Physical-mechanical modifications of the eggs for food-processing during storage and post-refrigeration

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Summary
The attitude of the yolk to remain separated from the albumen is an important aspect for the shelling process. Eggs can be stored for several months and processed some days after pulling out from the refrigerated cell. In the present research, eggs for food-processing of two genetic types of hens are stored for seven months at 0°C. During this time the parameters describing the strength of the vitelline membrane-yolk system were measured together the main egg quality parameters such as height of the thick albumen, Haugh and yolk indices. Measurements were carried out to assess the effects of different post-refrigeration treatments: eggs were analysed immediately after pulling out from the cell, after 5-6 h, when the temperature of 18°C is reached, and after further seven days at 18°C.

Multiple regression statistical models were given to evaluate the influence of the different parameters considered in the study. According to these models, about seven months of storage at 0°C cause a decrease in the maximum force absorbed by the membrane-yolk systems of 10-12% while the permanence of the eggs outside the cell for seven days before processing causes a decrease of 14-17%. The decrease in maximum force for the eggs after 5-6 h outside the cell is 4-5% if compared with the eggs analysed immediately after refrigeration. About seven months of storage at 0°C cause a decrease in the rupture energy of 14-17% and seven days at 18°C after refrigeration involve a decrease of 5-7%. After seven months of storage at 0°C it was observed a decrease in the Haugh index of 6–8 % only. The differences in force and energy of the membrane-yolk system measured after laying for the two genetic types of hen decrease during storage and post-refrigeration time.

Introduction
Deep changes of the chemical, physiological and structural characteristics of the eggs occur during storage. These modifications are influenced by both environmental parameters (Burley and Vadhera, 1989; Rossi *et al.*, 1995, 1999; Solomon, 1991) and intrinsic characteristics such as diet, age (Froning *et al.*, 1983) and genetic type of hen (Scott and Silversidest, 2000).

The liquefaction of the thick albumen is one of the most evident phenomenon correlated with the age of the eggs (Li-Chan and Nakai, 1989; Nakamura, 1963; Solomon, 1999). The Haugh index (Haugh, 1937) is the parameter widely accepted to describe this decay and it is used by the USA standards for the commercial classification. The attitude of the yolk to remain entire during shelling depends on the strength of the vitelline membrane that decreases during storage. Moreover, the yolk tends to flatten itself as consequence of the migration of the water inside and through the membrane (Funk, 1948). This last modification is well expressed by the yolk index that is the ratio between diameter and height of the yolk. Haugh unit and yolk index determination requires simple geometrical and ponderal measurements. The strength of the vitelline membrane-yolk system can be determined by measuring the pressure or the rupture time by suction (Fromm, 1964) or by measuring the force with a compression device (Kirunda and McKee, 2000; Ngoka *et al.*, 1983).

During shelling, if the vitelline membrane breaks, yolk and albumen mix and the separation process is prejudiced. The food processing industry that intends to prolong the time of storage and post-refrigeration have to face the biological and mechanical limits of the product. The eggs for food processing can be stored for more than six months and processed some days after pulling out from the refrigerator. During this time the membrane shows a progressive structural yielding together after modifications associated with the ageing of the egg.

The aim of the present research is the analysis of the physical-mechanical properties of the membrane-yolk system and albumen in eggs for food-processing considering different duration of storage, post-refrigeration treatments and genetic type of hen.

Material and methods

The measure of the physical and mechanical parameters was carried out for different times of storage at 0°C and post-refrigeration treatments and for two genetic type of hen.

Eggs on exam belong to *Hy-Line white* and *Lohmann brown* hens which lay white and brown eggs, respectively. These two types of hen were 40 weeks old when the samples were picked up. Hens were also fed with the same diet. One day after laying, samples were analyzed to characterize the material.

Evaluations were carried out at 15, 30, 45, 60, 75, 90, 120, 150, 180 and 210 days of storage at 0°C.

Three samples of 30 eggs each were picked up and were analyzed at three different times. The first immediately after the cell extraction (at 0°C), the second after the temperature reached 18°C (about 5-6 hours at 18°C) and the last after a further week at 18°C.

