Evaluation of eggshell quality characteristics in relation to the housing system of laying hens

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To investigate the influence of housing system on eggshell quality characteristics, fourteen samples of eggs laid by brown hens of known ages and strains, reared in conventional cage, free-range, barn and organic systems, were evaluated. The eggs were directly supplied by four poultry farms, each with different housing systems.
The following parameters were determined: cracks percentage; egg weight and surface area; equator diameter, height and shape index; percentage of eggshell; eggshell index and shell thickness. Breaking strength of eggshell was evaluated using an Instron dynamometer equipped with a plate and a probe (8 mm diameter) as compression elements.
Significant differences among housing systems were observed for egg weight, surface area, and shell thickness ($p \leq 0.001$), with thicker shell observed for barn system and a tendency to bigger eggs in organic production. The variables related to shell strength and hardness seemed to be less affected by the housing system. Only displacement, Young Modulus and slope of the stress/strain curve obtained with the probe assay showed significant differences ($p \leq 0.05$), but with a partial overlap of the different groups. Eggs from barn system showed a higher deformability than free-range and organic eggs, and a lower hardness than free range eggs.
The "poultry farm" factor seemed to affect eggshell characteristics much more than "housing system". In fact, when the samples were classified by producer, significant differences were observed for egg weight, surface area, egg diameter, height, and shell thickness ($p \leq 0.01$). Moreover, strength, displacement and breaking strength also resulted significantly different ($p \leq 0.05$).
In conclusion, shell characteristics are not clearly influenced by housing system but seem to be more affected by producer management and other factors such as hen age and strains.

Keywords: eggshell; housing system; shell strength; quality

Introduction

After the introduction of Directive 1999/74/EC (EU, 1999a) and of Regulation 1804/1999/EC (EU, 1999b), the rearing systems for laying hens are defined and classified as cage, barn, free range and organic. Moreover, conventional cages will be banned from 2012. To face the new legal situation, as well as consumers requirements for hens welfare, the poultry producers are more and more adopting alternative housing systems such as barn, free range and organic production: compared to conventional cages they are intended to improve the welfare of laying hens. Enriched cages are not yet very common at industrial level in Italy.

Few works have been carried out to understand the effect of housing systems on eggshell quality characteristics (Sauveur, 1991; Leyendecker *et al*, 2001), however a clear influence is not yet established. Shell strength has a great importance from an economic point of view, since broken eggs (6-8 %) are discarded, causing money loss (Hamilton, 1982; Coucke *et al.*, 1999). Shell mechanical properties are crucial also for shelf life and safety of eggs and eggs products (de Reu *et al.*, 2005; Rodriguez-Navarro *et al.*, 2002).

The present paper reports preliminary results, regarding eggshell quality characteristics, of a wider study aimed to investigate the possible influence of conventional cage, barn, free range and organic production on egg quality.

Materials and methods

Fourteen samples of eggs laid by brown hens of different ages (28-64 wks) and strains (Lohmann, Hy-Line and Isa-Brown) reared in conventional cage, free-range, barn and organic systems, were evaluated. The eggs were directly supplied by four poultry farms, named A, B, C and D, each bearing all the different housing systems. Each sample was made up of at least 20 eggs, amounting to a total of 280 eggs evaluated. The percentage of cracked eggs was evaluated by candling. Intact eggs were cleaned with blotting paper to eliminate filth. Surface area (SA, cm^2) of each egg was evaluated using the equation reported by Thompson *et al.* (1985). Equator diameter and height (cm) of each egg were measured using a manual calliper. Shape index was calculated as percentage ratio between egg diameter and egg height, using the equation reported by Khalafalla e Bessei (1995). Shell percentage on total egg weight was determined by weighing clean and albumen-free shell, including cuticle and membrane. Shell index (SI, g/cm^2) was calculated using the equation proposed by Rodriguez-Navarro *et al*., (2002).

Shell strength of uncracked eggs was measured using an Instron Universal Testing Machine (model 4301 Instron Ltd., High Wycombe, UK) supported by Series IX Automated Material Testing software (Instron Co., 1998). Analyses were carried out at room temperature with a constant cross-head speed of 20 mm/min. both compression and penetration tests were performed each on seven single eggs per sample, using a 100 N load cell. The egg was placed horizontally for measurements. A 35 mm diameter plate was used as a compression device, while a 8 mm diameter probe was used as penetration element. Strength (N), displacement (deformability) (mm) and breaking strength (N·mm) were determined in both compression and penetration tests. Penetration test also measured slope of force/deformation curve (N/mm) and Young modulus (hardness) (N/mm^2), i.e. the slope of the stress/deformation curve, indicating shell strength at small deformations. After breaking tests, the broken shells were recovered, cleaned and thickness, including cuticle and membrane, was measured at equator using a 550-501 digital micrometer (NSK, Japan). Results of thickness measurements are the average of three determinations per egg.

