.85(±0.14)[a] (*N* = 227)
Roche scale (RS)	10.80 (±0.14)[a] (*N* = 212)	10.60 (±0.18)[a] (*N* = 202)	10.50 (±0.22)[a] (*N* = 186)
Total protein (TP) (%)	9.32(±0.07)[a] (*N* = 151)	9.10(±0.09)[a] (*N* = 142)	9.40(±0.10)[a] (*N* = 140)
Moisture (M) (%)	76.40 (±0.14)[a] (*N* = 155)	76.01 (±0.18)[a] (*N* = 149)	76.17 (±0.19)[a] (*N* = 143)
Ash content (AS) (%)	0.92 (±0.02)[b] (*N* = 94)	1.07(±0.03)[a] (*N* = 92)	1.08 (±0.03)[a] (*N* = 88)
Total fat (TF) (%)	7.38 (±0.17)[a] (*N* = 77)	7.40 (±0.20)[a] (*N* = 73)	7.17(±0.21)[a] (*N* = 72)
Total yolk carotenoids (TYC) (μg/g)	3635 (±222)[a] (*N* = 48)	2990 (±194)[b] (*N* = 57)	3633 (±230)[a] (*N* = 44)
Saturated fatty acids (SFA) (%)	32.80 (±0.49)[a] (*N* = 56)	29.80 (±0.57)[b] (*N* = 52)	30.70 (±0.75)[b] (*N* = 47)
Monounsaturated fatty acids (MFA) (%)	49.10 (±0.61)[a] (*N* = 56)	48.50 (±0.71)[a] (*N* = 52)	48.60(±0.93)[a] (*N* = 47)
Polyunsaturated fatty acids (PFA) (%)	15.10 (±0.66)[b] (*N* = 56)	18.80 (±0.75)[a] (*N* = 52)	17.90 (±0.76)[a] (*N* = 47)

[abc]Means in the same row with the same superscript do not differ significantly (significant difference at $\alpha = 0.05$).
N, number of eggs.

scale, while in Europe and Asia the most accepted eggs are those with yolks with a more intense color scoring between 10 and 14 (Galobart et al., 2004). Organic food consumers prefer less pigmented and additive-free yolks (Paul and Rana, 2012). Significant differences observed in yolk color are mainly due to the addition of pigments (yellow or red xanthophylls) into the diet of conventional hens, that are banned in the composition of organic feed (Minelli et al., 2007).

Egg moisture is an important parameter for industrial egg processing as it is indicative of the percentage of dry product that can be produced per egg, in our study no significant differences were found between the production systems, in agreement with Alig, Malheiros and Anderson (2023a) who found no differences in dry matter in brown eggs from hens housed in enriched and cage-free cages. However, in white shell eggs cage-free eggs had a greater amount of egg dry matter than enriched cage eggs (Alig, Malheiros and Anderson, 2023b). The percentage of proteins in the egg is important for the nutritional intake of consumers but also for the industry since the functional properties of proteins are used in the food industry. Hidalgo et al. (2008) reported higher protein content in organic eggs while Rizzi and Marangon (2012) found no difference between both housing systems. DalleZotte et al. (2021) found a lower ash content in organic and conventional eggs because the organic diets had lower micronutrient contents. Küçükyılmaz et al. (2012) described higher ash proportion in conventional eggs and related this result to the fact that hens in the organic system were exposed to more variable environmental conditions with external stressors. Therefore, a higher mineral content in the organic eggs in our study can be related to a better balanced organic diet and a good housing

Table 5. Least squares means (± standard error) of egg quality traits for the interaction between the housing systems and hen lines

