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A market study on the quality characteristics of eggs from different housing systems

A. Hidalgo *, M. Rossi, F. Clerici, S. Ratti

Dipartimento di Scienze e Tecnologie Alimentari e Microbiologiche (DISTAM), Università degli Studi di Milano, via Celoria 2, 20133 Milano, Italy

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Abstract

To study the differences among commercial eggs from four housing systems i.e. cage, barn, free range and organic, 41 physical and chemical parameters were evaluated on 28 fresh egg samples from the Italian market. The univariate statistic analysis evidenced that organic eggs had the highest whipping capacity and foam consistency but the lowest freshness (the highest air cell height) and albumen quality (the lowest Haugh Unit); cage eggs presented instead the lowest whipping capacity and the highest shell resistance to breaking. The multivariate technique discriminant partial least-squares regression was unable to correctly classify the eggs from the four housing systems but successfully differentiated cage eggs from alternative (organic + barn + free range) eggs. The variables with the most discriminant power were shell breaking resistance, overrun, protein content, and shell thickness.

Keywords: Discriminant partial least-squares regression; Egg quality; Functional property; Housing system; Shell breaking resistance

1. Introduction

The most recent European Union (EU) legislative additions concerning commercial egg production underline the importance of housing systems. The introduction of the European Council Directive 1999/74/CE (EU, 1999a) set the minimum standards for the welfare protection of laying hens in cage, barn and free range housing systems. Regulation 1804/1999/CE (EU, 1999b) outlined organic production methods for animal origin products and Regulation 2295/2003 (EU, 2003) mandated that the housing system must be designated on the box and on the egg shell. The codes to be used are 0 for organic production, 1 for free range, 2 for barn, and 3 for cage systems.

Considering the cage system, starting from 2012, only eggs from hens housed in the so-called enriched cages (EU, 1999a), that is, those with at least 750 cm^2 of available space for hen, nest, litter and perches, will be allowed. Nevertheless the enriched cage system is not, at present, commonly implemented commercially. During the transition period, instead, the production of eggs from alternative systems (free range, barn, and organic) has been implemented. As a consequence, the consumers face a broad range of products at very different prices but without any real information about the specific qualities of alternative eggs *vs* cage eggs.

Several studies were done in order to evaluate the effect of housing systems on shell egg characteristics at farms (Hauser & Fölsch, 2002; Leyendecker et al., 2001a, 2001b; Sauveur, 1991; Van Den Brand, Parmentier, & Kemp, 2004) but distribution, retailing practices and product turnover, not directly related to the housing system, may play a major role on egg quality. Some studies on egg quality evaluation in the market were carried out in the USA, where housing systems differ from those established in Europe. Cherian, Holsonbake, and Goeger (2002) compared the fatty acid composition of conventional eggs to five commercial brands of specialty eggs in the USA and found no clear influence of housing system

* Corresponding author. Tel.: +39 02 50319189; fax: +39 02 50319190.
E-mail address: alyssa.hidalgovidal@unimi.it (A. Hidalgo).

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on lipid composition. A USA study on the quality of supermarket-purchased eggs (Patterson et al., 2001) showed that specialty eggs (nutritional altered eggs, organic eggs, fertile eggs, eggs from welfare-managed hens, or hens fed all vegetable diets) were on average older, based on carton pack date and had a lower albumen height, with lower Haugh Unit (HU) values and a higher proportion of <55 HU eggs. While the proportion of cracks was similar, the proportion of broken eggs was three times higher in specialty *vs* traditional eggs. Within the specialty eggs group, organic eggs had the poorest internal quality. Thus, this study found that specialty eggs were lower in classical egg quality standard measurements (EU, 1999b; USDA, 1995) than conventionally produced eggs. Finally, a recent European study on commercial eggs (Schlatterer & Breithaupt, 2006) evidenced a different xanthophyll composition of organic eggs from free range, barn, and cage eggs.

The aim of this study was to elucidate the differences among commercial eggs from different housing systems (cage, free range, barn, and organic), based on physical and chemical egg features.

2. Materials and methods

2.1. Eggs

Twenty-eight samples of commercial grade A eggs (sizes M or L; EU, 2003) from four different housing systems (cage, free range, barn, and organic) and of different brands were purchased in November–December 2005 in different Northern Italy supermarkets, not later than 17 days before the expiring-date. Each sample consisted of about 40 eggs of the same lot, contained in 4–8 packages. Table 1 reports some characteristics of the samples such as housing system, commercial class weight (EU, 2003) and age of eggs at purchase. Sample codes were assigned as follows: the first two letters correspond to the abbreviation of the housing system (Cg, cage; FR, free range; Ba, barn; Or, organic), the numbers to different commercial brands, the letters at the end of the code distinguish repeated samples of the same brand. At the arrival in the laboratory, the eggs were kept at 5 °C and analysed within 48 h from purchase.