ANOVA and Least Significant Difference (LSD) test, considering housing systems and poultry farm as factors, were computed using STATGRAPHIC software Version 4. Correlation analysis was computed with Systat software Version 5.0 following the Pearson approach.

Results and discussion

The mean values of variables according to housing systems are reported in Table 1. Significant differences were observed for egg weight, surface area, diameter, shell thickness, displacement, Young Modulus and slope of the stress/strain curve obtained in penetration test, while no difference was observed for shell strength and breaking strength. Also Sauveur (1991), comparing conventional cages, barn and free range system did not find differences for shell strength.

A tendency to bigger eggs in organic production was observed, while no significant weight differences resulted among the other rearing systems. In agreement with our results Sauveur (1991), comparing conventional cages, barn and free range systems, concluded that egg weight was not affected by housing system. Similarly, Van de Brand *et al.*, (2004) reported no differences in egg weight between free range and conventional cage, moreover Taylor and Hurnik (1996) comparing battery cages with barn system, found no differences.

Shell thickness resulted significantly higher in barn eggs, that also showed higher deformability (*vs* free range and organic eggs) and lower hardness (*vs* free range eggs).

Table 1. Mean values ± standard deviations of the variables analyzed according to housing systems.

Variable	Conventional cage	Free range	Barn	Organic	ANOVA Significance
	Factor: housing system				
	n = 2	n = 4	n = 4	n = 4	
Egg weight (g)	$61.1^{a} \pm 4.8$	$61.4^{a} \pm 4.7$	$62.4^{ab} \pm 5.9$	$63.8^{b} \pm 4.4$	**
Egg surface area (cm^2)	$72.4^{a} \pm 3.8$	$72.7^{a} \pm 3.8$	$73.4^{ab} \pm 4.7$	$74.5^{b} \pm 3.4$	**
Egg height (cm)	5.7 ± 0.3	5.7 ± 0.2	5.7 ± 0.2	5.8 ± 0.2	NS
Egg diameter (cm)	$4.4^{a} \pm 0.1$	$4.4^{ab} \pm 0.1$	$4.4^{ab} \pm 0.1$	$4.5^{b} \pm 0.1$	*
Shape index (%)	76.9 ± 3.0	77.7 ± 2.1	77.3 ± 2.5	77.0 ± 2.6	NS
Shell percentage (%)	10.6 ± 0.8	10.6 ± 0.8	10.4 ± 0.6	10.4 ± 0.6	NS
Shell thickness (mm)	$0.454^{a} \pm 0.008$	$0.463^{a} \pm 0.036$	$0.497^{b} \pm 0.051$	$0.467^{a} \pm 0.024$	***
Shell index (g/mm^2)	0.256 ± 0.001	0.258 ± 0.008	0.255 ± 0.006	0.255 ± 0.006	NS
Compression test					
Strength (N)	37.2 ± 6.8	38.2 ± 6.6	39.5 ± 5.8	40.6 ± 5.6	NS
Displacement (mm)	0.31± 0.04	0.36 ± 0.08	0.38 ± 0.11	0.38 ± 0.09	NS
Breaking Strength (N mm)	6.2 ± 1.3	7.1 ± 1.7	7.7 ± 2.2	7.9 ± 2.0	NS
Penetration test					
Strength (N)	37.3 ± 7.4	40.6 ± 6.7	38.8 ± 7.5	36.0 ± 5.8	NS
Displacement (mm)	$0.42^{ab} \pm 0.05$	$0.39^{a} \pm 0.10$	$0.46^{b} \pm 0.16$	$0.39^{a} \pm 0.09$	*
Breaking Strength (N mm)	6.4 ± 1.6	7.8 ± 2.5	9.0 ± 5.2	6.8 ± 2.3	NS
Young modulus (N/mm^2)	$100.7^{ab} \pm 19.9$	$105.4^{a} \pm 27.1$	$89.3^{b} \pm 17.4$	$95.5^{ab} \pm 21.2$	*
Slope (N/mm)	$97.1^{ab} \pm 19.9$	$102.1^{b} \pm 26.7$	$86.0^{a} \pm 15.6$	$91.1^{a} \pm 19.1$	*

^{a,b,c} means followed by different letters in the same row are significantly different at a probability level of 95%, according to LSD test.
^{NS} Non significant; * $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$.

