A comparison between the quality of eggs from indigenous chicken breeds and that from commercial layers

Madalena Lordelo,[*,1] Joana Cid,[*] Cláudia M. D. S. Cordovil,[*] Susana P. Alves,[†] Rui J. B. Bessa,[†] and Inês Carolino[‡]

*LEAF, Linking Landscape, Environment, Agriculture and Food, The School of Agriculture, University of Lisbon, Tapada da Ajuda 1349-017 Lisbon, Portugal; [†]CIISA, Faculty of Veterinary Medicine, University of Lisbon, Av. da Universidade Técnica, 1300-477 Lisboa, Portugal; and [‡]National Institute for Agricultural and Veterinary Research, Quinta da Fonte Boa, 2005-048 Santarém, Portugal

ABSTRACT There is an increased interest in animal products from more sustainable farming practices, which may include using local breeds. In addition, maintaining biodiversity is important, and naturally, indigenous breeds of chickens are well adapted to the local environmental conditions. In the current study, 286 eggs from 4 Portuguese breeds of chickens (Branca, Amarela, Pedrês Portuguesa, and Preta Lusitânica) and from a commercial hybrid laying hen were used. Chemical and physical characteristics of the eggs and the egg components such as weights, Haugh units, yolk color, albumen protein content, yolk fatty acid content, and mineral content in the albumen and yolk were analyzed. The Branca breed produced eggs with a lighter brown shell color and lower Haugh unit values than the remaining native breeds ($P < 0.05$). The commercial hens produced eggs that were found to be more rounded shape than the ideal and with a darker colored shell and yolk than eggs from the 4 local breeds. In addition, the commercial hens also produced heavier eggs but with lower Haugh units than the Amarela, Pedrês Portuguesa, and Preta Lusitânica breeds ($P < 0.05$). The range of saturated fatty acids, monounsaturated fatty acids, and total polyunsaturated fatty acids between eggs from the 4 breeds was small and not significantly different. No differences were found in the percentage of albumen protein between breeds. Albumen and yolk ash content was not different between breeds. The overall analysis indicated that eggs from these native genotypes match the quality of a commercial product in many characteristics. In markets where eggs from local breeds are available, consumers are purchasing a high-quality product while aiding in the expansion of local genetic resources and investing in local farmers.

Key words: egg quality, egg, fatty acid, mineral, native and hybrid breed

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INTRODUCTION

The conservation of indigenous farming animal breeds is vital for the maintenance of the local genetic resources, biodiversity, as well as for the sustainability of animal production. The Food and Agriculture Organization (**FAO**) launched an international program to find breeds that are in danger of extinction and help save and spread their genetic diversity (FAO, 2007). Members of the European Union, including Portugal, incentivized the development of actions to promote and protect native breeds in their original habitat.

Egg production in Portugal, as in other developed countries, depends on commercial hybrids of laying chickens, which are selected for their high production performance. However, the continuous use of commercial hybrids may be the forerunner to a progressive reduction in the genetic variability. Native breeds of chickens are characterized by their rusticity, resistance, and adaptability to the environment (Ajayi, 2010). They also provide a pool of potential useful genetic resources for commercial strains. Furthermore, there has been a shift in the demand for healthier and more sustainable products by the European consumer in light of recent emerging diseases and climate change. Eggs produced by indigenous breeds of poultry are a compelling option for consumers (FAO, 2007). Therefore, it is necessary to assess the quality of the eggs from local breeding stocks.

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[1]Corresponding author: mlordelo@isa.ulisboa.pt

Little research attention has been given to indigenous breeds of chickens and their products. In Italy, Zanon et al. (2006) concluded that chickens from Emilia-Romagna region lay eggs with very different characteristics from those of commercial strains, with the local breeds having smaller eggs and a higher percentage of yolk. Another study found that eggs from local Italian breeds have larger and more pigmented yolks and higher cholesterol content than hybrid breeds (Rizzi and Marangon, 2012). Haunshi et al. (2011) also developed a comprehensive report on the quality of eggs from 2 important native breeds from India, although no comparison was made with eggs from commercial hybrids.