Table 1
Characteristics of commercial shell egg samples

Sample code	Housing system	Weight class	Egg age[a] (days)
Cg-1a	Cage	M	8
Cg-2	Cage	M	7
Cg-3	Cage	M	8
Cg-4	Cage	M	11
Cg-5	Cage	M	11
Cg-6	Cage	M	9
Cg-7	Cage	M	7
Cg-1b	Cage	L	9
Cg-8	Cage	L	10
Cg-9	Cage	L	9
FR-10a	Free range	L[b]	5
FR-10b	Free range	L[b]	6
FR-11	Free range	M	6
FR-12	Free range	L	7
FR-13	Free range	L[b]	4
FR-14	Free range	L[b]	3
Ba-1	Barn	M[b]	11
Ba-15	Barn	M	5
Ba-11	Barn	M[b]	9
Ba-16	Barn	L	3
Ba-14	Barn	M[b]	4
Ba-9	Barn	M[b]	4
Or-1	Organic	L[b]	9
Or-17	Organic	L[b]	3
Or-11	Organic	L[b]	4
Or-16	Organic	L[b]	8
Or-12	Organic	M[b]	3
Or-18	Organic	L[b]	7

M: ⩾53 and <63 g; L: ⩾63 and <73 g.
[a] Calculated on the basis of the "best before" date reported on packages.
[b] Sold as packs of different egg sizes (EU, 2003).

2.2. Sample preparation

Chemical analyses were performed twice on two pools of yolk or whole egg, each obtained from 6–10 eggs randomly taken from the various packages. The shelling of the eggs and the separation of yolk from albumen were made manually. For yolk sample preparation, each yolk was freed from albumen residues rolling it on a blotting paper and the vitelline membrane was removed using a spatula. Yolk and whole egg were mixed at 2500–3000 rpm for 30 s using a Sörvall Omni Mixer (Dupont de Nemours & Co., Newton, CO). Whipping properties were measured twice on two other pools of whole eggs (6–10 eggs each), mixed at milder conditions (2500 rpm per 10 s), in order to prevent foam formation before analysis.

For shell characteristics evaluation, intact eggs were selected by candling and the surface cleaned using blotting paper.

2.3. Analytical methods

2.3.1. Analysis on individual eggs

All eggs were individually weighed. To determine the percentage of cracked eggs, all eggs were observed by candling. Albumen, yolk and shell percentages on total egg weight were determined on six eggs per sample by weighing both the yolk, with intact vitelline membrane freed from any albumen residue and the cleaned and dried shell (including cuticle and membranes). Albumen weight was calculated by difference. The percentage of eggs bearing blood or meat spots was calculated by visual inspection of all shelled eggs.

Air cell height (mm) was determined on six eggs per sample using a homemade graduated measuring card, as described by Sauveur and de Reviers (1988). Albumen height was measured on six eggs at 12 °C using the QCD System (Technical Services and Supplies, York, England). Based on albumen height, Haugh Units were estimated following the equation proposed by Haugh (Stadelman,

1995). Yolk colour was evaluated on six individual yolks by comparison with the Roche fan (DSM, 2005-HMB, 51548, Switzerland).

All egg shell parameters were measured at room temperature on 14 intact and cleaned shell eggs per sample. Eggs were first submitted to non-destructive and then to destructive analyses. The surface area (SA, cm^2) of each egg was evaluated using the equation reported by Thomson, Hamilton, and Grunder (1985): $SA = 4.67\ (\text{egg weight})^{2/3}$. The shape index (SI, %) was calculated using the equation proposed by Khalafalla and Bessei (1995): SI = 100 × equator diameter/egg height. The equator diameter and egg height (cm) of each egg were measured using a manual calliper. Shell index (SI, g/cm^2) was calculated using the equation proposed by Rodriguez-Navarro, Kalin, Nys, and Garcia-Ruiz (2002): SI = shell weight/(equator diameter × egg height). Shell thickness, including cuticle and membrane thickness, was measured at the equator using a 550–501 digital micrometer (NSK, Japan). Shell breaking strength (N) was measured using an Instron Universal Testing Machine (Instron Ltd., High Wycombe, England) supported by a series IX Automated Material Testing System software. Compression and penetration tests were each carried out on seven individual eggs per sample, at the constant cross-head speed of 20 mm/min using a 100 N load cell. A 35 mm diameter plate was used as a compression device, while a 8 mm diameter probe was used as the penetration element. Strength (N), displacement (mm) and energy (N mm) at breaking point were determined by both compression and penetration tests. By the penetration test, the slope of force/deformation curve (N/mm) and the Young modulus (N/mm^2) (i.e. the slope of the stress/deformation curve), indicating shell strength at small deformations, were also determined.