	Enriched cage system			Organic system		
Trait	Hy-Line	ISA Brown	Lohmann	Hy-Line	ISA Brown	Lohmann
Egg weight (EW) (g)	64.10 (±0.61)^{ab} (*N* = 131)	65.70 (±0.70)^{a} (*N* = 120)	65.80 (±0.60)^{a} (*N* = 129)	60.60 (±0.53)^{c} (*N* = 144)	62.50 (±0.65)^{bc} (*N* = 127)	65.70 (±0.75)^{a} (*N* = 125)
Egg shape index (SI)	77.40 (±0.34)^{ab} (*N* = 111)	78.20 (±0.39)^{a} (*N* = 105)	77.20 (±0.33)^{ab} (*N* = 105)	75.50 (±0.38)^{c} (*N* = 112)	76.50 (±0.42)^{bc} (*N* = 109)	76.10 (±0.51)^{bc} (*N* = 99)
Shell thickness (ST) (mm)	0.34 (±0.01)^{ab} (*N* = 100)	0.32 (±0.01)^{ac} (*N* = 93)	0.28 (±0.01)^{d} (*N* = 97)	0.31 (±0.01)^{c} (*N* = 98)	0.35 (±0.01)^{ab} (*N* = 92)	0.37 (±0.01)^{b} (*N* = 90)
Shell percentage (SP)	9.39 (±0.08)^{c} (*N* = 100)	9.59 (±0.10)^{c} (*N* = 93)	9.27 (±0.08)^{c} (*N* = 97)	10.66 (±0.11)^{c} (*N* = 101)	10.82 (±0.12)^{ab} (*N* = 95)	10.12 (±0.15)^{a} (*N* = 90)
Haugh units (HU)	86.00 (±1.00)^{ab} (*N* = 117)	78.3 (±1.12)^{c} (*N* = 111)	86.50 (±0.97)^{a} (*N* = 126)	82.40 (±0.90)^{bc} (*N* = 122)	82.60 (±1.21)^{abc} (*N* = 98)	80.30 (±1.14)^{c} (*N* = 116)
Dense albumen percentage (DAP)	59.50 (±0.48)^{a} (*N* = 99)	58.50 (±0.54)^{a} (*N* = 94)	60.20 (±0.47)^{a} (*N* = 103)	60.00 (±0.61)^{a} (*N* = 93)	59.40 (±0.69)^{a} (*N* = 89)	58.40 (±0.86)^{a} (*N* = 84)
Total albumen percentage (TAP)	66.70 (±0.23)^{ab} (*N* = 96)	65.70 (±0.26)^{ac} (*N* = 91)	67.20 (±0.23)^{b} (*N* = 93)	64.60 (±0.30)^{cd} (*N* = 102)	64.50 (±0.36)^{cd} (*N* = 86)	63.40 (±0.47)^{d} (*N* = 75)
Yolk percentage (YP)	23.90 (±0.21)^{bc} (*N* = 96)	24.60 (±0.24)^{c} (*N* = 92)	23.50 (±0.21)^{b} (*N* = 95)	24.70 (±0.27)^{c} (*N* = 96)	24.70 (±0.31)^{c} (*N* = 92)	27.00 (±0.39)^{a} (*N* = 87)
Yolk color (YC)	3.33 (±0.16)^{a} (*N* = 117)	3.54 (±0.18)^{a} (*N* = 110)	2.45 (±0.15)^{b} (*N* = 122)	1.74 (±0.14)^{c} (*N* = 125)	1.67 (±0.19)^{c} (*N* = 116)	1.76 (±0.23)^{c} (*N* = 98)
Roche scale (RS)	11.98 (±0.19)^{a} (*N* = 106)	12.53 (±0.22)^{a} (*N* = 95)	10.86 (±0.19)^{b} (*N* = 108)	9.66 (±0.21)^{bc} (*N* = 104)	8.68 (±0.28)^{c} (*N* = 95)	10.10 (±0.35)^{bc} (*N* = 91)
Total protein (TP) (%)	9.71 (±0.11)^{a} (*N* = 73)	9.79 (±0.13)^{a} (*N* = 71)	10.46 (±0.10)^{b} (*N* = 75)	8.93 (±0.10)^{c} (*N* = 74)	8.41 (±0.13)^{d} (*N* = 71)	8.33 (±0.16)^{d} (*N* = 69)
Moisture (M) (%)	76.39 (±0.20)^{a} (*N* = 78)	76.34 (±0.23)^{a} (*N* = 76)	76.43 (±020)^{a} (*N* = 79)	76.42 (±0.18)^{a} (*N* = 74)	75.68 (±0.27)^{a} (*N* = 71)	75.91 (±0.33)^{a} (*N* = 69)
Ash content (AS) (%)	0.91 (±0.03)^{a} (*N* = 46)	0.92 (±0.04)^{a} (*N* = 46)	0.94 (±0.03)^{a} (*N* = 48)	0.94 (±0.03)^{a} (*N* = 47)	1.21 (±0.03)^{b} (*N* = 47)	1.21 (±0.05)^{b} (*N* = 40)
Total fat (TF) (%)	8.67 (±0.21)^{a} (*N* = 39)	8.69 (±0.23)^{a} (*N* = 37)	8.48 (±0.21)^{a} (*N* = 41)	5.61 (±0.19)^{b} (*N* = 37)	6.12 (±0.23)^{b} (*N* = 35)	5.90 (±0.26)^{b} (*N* = 33)
Total yolk carotenoids (TYC) (μg/g)	4382 (±218)^{a} (*N* = 28)	4018 (±245)^{ab} (*N* = 25)	4165 (±218)^{a} (*N* = 30)	2888 (±387)^{bc} (*N* = 24)	1963 (±300)^{c} (*N* = 22)	3100 (±404)^{abc} (*N* = 20)
Saturated fatty acids (SFA) (%)	34.40 (±0.53)^{a} (*N* = 28)	31.30 (±0.62)^{b} (*N* = 25)	31.10 (±0.51)^{b} (*N* = 30)	31.30 (±0.83)^{b} (*N* = 27)	28.30 (±0.95)^{b} (*N* = 24)	30.40 (±1.41)^{ab} (*N* = 21)
Monounsaturated fatty acids (MFA) (%)	53.20 (±0.66)^{a} (*N* = 28)	52.90 (±0.77)^{a} (*N* = 25)	54.10 (±0.63)^{a} (*N* = 30)	45.50 (±1.04)^{b} (*N* = 27)	44.00 (±1.19)^{b} (*N* = 24)	43.10 (±1.75)^{b} (*N* = 21)
Polyunsaturated fatty acids (PFA) (%)	11.90 (±0.69)^{d} (*N* = 28)	15.50 (±0.78)^{bc} (*N* = 25)	14.60 (±0.68)^{c} (*N* = 30)	18.40 (±0.92)^{c} (*N* = 27)	22.10 (±0.99)^{a} (*N* = 24)	21.20 (±1.07)^{a} (*N* = 21)