In Portugal, there are 4 indigenous breeds, all at risk of extinction: Branca, Amarela, Pedrês Portuguesa, and Preta Lusitânica. The external pattern characteristic of these breeds is described in their corresponding genealogical books (DGAV, 2013). Most of these chickens are raised in small family farms under traditional production systems and serve as dual-purpose animals: meat and eggs. It has been established that growth performance and carcass yields of Portuguese native breeds are comparable to those of other native European breeds, with the Pedrês Portuguesa having the best aptitude for meat production (Soares et al., 2015). In addition, Soares (2015) has indicated that, in general, the physical and chemical characteristics of eggs from Amarela, Pedrês Portuguesa, and Preta Lusitânica breeds are within the acceptable range. However, no attempt was made to compare these eggs with eggs from commercial hybrid hens. In a study to characterize the quality of eggs available on market shelves in Portugal, including eggs from different housing systems, from indigenous breeds and specialty eggs, Lordelo et al. (2017) found that the shell and yolk color of eggs from the native breeds was lighter than that of other samples. However, eggs from local breeds had a higher Haugh unit (**HU**) value than eggs from other origins (Lordelo et al., 2017).

In the present study, eggs from a number of different small farms that raise indigenous chickens were characterized for their physical and chemical properties, such as weights, shape index (**SI**), HUs, yolk color, albumen protein content, yolk fatty acid content, and mineral content in the albumen and yolk and compared with eggs collected from a commercial poultry operation.

MATERIALS AND METHODS

Two hundred and eighty-six eggs from 4 Portuguese breeds of chickens, Branca, Amarela, Pedrês Portuguesa (**Pedrês**), and Preta Lusitânica (**Preta**) reared in small family farms and from a flock of Tetra Brown commercial hybrid laying hens (**Hybrid**) reared in furnished cages were collected randomly and not chosen by weight categories. Eggs from the Branca, Amarela, and Preta breeds were collected from 10 farms, and eggs from the Pedrês breed were collected from 9 farms. Eggs were collected on the laying day and were maintained at room temperature for 8 D to ensure consistent egg age and then analyzed. With the exception of protein and fatty acid analysis, eggs were examined with the same age (8 D old). Physical analyses described elsewhere in this article were performed in all eggs individually. Chemical analysis (protein, fatty acid, and mineral elements) described below were performed in a pool of eggs originated from the same farm and breed resulting in 10 pooled samples for Amarela, Pedrês, and Preta breeds; 9 pooled samples for Branca breed; and 1 pooled sample for Hybrid genotype. Each pooled sample contained 4 eggs that were mixed together.

Analysis of Physical Characteristics and pH

Whole eggs were individually weighed and candled to determine the percentage of eggs with precracks. Egg shell color was scored using a scale from 1 through 6, with 1 being very light brown and 6 very dark brown according to the procedure from the study by Lordelo et al. (2017). The egg equator diameter and egg height of each egg were measured using a digital caliper. The SI was calculated using the equation proposed by Khalafalla and Bessei (1995), SI = 100 × equator diameter/egg height. Eggs were then opened, and air cell height was determined using a graduated measuring card (Moba BV, Barneveld, Netherlands). Egg shells were then separated and dried in an oven for 24 h at 50°C, after which they were weighed to determine shell percentage. Blood and meat spots in the yolk and albumen were detected visually. Yolk color was scored using the Roche egg yolk fan (DSM, Heerlen, Netherlands). Thick albumen height was measured using a micrometer (Baxlo Precision, Barcelona, Spain), followed by the calculation of HU using the formula $100*\log(h-1.7*w^{0.37}+7.57)$, where h is the height of the thick albumen and w is the egg weight (Haugh, 1937).

The thick and the thin albumen were separated from the yolk using a pipette to guarantee that the vitelline membrane of the yolk would be intact and without any albumen residue. One milliliter of each intact albumen was used to measure the viscosity of the thick and thin albumen separately using a viscometer with a spindle at 6 rpm (Model LVDVCP-II; Brookfield Engineering Laboratories, Middleboro, MA). Intact yolk was weighed for determination of yolk percentage, and albumen weight was calculated by difference. Albumen pH was determined using a potentiometer 744 pH Meter (Metrohm, Herisau, Switzerland).

Determination of Protein Content and Fatty Acid Composition

Albumen was analyzed for nitrogen content using the Kjeldahl method, and the conversion factor from nitrogen to protein was 6.25. Before fatty acid preparation, yolk samples were freeze-dried (ScanVac CoolSafe; Labogene, Lynge, Denmark) and homogenized. Fatty acid methyl esters (**FAMEs**) were prepared by a direct transesterification procedure with the addition of 19:0 (1 mg/mL) as internal standard. Briefly, 1 mL of toluene was added to