2.3.2. Analysis on pooled eggs

Whole egg pH was detected potentiometrically on pooled samples using a PHM62 Standard pH meter (Radiometer Analytical A/S, Copenhagen, Denmark). Whole egg dry matter (g/100 g) was assessed following the AOAC method no. 925.30 (AOAC, 1995) and the protein content (g/100 g) was calculated as total nitrogen multiplied by the factor 6.25. Total nitrogen analysis was performed using the Kjeldahl AOAC method no. 925.31 (AOAC, 1995). Whole egg whipping capacity was measured using the Cream tester CT II (Gerber Instruments, Effretikon, Switzerland). The instrument consists of two wire whipping elements rotating in a stainless steel cylindric vessel, equipped with a purposely manufactured thermostating jacket for temperature control and a display for temperature and for electric current absorbed (mA) by the motor. The 50 mL whole egg samples were weighed, conditioned at 20 °C and poured in the whipping vessel preconditioned at 20 °C. The sample was whipped at 300 rpm (fixed rotation speed of the instrument) for 8 min and the final value of electric current registered. The volume (V) of foam developed was calculated using the following equation: $V = (\pi r^2)h$, where r is the vessel radius (3.72 cm) and h is the average foam height (cm) measured at four different points using a graduated dipstick. The whipping capacity was calculated as overrun (%) expressing the percent volume increase as follows: $\text{Overrun}\ (\%) = \frac{V - V_o}{V_o} 100$, where V_o is the whole egg sample volume. The registered electric current value was taken as an index of foam consistency.

Yolk pigments were determined on acetone extracts, following the AOAC method no. 958.05 (AOAC, 1995) using a UVIDEC-610 spectrophotometer (Japan Spectroscopic Co., Ltd., Tokyo, Japan) set at 450 nm. The results are expressed as β-carotene equivalents (μg β-carotene eq./g), calculated by comparison with a calibration curve prepared with eight β-carotene (code C-4582, Sigma Chem. Co., St. Louis, MO) acetone solutions, in the concentration range 0–6 μg/mL. Yolk total lipids (g/100 g) were measured gravimetrically after Soxhlet extraction for 5 h, using chloroform as the solvent and solvent evaporation under vacuum in a rotary apparatus. Lipid extraction was performed as follows: 3 g yolk were placed in a porcelain evaporating dish and mixed with 3 g quartz and 20 g anhydrous sodium sulphate. The mix was dried overnight in a vacuum oven at 60 °C (pressure < 5 mmHg) and then finely pestled and transferred for extraction into a Whatman cellulose thimble (Whatman International Ltd., Maidstone, England). Fatty acid composition was determined by gas chromatography of fatty acid methyl esters (FAMEs) prepared as follows: 0.5 g fat extracted as described above was weighed in a 25 mL conical flask. To this a methylation mix made of methanol (code 6007, Merck, KGaA, Darmstadt, Germany), hexane (code 4391, Merck, KGaA, Darmstadt, Germany) and sulphuric acid (code 731, Merck, KGaA, Darmstadt, Germany) (75:25:1 by volume) was added, and the conical flask mounting a 80 cm long condensing tube was maintained for 2.5 h in a heating bath (90 °C) to perform the methylation. The methylated mix was then transferred into a separatory funnel and extracted with 40 mL extra pure diethyl ether (code 921, Merck, KGaA, Darmstadt, Germany) plus 40 mL water. After separation, the ether extract was three fold washed with 40 mL water and filtered through anhydrous sodium sulphate. Gas chromatographic analysis of FAMEs was performed as described by Rossi, Alamprese, and Ratti (2007).

2.3.3. Statistical analysis

Analysis of variance (ANOVA) or analysis of covariance (ANCOVA) considering housing system and replicates, as factors and egg age or egg weight as covariate, were performed using the Statgraphics Plus software (version 4.0, StatPoint Inc., Herndon, VA, USA). In ANCOVA, when significant covariate effect was detected, multiple comparisons of ANCOVA-adjusted treatment means were performed applying Fisher's least significant difference (LSD) test (at $p < 0.05$) using the Statgraphics Plus software. The variables with non-significant ($p > 0.05$) covariate effect in ANCOVA, were submitted to the