Several Authors reported variable results about the influence of the rearing systems on shell thickness. Leyendecker *et al.*, (2001, 2005) reported thicker shells in free range eggs when compared to conventional cage and aviary systems (2001), and to conventional and furnished cages (2005). On the other hand, Tumova and Ebeid (2003) noticed thicker shells in battery cage compared to barn system, while Van de Brand *et al.*, (2004) did not find differences between free range and battery cage. Measuring eggshell deformation, Taylor and Hurnik (1996) did not find differences between barn system and battery cages.

The mean values of variables according to poultry farms are reported in Table 2. Actually, the “poultry farm” factor seems to affect eggshell characteristics much more than the “housing system”. Significant differences existed for all variables (Table 2), with the exception of shape index and shell strength of penetration test (measured by probe assay).

Weight and the others parameters related to egg dimension showed significantly higher values for poultry farm C, even if the average age of the hens housed by this producer (31.5 wks) was the lowest, when compared to the average hen age in the other farms (A, 43 wks; B, 57 wks; D, 41 wks). Eggs from poultry producer C also showed lower value for shell percentage and index, and for strength, displacement and breaking strength by compression test, thus indicating higher brittleness. Actually, a highly significant indirect correlation existed between egg weight and breaking strength (evaluated by penetration test) as shown in Figure 1. This findings is in agreement with the results reported in a previous study, carried out on marketed hen eggs of different weight grades (Casiraghi et al., 2005).

Table 2. Mean values ± standard deviations of the variables analyzed according to poultry farms.

Variable	A n = 3	B n = 3	C n = 4	D n = 4	ANOVA Significance
	Factor: poultry farm				
Egg weight (g)	$60.8^{a} \pm 5.7$	$62.1^{a} \pm 5.2$	$64.3^{b} \pm 2.9$	$61.4^{a} \pm 5.6$	***
Egg surface area (cm^2)	$72.2^{a} \pm 4.6$	$73.2^{a} \pm 4.1$	$75.0^{b} \pm 2.3$	$72.6^{a} \pm 4.4$	***
Egg height (cm)	$5.7^{a} \pm 0.2$	$5.7^{a} \pm 0.2$	$5.8^{b} \pm 0.2$	$5.7^{a} \pm 0.2$	**
Egg diameter (cm)	$4.4^{a} \pm 0.2$	$4.4^{a} \pm 0.1$	$4.5^{b} \pm 0.1$	$4.4^{a} \pm 0.1$	**
Shape index (%)	77.6 ± 2.4	76.9 ± 2.4	76.9 ± 2.7	77.7 ± 2.3	NS
Shell percentage (%)	$10.4^{ab} \pm 1.0$	$10.5^{bc} \pm 0.5$	$10.3^{a} \pm 0.6$	$10.8^{c} \pm 0.6$	**
Shell thickness (mm)	$0.521^{a} \pm 0.035$	$0.459^{b} \pm 0.045$	$0.462^{b} \pm 0.016$	$0.457^{b} \pm 0.014$	***
Shell index (g/mm^2)	$0.252^{a} \pm 0.010$	$0.257^{ab} \pm 0.010$	$0.253^{a} \pm 0.002$	$0.262^{b} \pm 0.006$	**
Compression test					
Strength (N)	$41.8^{a} \pm 6.2$	$37.3^{b} \pm 4.5$	$37.0^{b} \pm 5.8$	$40.8^{a} \pm 6.7$	*
Displacement (mm)	$0.49^{a} \pm 0.04$	$0.36^{b} \pm 0.08$	$0.32^{c} \pm 0.05$	$0.33^{bc} \pm 0.06$	***
Breaking Strength (N mm)	$9.7^{a} \pm 1.7$	$6.8^{bc} \pm 1.6$	$6.3^{c} \pm 1.3$	$7.3^{b} \pm 1.6$	***
Penetration test					
Strength (N)	38.4 ± 6.7	37.8 ± 7.7	36.7 ± 6.6	40.0 ± 6.7	NS
Displacement (mm)	$0.52^{a} \pm 0.10$	$0.44^{b} \pm 0.18$	$0.37^{c} \pm 0.05$	$0.33^{c} \pm 0.04$	***
Breaking Strength (N mm)	$9.8^{a} \pm 3.4$	$8.6^{ab} \pm 5.6$	$6.4^{c} \pm 1.7$	$6.8^{bc} \pm 1.3$	**
Young modulus (N/mm^2)	$85.0^{a} \pm 18.8$	$96.2^{ab} \pm 22.7$	$95.5^{a} \pm 22.1$	$107.8^{b} \pm 21.3$	**
Slope (N/mm)	$83.9^{a} \pm 17.0$	$92.9^{ab} \pm 22.3$	$89.9^{a} \pm 20.1$	$104.2^{b} \pm 21.5$	**

[a,b,c] means followed by different letters in the same row are significantly different at a probability level of 95%, according to LSD test.
[NS] Non significant; * p ≤ 0.05; ** p ≤ 0.01; *** p ≤ 0.001.