100 mg of yolk sample, then 2 mL of sodium methoxide in methanol (0.5 N) was added, and after reaction for about 10 min at 50°C, another 3 mL of 10% HCl in methanol was added to the reaction vessel and left to react for more 10 min at 80°C. After cooling, samples were neutralized with 6% aqueous potassium carbonate, and FAMEs were extracted with hexane. The solvent was removed under a flow of nitrogen at 37°C, and the final residue was dissolved in 1.5 mL of hexane and stored at −20°C until gas chromatography (**GC**) analysis. FAME were quantified by fast-GC using a Shimadzu GC-2010 Plus chromatograph (Shimadzu, Kyoto, Japan) equipped with a Suprawax280 capillary column (10 m, 0.10 mm i.d., 0.10 µm film thickness; Teknokroma, Barcelona, Spain) and a flame ionization detector. Helium was used as carrier gas at a constant pressure of 296.7 kPa, and the injector and detector were maintained at 280°C. Column oven programmed temperature was as follows: the initial oven temperature of 120°C was increased to 175°C at 35°C/min and held for 0.5 min, then increased to 260°C at 70°C/min, and was maintained for more than 15 min. Identification of FAME was achieved by comparison of the FAME retention times with those of authentic standards (FAME mix 37 components from Supelco Inc., Bellefonte, PA). Additional identification of the FAME was achieved by electron impact mass spectrometry using a Shimadzu GC-MS QP2010 Plus (Shimadzu, Kyoto, Japan). The mass spectrometer conditions were as follows: ion source temperature, 200°C; interface temperature, 220°C; ionization energy, 70 eV; scan, 50 to 500 atomic mass units.

The total fatty acid content in yolk samples was calculated using an internal standard and assuming direct proportionality between GC-flame ionization detector peak area and FAME weight. Results for each fatty acid were expressed as a percentage of the sum of detected fatty acid (g/100 g of total fatty acid).

We calculated the fatty acid content in yolks (mg/g of yolk), assuming a yolk water content of 52.3 g/100 g as indicated in the USDA food composition database.

Determination of Ash and Mineral Content

Ash content was determined by holding samples at 550°C for 24 h. Methods for mineral content determination are described in the study by Sparks et al. (1996): pH was measured by a glass electrode using a 1:2 (egg: water) ratio; TKN was determined by Kjeldahl method after sample digestion; N_{min} ($N\text{-}NH_4^+ + N\text{-}NO_3^-$) was determined by molecular absorption spectrophotometry using a segmented flow auto-analyzer (Skalar) after extraction with 2M KCl (1:5 ratio) at room temperature and centrifuged at 3,000 rpm for 5 min (Cordovil et al., 2005); available P and K concentrations were determined by Egner-Riehm procedure; total P and K concentration was determined by ammonium vanadate method; and micronutrients concentration was determined by flame atomic absorption spectrophotometry after calcination of the samples. Calcium, magnesium, and sodium were determined by spectrophotometry after sample calcination, followed by digestion with HCl 3*N*.

Statistical Analysis

Analyses of physical properties were performed in individual eggs (67 eggs from Branca, Amarela, and Preta; 61 eggs from Pedrês; and 24 eggs from the hybrid breed). Analyses of chemical properties were performed in a mixture of 4 pooled eggs (10 mixtures from Amarela, Pedrês, and Preta; 9 mixtures from Branca; 1 mixture from the hybrid breed). Data were analyzed using one-way analysis of variance. For chemical analysis data, the Hybrid group was excluded from the analysis of variance. Differences between means were determined by the Duncan's test using the GLM procedure of SAS (SAS Institute Inc., 2012). All statements of significance were based on testing at the $P < 0.05$ level. Chi-squared test was performed to statistically assess if the presence of blood spots, meat spots, and shell cracks was different among groups (SAS Institute Inc., 2012).

RESULTS

Physical Characteristics, pH, and Protein Content

The Branca and Hybrid hens had heavier ($P < 0.05$) eggs (58.08 g and 59.37 g, respectively) than the remaining breeds (Table 1). The percentage of yolk was lower ($P < 0.05$), and the percentage of albumen was higher ($P < 0.05$) in eggs originated from the Hybrid hens (25.17 and 64.90%, respectively). Percentage of shell was also found to be higher ($P < 0.05$) in eggs from the Hybrid genotype (9.93%). Among the native breeds, the Amarela produced eggs with a lower ($P < 0.05$) shell percentage than the Preta (Table 1). Shell color was lighter in the Branca breed eggs and darker in the Hybrid eggs ($P < 0.05$). It was found that the egg SI in the Hybrid genotype was 79.86% and was higher ($P < 0.05$) than that of the remaining groups of eggs, with no differences between the native breeds (Table 1).