ANOVA and LSD test, when significant differences were found. Discriminant partial least-squares regression (DPLS) analysis (Cozzolino, Smyth, & Gishen, 2003; Esbensen, 2002; Lee, Paterson, Piggott, & Richardson, 2001; Martens & Martens, 2001; Næs, Isaksson, Fearn, & Davies, 2002) was performed to investigate group patterns within samples using the software package The Unscrambler version 9.2 (CAMO a/s, Trondheim, Norway). Full cross-validation (i.e. leave-one-out) was used to develop and evaluate the regression model. The optimum number of calibration factors for each model was selected on the basis of the predicted residual error sum of squares (PRESS). A DPLS2 model was first developed with the 41 variables analysed, by regression of the analytical data (*X*-matrix) against the four housing system categories, assigning dummy variables by splitting the category variable (*Y*-matrix): 0 or 1 were attributed as reference values and the cutoff value considered was 0.5. A sample belonged to a particular group if its predicted value was above 0.5 and to another group if the value was below 0.5. The model was then recalculated with the variables selected by the Martens uncertainty test (Esbensen, 2002). A DPLS1 was also developed to test the ability of the method to discriminate between cage and alternative eggs, considered as a single group. The model was initially developed using the 41 variables and then using the variables selected by the Martens uncertainty test (Esbensen, 2002). Statistics calculated for calibrations and predictions included the correlation coefficient and the root mean square error (RMSE).

3. Results and discussion

Some characteristics of the egg samples are reported in Table 1. Ten samples out of 28 are from the cage system, while only six samples from each of the alternative systems (free range, barn, and organic) were available for purchase. In fact in Italy and Europe, alternative eggs still represent only 4 and 12%, respectively, of the market share (European Commission, 2004). Moreover, while all egg weight classes (S, M, L, and XL) were available for cage eggs, alternative systems were commonly found to have packs with eggs of different sizes (EU, 2003). In Table 1, the weight class of alternative egg samples was attributed on the basis of the average weight. Only egg samples of M and L class were considered in this study. The average ± standard deviation egg age at purchase (based on the minimum durability date stated on package) was 8.9 ± 1.5 days for cage, 5.2 ± 1.5 days for free range, 6.0 ± 3.2 days for barn, and 5.7 ± 2.7 days for organic egg samples.

Mean relative fatty acid composition for each housing system is reported in Table 2. Oleic (C18:1*n*9, 33–36%), palmitic (C16:0, 25–26%), and linoleic (C18:2*n*6, 17–20%) acids were the major fatty acids, followed by stearic acid (C18:0, 8–10%), similarly to the values previously reported for eggs by Privett, Blank, and Schmit (1962), Nielsen (2001) and Cherian et al. (2002), but lower than the percentages reported by Privett et al. (1962) for stearic acid (14–16.5%) and by Cherian et al. (2002) for oleic acid in cage (42.6%) and organic (43.5%) commercial eggs. These differences are justified by the known influence of hen feed formulation on fatty acid composition of egg yolk (Milinsk, Murakami, Gomes, Matsushita, & de Souza, 2003; Szymczyk & Pisulewski, 2003). In any case, information about feed formulation is not usually reported on the packs of commercial eggs. Among long chain polyunsaturated fatty acids (PUFA), arachidonic (C20:4*n*6) and docosahexaenoic (DHA, C22:6*n*3) acids were the most abundant, while eicosapentaenoic acid (C20:5*n*3) was not detected. Similarly, Farrell (1994) reported DHA as the main *n*3 fatty acid of yolk lipids.

Table 2
Fatty acid composition (%) in commercial egg samples from different housing systems (mean ± standard error)