^{abcd}Means in the same row with the same superscript do not differ significantly (significant difference at $\alpha = 0.05$).
N, number of eggs.

design that limits environmental stressors. Eggs are a source of MFA and PFA, which are beneficial as the consumption of this type of fat lowers the risk of heart disease (Samman et al., 2009). Some authors do not describe statistically significant differences between the lipid profile of conventional and organic eggs (Hidalgo et al., 2008), while others such as Samman et al. (2009), DalleZotte et al. (2021) and Marelli et al. (2021) agree with those obtained in the present study. The genetic line in organic production systems and its interaction with the housing system can have a significant influence on egg quality parameters (Hammershøj and Steenfeldt, 2015). Rakonjac et al. (2017) observed significant differences in the interaction between genotype and housing system, with lower values for organic production in EW, ST, HU, YP, SFA, MFA, and PFA. The interaction between genotype and housing system involved floor or organic *vs* Isa Brown or New Hampshire and compares organic production with the enriched cage system (litter floor and free-range *vs* organic production). Sokołowicz et al. (2018) compared three housing systems (litter floor, free range, and organic) with three types of genotype (Green leg Partridge, Rhode Island red, and Hy-line brown) with the same trend. Sokołowicz et al. (2018) also measured SFA, MFA, and PFA, with similar results to those of this study and showed significant high values in the genotypes included in organic system. Some researchers found no significant interaction concerning egg shell quality traits and also observed that the interaction effect was more important than the effect of individual factors (Singh, Cheng and Silversides, 2009; Ketta and Tumova, 2017). Sharma et al.

(2022) described that Hy-line hens with access to the outside yard had the highest shell thickness, contrary to the results of this study. Possible differences in the studies cited above could be due to the fact that the interactions measured are different. In some studies, they do not use the organic system and in others, the genetic lines are not in common.

Conclusions

The external traits studied related to weight and shape were better in eggs from an enriched cage housing system, but organic eggs had a shell that was more resistant to breakage. With regard to internal quality, cage eggs had a higher quality of albumen and the yolk color was more intense; however, organic eggs contain a higher proportion of yolk. Food industries using eggs as an ingredient must take these differences into account when selecting which type of egg to incorporate into their products. From a nutritional point of view, eggs from hens housed in enriched cages had a higher proportion of proteins and fats, which are mainly monounsaturated and saturated, however organic eggs contained more polyunsaturated fatty acids. Therefore, health-conscious consumers should choose organic eggs. Although there were differences in some of the quality traits studied, eggs from both housing systems were suitable for marketing. It would be interesting to incorporate quality-related information on labeling of eggs to enable consumers to make more informed choices.

Data availability statement. The data supporting the study will be made available by the authors, without undue reservation.

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