Albumen pH was higher ($P < 0.05$) in the Hybrid eggs (9.36), with the Preta eggs having a lower ($P < 0.05$) pH (9.13) than the Amarela eggs (9.24). Conversely, yolk pH was lower ($P < 0.05$) in eggs from the Hybrid hens (6.09) than that in the remaining groups (Table 1). Yolk color was markedly lighter ($P < 0.05$) in eggs from all the native breeds than that in eggs from the Hybrid genotype (Table 1). No differences were found in the percentage of albumen protein among eggs from the different indigenous breeds, which varied between 10.54 and 10.63. The viscosity of the thick and thin albumen was not different among groups (Table 1). The viscosity of the thick albumen ranged from 43.58 to 47.45 cpo and of the thin albumen from 23.38 to 24.78 cpo.

No differences were found in the probability of occurrence of blood spots in the yolk and meat spots in the albumen of eggs from the different groups (Table 2).

Table 1. Effect of breed on the quality characteristics of eggs.

	Genotype/Breed[1]					Significance	
Egg characteristics	Hybrid	Amarela	Branca	Pedrês	Preta	RSD	P(F)
Egg components							
Whole egg (g)	59.37[a]	52.32[b]	58.08[a]	52.34[b]	54.84[b]	6.764	<0.001
Yolk (%)	25.17[c]	34.35[a]	32.46[b]	33.01[a,b]	33.26[a,b]	3.262	<0.001
Albumen (%)	64.90[a]	56.71[b]	58.34[b]	57.72[b]	57.39[b]	3.389	<0.001
Shell (%)	9.93[a]	8.99[c]	9.33[b,c]	9.25[b,c]	9.42[b]	0.914	<0.001
Shell color	5.33[a]	2.24[b]	1.69[c]	2.49[b]	2.36[b]	0.912	<0.001
Shape index (%)	79.86[a]	73.44[b]	73.95[b]	74.11[b]	73.72[b]	4.499	<0.001
Albumen pH	9.36[a]	9.24[b]	9.14[b,c]	9.18[b,c]	9.13[c]	0.238	<0.001
Yolk pH	6.09[b]	6.34[a]	6.28[a]	6.35[a]	6.31[a]	0.219	<0.001
Haugh units	66.48[b]	73.99[a]	70.51[b]	74.37[a]	74.63[a]	11.985	0.018
Yolk color	13.33[a]	9.08[b]	8.82[b]	8.64[b]	9.55[b]	3.040	<0.001
Albumen protein (%)	10.54[2]	10.56	10.57	10.63	10.54	0.134	0.473
Albumen viscosity (mPa.s)							
Thick albumen	47.45	45.19	44.00	44.89	43.58	7.686	0.282
Thin albumen	24.78	24.06	23.38	23.62	23.74	6.581	0.905

[a-c]Means with no common superscripts are different ($P < 0.05$).
Abbreviations: RSD, residual standard deviation.
[1]Eggs from commercial hybrid genotype (n = 24) and Amarela (n = 67), Branca (n = 67), Pedrês Portuguesa (n = 61), and Preta Lusitânica (n = 67) breeds.
[2]Data of hybrid eggs not used in statistical analysis.

However, eggs from the hybrid breed had markedly less meat spots (4.17%) than eggs from the other breeds (ranging between 31.3 and 18.8%). The results also show that there were no differences in the probability of occurrence of shell cracks between groups, although almost 7% of eggs from the Branca breed presented cracks while only less than 1.54% of eggs from the remaining breeds had cracks (Table 2).

Fatty Acid Composition and Ash and Mineral Content

Amarela and Preta breeds produced eggs with a lower ($P < 0.05$) level of palmitic acid (16:0) than the Branca breed eggs (Table 3). The range of saturated fatty acids (SFA), monounsaturated fatty acids, and total polyunsaturated fatty acids (**PUFA**) between groups of eggs were small and not significantly different (Table 3). Oleic acid (18:1 *cis*-9), palmitic acid (16:0), and linoleic acid (18:2 n-6) were the most abundant fatty acids in all groups of eggs, comprising about 80% of total fatty acids (Table 3).

Total fatty acid and nutritionally relevant fatty acids and sums expressed in mg per yolk are presented in Table 4. Yolk of eggs from native breed supplied from 4.7 g to 5.3 g of fatty acids, and no significant differences were detected among breeds. Each yolk/egg from the native breeds contained about 2.0 to 2.3 g of 18:1 *cis*-9, 108 to 118 mg of 20:4n-6, and 46 to 52 mg of docosahexaenoic acid (**DHA**). Although not statistically contrasted with native breeds, eggs from Hybrid hens presented numeric lower content of total fatty acid, monounsaturated fatty acid, and SFA.