Fatty acid	Housing system			
	Cage $n = 10$	Free range $n = 6$	Barn $n = 6$	Organic $n = 6$
C14:0	0.38 ± 0.03	0.43 ± 0.03	0.42 ± 0.02	0.44 ± 0.02
C14:1*n*5	0.06 ± 0.01	0.08 ± 0.01	0.08 ± 0.01	0.09 ± 0.01
C15:0	0.07 ± 0.00	0.08 ± 0.01	0.09 ± 0.01	0.08 ± 0.00
C16:0	25.0 ± 0.61	25.4 ± 0.63	26.3 ± 0.38	25.7 ± 0.50
C16:1*n*9	0.56 ± 0.05	0.72 ± 0.06	0.69 ± 0.03	0.64 ± 0.03
C16:1*n*7	2.63 ± 0.22	2.94 ± 0.34	2.95 ± 0.23	2.77 ± 0.36
C17:0	0.19 ± 0.01	0.20 ± 0.01	0.20 ± 0.02	0.19 ± 0.01
C17:1*n*8	0.17 ± 0.03	0.18 ± 0.02	0.16 ± 0.01	0.14 ± 0.01
C18:0	8.11 ± 0.24	8.22 ± 0.22	8.11 ± 0.23	9.83 ± 1.47
C18:1*n*9*trans*[a]	0.11 ± 0.01	0.13 ± 0.02	0.12 ± 0.02	0.11 ± 0.01
C18:1*n*9	34.0 ± 1.17	36.5 ± 1.37	34.8 ± 0.61	33.1 ± 1.71
C18:1*n*7	2.92 ± 0.14	3.04 ± 0.29	2.86 ± 0.23	2.77 ± 0.39
C18:1*n*3	0.04 ± 0.00	0.04 ± 0.01	0.04 ± 0.00	0.05 ± 0.01
C18:2*n*6	20.1 ± 1.50	17.0 ± 1.71	18.1 ± 0.90	18.6 ± 2.14
C18:3*n*6	0.11 ± 0.01	0.09 ± 0.01	0.10 ± 0.00	0.10 ± 0.01
C18:3*n*3[b]	0.91 ± 0.12	0.70 ± 0.11	0.75 ± 0.08	0.82 ± 0.15
C20:2*n*6	0.17 ± 0.02	0.14 ± 0.02	0.13 ± 0.01	0.14 ± 0.03
C20:3*n*6	0.05 ± 0.00	0.05 ± 0.01	0.05 ± 0.01	0.05 ± 0.01
C22:0	0.16 ± 0.00	0.15 ± 0.01	0.15 ± 0.01	0.14 ± 0.01
C20:4*n*6	2.19 ± 0.09	2.20 ± 0.13	2.20 ± 0.13	2.47 ± 0.23
C22:4*n*6	0.21 ± 0.01	0.21 ± 0.02	0.20 ± 0.02	0.22 ± 0.01
C22:5*n*6	0.63 ± 0.09	0.49 ± 0.07	0.48 ± 0.09	0.56 ± 0.09
C22:5*n*3	0.12 ± 0.02	0.11 ± 0.01	0.10 ± 0.01	0.11 ± 0.02
C22:6*n*3	1.08 ± 0.07	0.99 ± 0.11	0.91 ± 0.05	1.04 ± 0.08

[a] C18:1*n*9*trans* + C18:1*n*7*trans*.
[b] C18:3*n*3 + C20:1*n*11.

In order to compare eggs from different housing systems, an analysis of covariance (ANCOVA) with egg age as covariate was performed on those traits possibly affected by egg age, such as pH, air cell height, albumen height, and HU. ANCOVA was also applied to egg weight, dry matter, proteins, and lipid percentage because of water loss through the shell during egg aging (Thapon, 1994) and to foam consistency and overrun, since functional properties might be influenced by proteins modifications during egg aging (Rossi, Fessas, & Pompei, 2001). Air cell height was the only variable significantly ($p \leqslant 0.05$) influenced by egg age, therefore all the other parameters were submitted to ANOVA, as shown in Table 3.

Table 3
Mean values ± standard error of several egg quality variables and significance levels of the factor housing system (p) in the ANCOVA or ANOVA; different letters after the mean values indicate significant differences at $p \leqslant 0.05$ following LSD test

Variable	Housing system				
	Cage ($n = 10$)	Free range ($n = 6$)	Barn ($n = 6$)	Organic ($n = 6$)	p
ANCOVA					
Air cell height (mm)	3.44b[a]	3.65ab[a]	3.30b[a]	3.80a[a]	*
ANOVA					
Blood spots (%)	9a ± 1.1	3b ± 1.8	8a ± 0.4	11a ± 1.4	**
Meat spots (%)	12 ± 1.8	16 ± 2.6	18 ± 1.2	11 ± 1.9	n.s.
pH whole egg	7.6 ± 0.02	7.5 ± 0.02	7.6 ± 0.02	7.6 ± 0.05	n.s.
Albumen height (mm)	5.3 ± 0.17	5.2 ± 0.44	5.1 ± 0.11	4.7 ± 0.44	n.s.
Haugh Unit	69.2a ± 1.18	66.2a ± 3.61	67.6a ± 1.02	61.0b ± 5.27	**
Dry matter (g/100 g)	23.5 ± 0.14	23.6 ± 0.28	23.7 ± 0.12	23.2 ± 0.14	n.s.
Proteins (g/100 g)	12.1b ± 0.09	12.5a ± 0.20	12.6a ± 0.02	12.5a ± 0.11	*
Lipids (g/100 g)	9.5 ± 0.25	9.4 ± 0.32	9.5 ± 0.09	10.1 ± 0.18	n.s.
Foam consistency (mA)	343c ± 3.0	356ab ± 3.3	348bc ± 3.1	361a ± 3.2	**
Overrun (%)	480c ± 4.0	517ab ± 3.8	513b ± 3.5	530a ± 4.3	***
SFA (%)	33.9b ± 0.56	34.4b ± 0.66	35.3ab ± 0.11	36.4a ± 1.02	*
MUFA (%)	40.5 ± 1.48	43.6 ± 1.86	41.7 ± 0.26	39.6 ± 2.42	n.s.
PUFA (%)	25.5 ± 1.64	22.0 ± 1.92	23.1 ± 0.27	24.0 ± 2.16	n.s.
*n*6 (%)	23.4 ± 1.47	20.2 ± 1.73	21.3 ± 0.25	22.1 ± 1.96	n.s.
*n*3 (%)	2.2 ± 0.20	1.8 ± 0.19	1.8 ± 0.03	1.9 ± 0.22	n.s.
MUFA/SFA	1.2 ± 0.05	1.3 ± 0.06	1.2 ± 0.01	1.1 ± 0.08	n.s.
PUFA/SFA	0.8 ± 0.05	0.6 ± 0.06	0.7 ± 0.01	0.7 ± 0.06	n.s.
*n*6/*n*3	11.2 ± 0.65	11.1 ± 0.57	12.0 ± 0.15	11.5 ± 0.42	n.s.
Linoleic/linolenic	23.7 ± 1.62	26.4 ± 3.49	25.2 ± 0.71	24.4 ± 1.79	n.s.
Yolk pigments (μg β-carotene eq./g)	81a ± 24.6	38b ± 1.7	66ab ± 1.9	38b ± 4.6	*
Yolk color (Roche scale)	10.5a ± 0.5	10.0ab ± 0.6	9.7b ± 0.1	9.4b ± 0.5	**