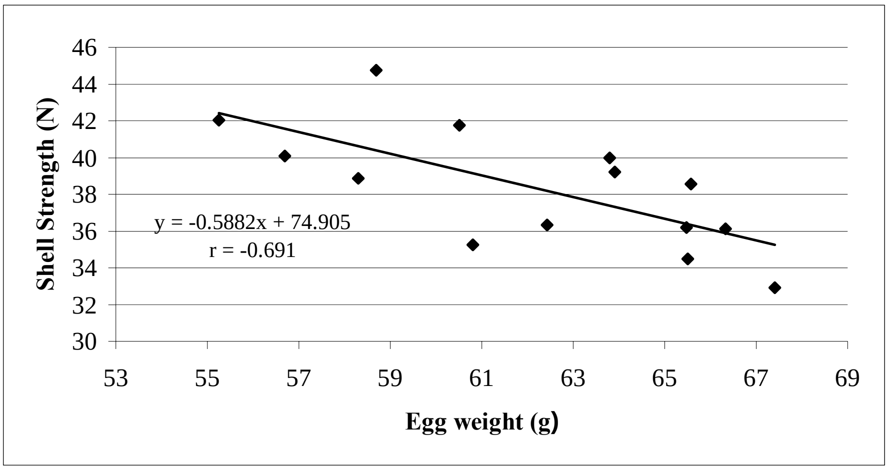

Figure 1. Correlation between egg weight and shell strength (compression test) (p≤0.01).

Eggs from poultry producer A had the thickest shell and together with eggs from producer D the highest values for shell strength. Moreover, eggs from producer A showed the highest values for displacement and breaking strength in both compression and penetration tests, indicating the highest deformability and resistance to fracture. Shell thickness was linked to egg deformation, since a highly significant direct correlation ($p \leq 0.001$) was found between thickness and displacement (evaluated by penetration test) as shown in Figure 2.

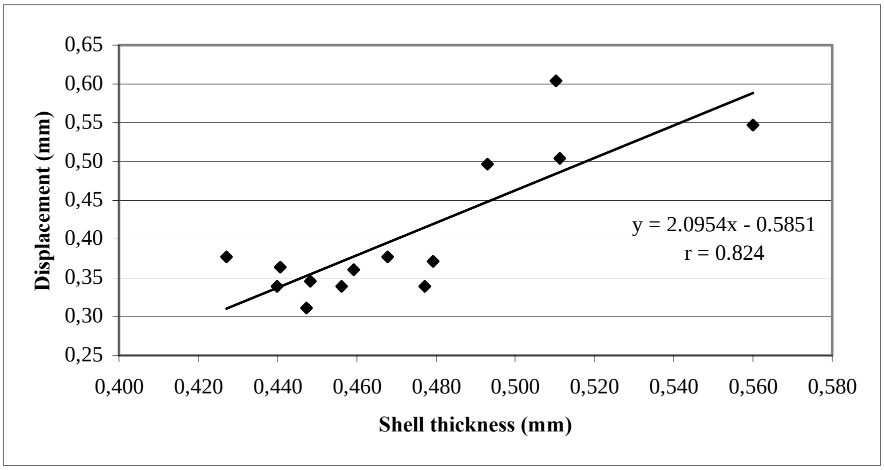

Figure 2. Correlation between thickness and displacement (compression test) ($p \leq 0.001$).

Referring to penetration tests, eggs from poultry producers A, B and C, showing lower Young Modulus, appeared to be more elastic than eggs from producers D.

The different eggshell characteristics observed for eggs from producer A might be linked to the composition of feed administered, since dietary calcium and available phosphorus strongly affect eggshell quality (Van de Brand *et al.*, 2004).

In conclusion, shell characteristics, shell strength and breaking strength in particular, are not clearly affected by housing system. Factors related to animal management (e.g. feed) seems to have much more influence on eggshell quality.

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