Among the minerals analyzed, potassium and sodium were prevalent in the albumen of all native breeds of chickens (Table 5). As expected, the yolk presented a higher mineral content than the albumen, with calcium, phosphorus, potassium, and sodium being more prevalent in the yolk in all groups of eggs (Table 5). No differences were found in the albumen and yolk ash content among native breeds. Even though mean comparison to the Hybrid genotype was not performed, a markedly lower absolute value was found for ash content in these breeds than that in the indigenous breeds.

Phosphorus level was higher ($P < 0.05$) in the albumen of eggs from the Pedrês breed than that in the remaining native breeds (Table 5). In relation to the yolk, results demonstrate that eggs from the Preta breed had noticeably higher ($P < 0.05$) levels of calcium than eggs from the Amarela and Pedrês breeds (Table 5).

DISCUSSION

Physical Characteristics, pH, and Protein Content

In the present study, the comparison between eggs from local breeds under small family farm practices and

Table 2. Percentage of eggs with blood spots, meat spots, and shell cracks.

	Genotype/breed[1]					Significance	
Egg defects	Hybrid	Amarela	Branca	Pedrês	Preta	Chi-square	P(F)
Blood spots	12.50	15.63	8.20	20.90	23.88	6.270	0.099
Meat spots	4.17	18.75	22.95	23.88	31.34	2.943	0.401
Shell cracks	0.00	1.54	6.78	0.00	1.49	7.130	0.068

[1]Eggs from commercial hybrid genotype (n = 24) and Amarela (n = 67), Branca (n = 67), Pedrês Portuguesa (n = 61), and Preta Lusitânica (n = 67) breeds.

Table 3. Effect of breed on the fatty acid composition (g/100 g of fatty acids) and fatty acid content (mg/g yolk DM) of eggs.

	Genotype/breed[1]					Significance	
Fatty acid	Hybrid[2]	Amarela	Branca	Pedrês	Preta	RSD	*P*(F)
14:0	0.28	0.30	0.32	0.33	0.31	0.008	0.554
14:1 *cis*-9	0.06	0.05	0.06	0.06	0.05	0.004	0.460
15:0	0.07	0.05	0.05	0.06	0.06	0.003	0.825
16:0	24.3	24.2[b]	25.3[a]	24.8[a,b]	24.1[b]	0.17	0.044
16:1 *cis*-9	3.30	3.17	3.35	3.26	3.16	0.071	0.766
17:0	0.19	0.19	0.18	0.19	0.21	0.006	0.424
17:1 *cis*-9	0.16	0.15	0.12	0.15	0.14	0.005	0.212
18:0	7.97	9.27	9.10	9.38	9.18	0.135	0.914
18:1 *cis*-9	39.6	45.1	42.9	43.2	43.9	0.43	0.287
18:2 n-6	18.7	12.4	13.5	13.2	13.4	0.43	0.837
18:3 n-3	0.61	0.39	0.39	0.40	0.43	0.032	0.882
20:0	0.03	0.04	0.03	0.03	0.03	0.002	0.795
20:2 n-6	0.22	0.13	0.15	0.13	0.13	0.006	0.676
20:3 n-6	0.19	0.20	0.22	0.22	0.21	0.010	0.924
20:4 n-6	2.12	2.20	2.12	2.29	2.38	0.050	0.297
20:5 n-3	0.00	0.01	0.01	0.01	0.01	0.003	0.986
22:4 n-6	0.23	0.27	0.28	0.28	0.32	0.013	0.489
22:5 n-6	0.73	0.53	0.72	0.57	0.65	0.031	0.122
22:5 n-3	0.16	0.19	0.17	0.20	0.20	0.014	0.830
22:6 n-3	0.92	0.91	0.90	1.04	1.05	0.048	0.574
Sums							
SFA	32.8	34.0	35.0	34.8	33.9	0.20	0.141
MUFA	43.4	48.7	46.7	46.9	47.4	0.45	0.378
n-6 PUFA	22.2	15.8	17.0	16.7	17.1	0.42	0.711
n-3 PUFA	1.53	1.31	1.26	1.45	1.48	0.071	0.658
Total PUFA	23.8	17.3	18.4	18.3	18.7	0.43	0.662
FA content	560	546	528	532	532	3.0	0.201

[a,b]Means with no common superscripts are different ($P < 0.05$).

Abbreviations: FA, fatty acid content (mg/g yolk DM); MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; RSD, residual standard deviation; SFA, saturated fatty acids.

[1]Eggs from Amarela (n = 10), Branca (n = 9), Pedrês Portuguesa (n = 10), and Preta Lusitânica (n = 10) breeds.