$^{*}p \leqslant 0.05$; $^{**}p \leqslant 0.01$; $^{***}p \leqslant 0.001$; n.s.: non-significant.
[a] ANCOVA-adjusted treatment means.

Organic eggs presented mean air cell height similar to free range eggs, but higher than cage and barn eggs. Factors other than egg age, such as the environment conditions (temperature and relative humidity) of transport and handling from farm to retail, could have influenced air cell height but the random sampling and the survey period of the year (autumn–winter, with temperatures seldom exceeding 20 °C) limited the influence of these factors. Therefore, the lower freshness suggested by air cell height values could be attributed to inefficient farming management delaying egg collection *vs* laying time. ANOVA and LSD also evidenced significant differences among housing systems for HU ($p \leqslant 0.01$), organic eggs presenting the lowest value. Also Patterson et al. (2001), analysing different shell egg types, observed lower HU values in organic eggs than in cage and other specialty eggs, probably as a consequence of a slower retail turnover in the USA market. The causes of the low HU values in organic eggs have to be further investigated since albumen quality could be determined not only by egg freshness but also by other factors such as hen age and genotype and dietary ingredients (Sauveur & de Reviers, 1988).

From a nutritional point of view, even though the statistical tests evidenced significant differences for proteins and SFA, the variations were minimal. Moreover, no significant differences were found in the unsaturated fatty acid groups. Similar results were obtained by Cherian et al. (2002) analysing fatty acids of cage and organic eggs commercial samples.

With regards to functional properties, organic and free range eggs presented the highest whipping capacity (as overrun) and foam consistency, while cage eggs showed the lowest values. Albumen proteins are the main constituents responsible for foam development (MacDonnell, Feeney, Hanson, Campbell, & Sugihara, 1955); hence, these results could be related to the higher protein content and albumen percentage (Table 4) observed in organic and free range eggs. With reference to yolk colour, a characteristic highly influenced by hen diet (Sauveur & de Reviers, 1988), a tendency for higher values in cage eggs and lower in organic eggs was observed. The ban of the addition of synthetic xanthophylls in organic feeds (EU, 1999b) probably accounts for the low yolk pigmentation in organic eggs.

Egg size is known to affect albumen height and HU (Silversides & Villeneuve, 1994; Silversides, Twizeyimana, & Villeneuve, 1993), therefore these parameters, as well as all the variables presented in Table 4 (with exception of egg weight, surface area, diameter, and height) were submitted to ANCOVA considering the egg weight as covariate. However, this cofactor was always non significant ($p > 0.05$) and an ANOVA was thus performed (Table 4). Egg weight was significantly different among all kinds of

Table 4
Mean values ± standard error of several egg quality variables and significance levels of the factor housing system (p) in the ANOVA; different letters after the mean values indicate significant differences at $p \leqslant 0.05$ following LSD test