[2]Eggs from commercial hybrid hens, data not used in the statistical analysis (n = 1).

commercial eggs from intensive production is purely indicative because the majority of genetic and environmental factors affecting egg characteristics were not taken into account. The proportion of egg components at ovoposition is affected by hen strain and age (Zita et al., 2009). As the hen ages, the percentage of yolk increases and albumen decreases (Van Den Brand et al., 2004; Zita et al., 2009). Egg component yields may have

Table 4. Effect of breed on the fatty acid content (mg/yolk) of eggs.

	Genotype/breed[1]					Significance	
Fatty acid	Hybrid[2]	Amarela	Branca	Pedrês	Preta	RSD	*P*(F)
SFA							
16:0	997	1,241	1,336	1,172	1,205	159	0.124
18:0	327	474	484	441	457	64.4	0.167
Total	1,347	1,745	1,852	1,642	1,692	211	0.103
MUFA							
16:1 *cis*-9	135	163	177	154	158	31.8	0.478
18:1 *cis*-9	1,627	2,320	2,289	2,050	2,201	367	0.248
Total	1,783	2,506	2,489	2,225	2,380	392	0.254
n-6 PUFA							
18:2 n-6	767	639	709	627	668	155	0.729
20:4 n-6	87	112	113	108	118	18.1	0.469
Total	910	810	894	791	851	165	0.666
n-3 PUFA							
18:3 n-3	25	19	18	19	21	9.9	0.937
22:6 n-3	38	46	46	49	52	12.5	0.658
Total	69	75	73	78	84	22.1	0.741
Total PUFA	979	885	967	869	935	164	0.676
Total FA	4,110	5,136	5,308	4,736	5,007	680	0.266

Abbreviations: MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; RSD, residual standard deviation; SFA, saturated fatty acids.

[1]Eggs from Amarela (n = 10), Branca (n = 9), Pedrês Portuguesa (n = 10), and Preta Lusitânica (n = 10) breeds.

[2]Eggs from commercial hybrid hens, data not used in the statistical analysis (n = 1).

Table 5. Effect of breed on the mineral and ash content (mg/100 g of albumen and mg/100 g of yolk) of the albumen and yolk of eggs.

	Genotype/breed[1]					Significance	
Mineral	Hybrid[2]	Amarela	Branca	Pedrês	Preta	RSD	*P(F)*
Albumen							
Sodium	158	166	144	159	163	3.8	0.189
Potassium	71	111	88	110	96	3.6	0.069
Phosphorus	6.2	9.6[b]	10.7[b]	14.2[a]	10.2[b]	0.59	0.017
Magnesium	6.7	6.8	6.9	8.0	7.5	0.25	0.297
Calcium	0.62	0.00	0.35	0.03	0.16	0.069	0.308
Copper	0.53	0.63	0.56	0.76	0.72	0.055	0.618
Iron	0.40	1.36	0.41	0.52	0.37	0.202	0.257
Zinc	0.14	0.38	0.32	0.42	0.41	0.031	0.706
Manganese	0.00	0.002	0.013	0.011	0.003	0.002	0.070
Ash	490	497	526	517	518	13.6	0.909
Yolk							
Sodium	43	53	56	53	68	2.4	0.080
Potassium	106	135	142	137	147	4.5	0.797
Phosphorus	530	474	448	454	430	7.0	0.173
Magnesium	6.8	9.8	8.9	9.0	10.2	0.40	0.609
Calcium	65	55[b]	69[a,b]	59[b]	79[a]	3.4	0.043
Copper	0.50	0.66	0.49	0.44	0.35	0.042	0.066
Iron	4.7	5.0	6.3	6.1	4.8	0.28	0.118
Zinc	2.2	2.6	2.6	2.5	2.2	0.09	0.207
Manganese	0.00	0.03	0.21	0.02	0.02	0.033	0.121
Ash	684	813	773	835	806	18.3	0.701

[a,b]Means with no common superscripts are different ($P < 0.05$).

Abbreviations: RSD, residual standard deviation.

[1]Eggs from Amarela (n = 10), Branca (n = 9), Pedrês Portuguesa (n = 10), and Preta Lusitânica (n = 10) breeds.

[2]Eggs from commercial hybrid hens, data not used in the statistical analysis (n = 1).

little importance to the consumer, but they are significant to the egg-processing industry, with yolk having a higher market value. In the present study, eggs from Hybrid hens presented a higher albumen and lower yolk percentage relative to the whole egg than native hens. This difference may have been attributable to the hen's genotype, with the native breeds having a higher percentage of yolk. Interestingly, in other studies conducted with purebred and hybrid chickens, the percentage of albumen was also consistently higher in commercial hybrids (Rizzi and Marangon, 2012).

Shell failures represent an important economic concern for the egg industry, and thus, egg cracks should be minimized. When analyzing eggs from different weight categories, it has been reported that shell percentage is lowest in larger eggs (Casiraghi et al., 2005; Hidalgo et al., 2008). In the present study, however, a higher percentage of egg shell was found in the Hybrid group that also produced a larger egg. Conversely, the Amarela breed that produced some of the lightest eggs, also produced eggs with some of the lowest shell percentages. This may indicate that the inverse relationship between shell percentage and egg weight only holds true within the same breed of chicken, with genetics playing a significant role affecting eggshell characteristics. Nevertheless, in the present study, the prevalence of shell precracks only tended to be higher in eggs from the Amarela breed than that in other breeds. The appearance of shell cracks is a result of the combination of shell content, thickness, shell strength and integrity, and the extent of the trauma received by the egg during handling (Hunton, 2005).

Shell color is not an indicator of the nutritive value or the quality of the egg. However, many consumers who prefer brown eggs, also pay attention to the intensity and consistency of the colors of the shells in the egg cartons (Cavero et al., 2012). As the heritability of eggshell color is relatively high (Zhang et al., 2005), commercial brown-egg lines have been selected for darker brown shells for many years. Differences found in eggshell color in the present study may have been due to differences in breed. The considerable lighter color of eggshells laid by the native breeds, in particular, the Branca breed, may have been because of their differentiated genetic background. The darker eggshell found in the Hybrid breed is probably a consequence of intensive breeding for that characteristic.

A normal shaped egg has an SI between 72 and 76. An SI below 72 indicates a too sharp egg shape and above 76 is too round (Sarica and Erensayin, 2004). In the present study, native breeds presented eggs with an SI between the normal range. However, eggs originated from the commercial Hybrid group were rounder than the normal ones. Despite the fact that round and unusually long eggs have poor appearance and they do not fit properly in preformed packaging, Altuntas and Sekeroglu (2008) found that greater force was required to rupture eggs with high SI values while being tested using a low compression speed. This may explain why, in the present study, larger egg shell percentages were found in rounder eggs.

It has been shown that albumen pH is determined almost entirely by storage time, and that is a reliable predictor of egg quality and freshness (Silversides and

Scott, 2001). As the egg ages, it loses water and carbon dioxide, which leads to an increase in albumen pH. Although eggs analyzed in the present study had the same age and were stored under the same conditions, it was found that albumen pH was higher in eggs from the Hybrid breed and that the Preta breed had a lower albumen pH than the Amarela breed. This may indicate that factors other than storage time and condition may influence the pH of the albumen. It has been reported that albumen pH may decrease with layer age (Lapão et al., 1999; Silversides and Scott, 2001). However, according to our results, genetic background may also largely influence the albumen pH.

Other than the pH, the egg industry also measures HU as a way of assessing egg quality by adjusting the height of the albumen with the weight of the egg in a logarithmic scale—a higher HU indicates a better internal egg quality (Haugh, 1937). There are many factors such as age and strain or breed of the hen as well as time of storage and storage conditions, dietary ingredients, and possible disease which affect HU values (Williams, 1992; Roberts, 2004). In this study, it was found that hens from both Branca and Hybrid breeds produced eggs with lower HU values, indicating that most of the native Portuguese breeds (Amarela, Pedrês, and Preta) have in fact a better internal quality than a commercial Hybrid breed.

A darker yolk color is highly preferred by European consumers and is largely affected by feed, mainly by the presence of xanthophyll carotenoids (luthein and zeaxanthin), derived from plant material (Whiting et al., 2019). In the present study, eggs from the Hybrid group contained a darker yolk color. Yolk color was markedly lighter in eggs laid by native chicken breeds, which is consistent with previously reported results (Lordelo et al., 2017). Local breeds in Portugal are mostly raised in free-range systems with less access to high-quality feeds in comparison to Hybrids in commercial poultry operations, which may have explained the lighter yolks in eggs laid by native breeds. Even though hens in a free-range system may have access to feedstuffs rich in carotenoid pigments such as grass and herbs, the quality of the range is not always consistent and may not be available throughout the year. It is clear that chickens from a commercial hybrid breed produce eggs with many characteristics that have some degree of heritability and are used in conventional breeding practices such as, higher percentage of shell, darker yolk colors, and less meat spots. These are traits that do not influence the nutritional quality of the egg but are important to the consumer.

It is well established that the protein content of the egg is highly influenced by the diet of the hen (Wang et al., 2017). Although most likely the chickens that laid the eggs for this study had access to very different feeds, no differences were found in the protein content of the albumen between eggs laid by the different breeds of chickens.