Variable	Housing system				
	Cage ($n = 10$)	Free range ($n = 6$)	Barn ($n = 6$)	Organic ($n = 6$)	p
Egg weight (g)	63.4c ± 1.19	66.7a ± 1.39	62.1d ± 0.44	64.9b ± 1.31	***
Egg surface area (cm^2)	73.5d ± 1.04	78.0a ± 1.07	74.6c ± 0.34	76.9b ± 1.12	***
Egg diameter (cm)	4.41c ± 0.03	4.59a ± 0.10	4.54ab ± 0.03	4.50b ± 0.03	***
Egg height (cm)	5.74c ± 0.05	6.05a ± 0.08	5.89b ± 0.02	5.92b ± 0.06	***
Cracked eggs (%)	14 ± 2.3	10 ± 3.3	11 ± 1.5	5 ± 2.0	n.s.
Egg shape index (%)	76.9 ± 0.44	76.0 ± 1.04	77.1 ± 0.25	76.1 ± 0.48	n.s.
Albumen (%)	64.2b ± 0.67	65.4a ± 0.50	63.9b ± 0.19	65.3a ± 0.43	*
Yolk (%)	24.8 ± 0.59	24.5 ± 0.39	25.2 ± 0.13	24.5 ± 0.37	n.s.
Shell (%)	11.0a ± 0.19	10.2b ± 0.20	10.8a ± 0.07	10.2b ± 0.14	***
Shell thickness (mm)	0.41c ± 0.01	0.50a ± 0.01	0.50a ± 0.00	0.48b ± 0.01	***
Shell index (g/cm^2)	0.276a ± 0.00	0.253b ± 0.01	0.260b ± 0.00	0.253b ± 0.01	***
Compression test (CT)					
Strength (N)	41.9a ± 1.27	37.6b ± 1.47	37.9b ± 0.19	36.4b ± 2.12	***
Displacement (mm)	0.31a ± 0.01	0.27b ± 0.01	0.27b ± 0.00	0.27b ± 0.01	***
Energy (N mm)	7.0a ± 0.28	5.8b ± 0.30	5.7b ± 0.09	5.5b ± 0.39	***
Penetration test (PT)					
Strength (N)	37.3 ± 0.74	37.0 ± 1.41	39.3 ± 0.51	35.8 ± 1.14	n.s.
Displacement (mm)	0.35 ± 0.02	0.34 ± 0.04	0.29 ± 0.00	0.29 ± 0.01	n.s.
Energy (N mm)	6.5 ± 0.42	5.9 ± 0.52	6.1 ± 0.11	5.5 ± 0.31	n.s.
Young module (N/mm^2)	124.5 ± 4.72	120.7 ± 6.11	125.6 ± 0.68	125.1 ± 5.41	n.s.
Slope (N/mm)	121.2 ± 3.76	114.1 ± 5.48	121.8 ± 0.70	118.4 ± 4.58	n.s.

$^{*}p \leqslant 0.05$; $^{**}p \leqslant 0.01$; $^{***}p \leqslant 0.001$; n.s.: non-significant.

Table 5
DPLS2 calibration and prediction statistics for classification of egg samples from different housing systems

	Forty-one variables		Nine variables	
	Calibration	Prediction	Calibration	Prediction
No. of components	1	1	1	1
Cage ($n = 10$)				
r	0.91	0.83	0.88	0.85
RMSE	0.193	0.270	0.223	0.248
No. of samples correctly classified	10	10	10	10
Free range ($n = 6$)				
r	0.44	0.24	0.36	0.20
RMSE	0.368	0.402	0.383	0.408
No. of samples correctly classified	0	0	1	0
Barn ($n = 6$)				
r	0.16	−0.24	0.23	−0.01
RMSE	0.405	0.427	0.406	0.423
No. of samples correctly classified	0	0	0	0
Organic ($n = 6$)				
r	0.47	0.30	0.44	0.31
RMSE	0.363	0.393	0.368	0.394
No. of samples correctly classified	0	0	0	0

housing systems: free range eggs were the largest, followed by organic, cage, and barn eggs. Roughly the same order was observed for the size-related parameters (surface area, diameter, and height). Moreover, shell percentage was the lowest in the largest eggs (i.e. free range and organic), as already reported by Casiraghi, Hidalgo, and Rossi (2005) for cage eggs of different sizes. Shell thickness (Table 4) was lowest in cage eggs, while free range and barn eggs presented the highest values. The contrasting results found in literature refute a clear influence of housing system on shell thickness: comparing aviary (barn), free range and cage systems, Pavlovski, Hopic, and Lukic (2001) detected thicker shells in barn eggs and thinner shells in free range

Table 6
DPLS1 calibration and prediction statistics for classification of cage and alternative eggs

	Forty-one variables		Six variables	
	Calibration	Prediction	Calibration	Prediction
No. of components	2	2	2	2
r	0.96	0.85	0.94	0.90
RMSE	0.138	0.249	0.163	0.209
No. of samples correctly classified:				
Cage ($n = 10$)	10	10	10	10
Alternative ($n = 18$)	18	18	18	18