There is little or no information concerning the factors that affect albumen viscosity. However, this can be an important property as it is related to the whipping, emulsifying, and gelling properties of the albumen (Kemps et al., 2010). As expected, in this study, the viscosity of the thick albumen was consistently higher than the viscosity of the thin albumen, but no differences were found in the thick and thin albumen viscosity between eggs from different breeds.

In the present study, there was a lower percentage of meat spots in eggs originated from the Hybrid breed in relation to eggs from native breeds. The incidence of meat and blood spots in eggs depends on several factors such as nutrition, environment, and genetics (Becker and Bearse, 1973; Campo and Garcia, 1998). When the supply of vitamin A is insufficient or when the hen is under environmental stresses, such as sudden loud noises, temperature changes, and infections, there is a higher probability of the hen producing eggs with blood spots (Becker and Bearse, 1973; Deaton et al., 1986), although in the present study, the incidence of blood spots was not different among breeds. However, in conventional breeding programs, families with a higher incidence of meat and blood spots are eliminated. Therefore, it would be expected that native chickens, that were not submitted to a selection program, under a free-range system, such as the ones used in this study, produced eggs with a higher prevalence of spots.

Fatty Acid Composition and Mineral Content

Diet is the main single determinant of fatty acid composition of yolk (Goldberg et al., 2013), nevertheless the diet fed to layer hens in Portugal small-scale farms are not expected to differ widely. No relevant breed effect on fatty acid composition of yolk lipid was detected as the fatty acid profile was notably constant among the eggs from native breeds. The single exception was the slightly but significantly relative abundance (% of total fatty acids) of palmitic acid (16:0) in Branca eggs compared with palmitic acid content in Amarela and Preta eggs. The 16:0 is the major SFA and is considered hypercholesterolemic (FAO, 2010), but the 1% point difference detected here does not seem relevant as the amount of 16:0 supplied per yolk ($\approx$1.24 g/yolk) did not differ significantly among native breeds.

In general, the fatty acid profile reported here is similar to that reported earlier for eggs from native breeds (Simcic et al., 2011; Lordelo et al., 2017) with little or no differences between egg origins. Unless the hen diet is specially modified to guarantee a special fatty acid profile, it seems like neither production system nor breed will affect this characteristic to a great extent (Lordelo et al., 2017). Eggs are particularly interesting as a dietary source of long-chain PUFA, in particular DHA (22:6n-3) and arachidonic acid (20:4n-6). Each egg from native breed hens supplied circa 48 mg of 22:6n-3, 9.3 mg of 22:5n-3, and only 0.5 mg of 20:5n-3. The very low content of 20:5n-3 found in eggs is an indicator

that the conversion of 18:3n-3 to 22:6n-3 is particularly efficient in the liver of hens (Fraeye et al., 2012; Lordelo et al., 2017). Nevertheless, each egg provides about 20% of daily recommend intake of n-3 long-chain PUFA for adults.

The mineral composition of a chicken egg is influenced by the quality of the feed, the production system, and genetics (Kücükyilmaz et al. 2012). These factors may explain the few differences found in macroelement content among the native breeds in this study, such as the Pedrês producing eggs with higher phosphorus content in the albumen and the Preta producing eggs with a higher calcium content in the yolk. Interestingly, and even though eggs from the Hybrid breed were not used for mean comparison, they indicate that ash content, especially in the yolk, can be lower than that in the native breeds. Egg production rate may have played a role here because selected commercial hybrids have a much higher egg production rate than indigenous dual-purpose breeds; the requirements for an adequate mineral deposition in the egg may also be higher. Kiczorowska et al. (2015) also stated that eggs from the production systems allowing chickens to use free ranges, such as the Portuguese native breeds, were the richest in nutrients, specifically minerals, because it allows hens to supplement their usual dietary ration, which may contribute to a significant increase in the content of macroelements and microelements.

CONCLUSION

Among the 4 Portuguese native breeds that were studied, all of them had a better egg shape than the hybrid. In addition, the Amarela, Pedrês, and Preta breeds had better internal quality than the Branca and Hybrid breeds. The Amarela, in turn, had less percentage of shell and more prevalence of shell cracks. No differences were found in albumen protein and ash content between eggs from the different breeds. Palmitic acid was the only fatty acid present at different levels among groups of eggs. According to the present results, the overall physical and chemical analyses indicated that eggs from these native breeds, especially the Pedrês and Preta, match or supersede the quality of a commercial product in many characteristics. Within specialized market niches where this type of eggs is available, consumers are purchasing a high-quality product while investing in local farmers and maintaining biodiversity. Incentives from local governments to promote and market these products could be an important measure to inform the consumers.

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