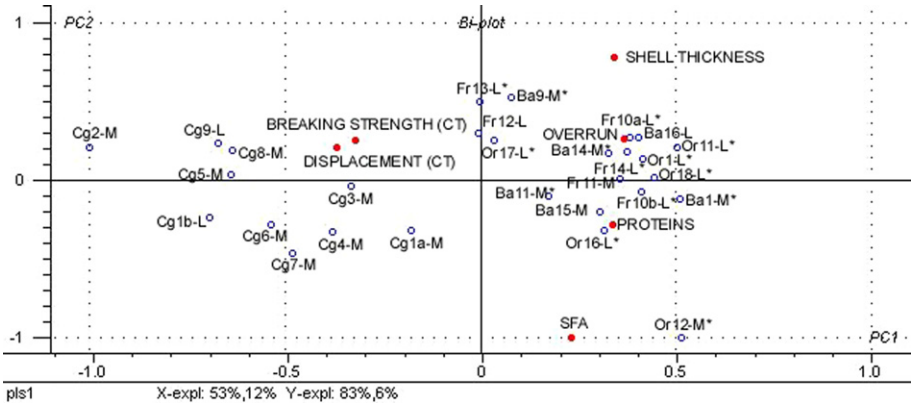

Fig. 1. Bi-plot of loadings and scores of components 1 and 2 obtained from DPLS1 model developed using six variables and two housing systems (cage and alternative). Codes for samples are defined in Table 1.

eggs, while Leyendecker et al. (2001b) observed thicker shells in free range. The lowest shell thickness registered for cage eggs in the present study (Table 4) corresponds to the highest shell index and overall shell resistance, when measured by the compression test. This result might be explained by the low average size observed for these eggs: an indirect correlation between egg weight and shell breaking strength was previously reported by Casiraghi et al. (2005). Moreover, thinner shells, as those measured for cage eggs in the present study, may show beneficial ultrastructural features which contribute to eggshell strength (Roberts, Brackpool, & Solomon, 1995). No significant shell resistance differences among housing systems were evidenced by the penetration test.

The results were subjected to DPLS2, with the 41 parameters regressed on to the four housing systems. Only one component was significant, explaining 16% of *X*-variance (analytical data) and 32% of *Y*-variance (housing systems). All cage egg samples were correctly classified in both calibration and prediction, whereas none of the samples belonging to the other three alternative housing systems were correctly classified (Table 5). In order to improve the model, DPLS2 was recalculated using the nine variables (overrun; strength, displacement, and energy by the compression test; shell index; shell percentage; proteins; shell thickness; and foam consistency) selected by the Martens uncertainty test (Esbensen, 2002). The new model increased *X*-variance to 50% and *Y*-variance to 29%, with only one significant component. This model was not able to classify barn, free range, and organic eggs; however, it thoroughly discriminated cage eggs (100%). Hence, these results suggest the possibility to discriminate the category "cage eggs" from the category "alternative eggs", obtained by grouping barn, free range and organic eggs. The DPLS1 method was thus applied considering these two categories. The first two components of DPLS1 explained 22 and 92% respectively of the *X*- and *Y*-variance in the 41 variable model, while the explained variability increased to 65 and 89% when the number of variables used to calculate the model was reduced to six. Summary data describing these models and their performance are shown in Table 6. An overall correct classification of the samples was achieved with both models, however the simplified six variables model improved the prediction ability. The bi-plot of sample scores and variable loadings (six variables) in the DPLS1 space of the first two components is shown in Fig. 1. Cage and alternative egg samples were well separated along the first principal component (PC1). Along the PC1, overrun, shell thickness, proteins, displacement and the breaking strength by the compression test had the largest contribution to sample discrimination, while on PC2, SFA and shell thickness had the largest effect. In general, in this DPLS1 space, alternative eggs are characterised by higher whipping capacity, shell thickness and protein content, while cage eggs present more resistant shells.

4. Conclusion

The analysis of the characteristics of Italian market eggs did not allow a clear differentiation among the eggs from the four different housing systems. However, the multivariate approach permitted the clear-cut separation of cage eggs from alternative eggs. The DPLS1 prediction model enabled a preliminary assessment of its ability to classify eggs from different housing systems and, furthermore, allowed the identification of the variables with the best discriminant power that could be considered in future studies with a larger number of samples.

From the consumer point of view, apart from psychological and ethical motivations, the quality features characterising eggs from the different housing systems do not justify the higher prices for alternative eggs: the average price in euros (€) for cage eggs used in this study was 0.17 ± 0.06 €/egg, lower than the 0.22 ± 0.03 €/egg (+38%) for barn, the 0.27 ± 0.03 €/egg (+59%) for free range, and the 0.33 ± 0.03 €/egg (+95%) for organic systems.

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