Physical and mechanical parameters considered were: thick albumen height (mm), Haugh and yolk indices and vitelline membrane-yolk system strength in terms of rupture energy (mJ) and maximum force (mN). Mass (g), equatorial and longitudinal diameter (mm) were also measured for each egg before breaking.

Thick albumen height, Haugh index and yolk index were measured as widely reported in the literature. To measure the vitelline membrane-yolk system strength an equipment for traction-compression tests characterized by an electro mechanical system with vertical speed of $7x10^{-4}$ m/s was used. The equipment was provided with a load cell to measure the force (Tekkal, 1 N) and a potentiometer to measure the displacement (Novotechnick, 150 mm): sensors were connected to an acquisition board on PC. Force measurements were carried out using a probe with 2 mm diameter cylindric probe. The vitelline membrane-yolk system strength was described by determining the maximum force reached during displacement and the rupture energy, where this last parameter is obtained by integrating the instantaneous force in the displacement.

Data were statistically elaborated by multiple linear regression analysis (*step-wise* method to exclude non-significant variables with *p-level* over 0.05) to search possible correlations between dependent variables such as thick albumen height, Haugh index, yolk index, vitelline membrane-yolk system strength and independent variables such as days of storage, post-refrigeration treatment and genetic type of hen.

Choice of linear and multiple regression follows the higher values of determination coefficients (R^2) obtained respect to the non linear models supposed to describe the trends. One day after laying, for each qualitative index, significant differences between *Hy-Line white* and *Lohmann brown* were investigated.

Result and discussion

For both genetic type, the eggs used in the research were characterized by a mean mass of about 60 g (± 4.4 g) and a mean equatorial and longitudinal diameter of about 44 mm (± 1.4 mm) and 57 mm (± 2.5 mm), respectively. A day after laying, the mean values of the measured parameters, for *Hy-Line white* and *Lohmann brown* were the following, respectively:

5.7 mm (± 0.8 mm) and 4.9 mm (± 0.9 mm) for the thick albumen height; 74.2 (± 6.0) and 68.7 (± 12.4) units for the Haugh index; 0.42 (± 0.04) and 0.43 (± 0.03) units for the yolk index; 0.104 mJ (± 0.03 mJ) and 0.135 mJ (± 0.04 mJ) for the rupture energy and 27.3 mN (± 4.8 mN) and 35.9 mN (± 4.9 mN) for the maximum force.

The relations obtained by performing the multiple linear regression analysis (*step-wise* method) between the physical parameters and the days of storage at 0°C, the post-refrigeration treatments and the genetic type are shown in Table 1. The significances (*p-level*) of the models in Table 1 are given in Table 2.

In accordance with the obtained models, after 90 and 210 days of storage, with respect to 15 days of storage, the following decreases are shown, respectively: about 0.3 mm and 0.7 mm for the albumen height, about 1.8 and 4.6 units for Haugh index; about 0.01 mJ and 0.02 mJ for the rupture energy and about 1.5 mN and 3.5 mN for the maximum force. The yolk index is not correlated with the days of storage.

The post-refrigeration treatment after a further week at 18°C produces a decrease of about 1 mm in the albumen height, of about 9.5 and 0.06 units in the Haugh index and yolk index, respectively, and of about 0.01 mJ and 5.2 mN in the parameters describing the membrane-yolk system strength.
The treatment at 18°C (5–6 h after pulling out from the cell) does not show a substantial decrease in the parameters associated to the albumen quality; for the yolk index and the maximum force, these decreases are of about 0.03 units and 1.5 mN, respectively. This treatment, compared with the treatments at 0°C, produces, on the contrary, an increase of about 0.01mJ in the rupture energy.

In accordance with the models, for the *Lohmann brown* eggs, respect to the *Hy-Line white* ones, it can be observed as follow: the thick albumen height and the Haugh index decreases, respectively, of about 0.7 mm and 7.6 units; however, one day after laying, a significant difference of about 5.5 units between *Hy-Line white* and *Lohmann brown* was found for the Haugh index by performing the non-parametric *Mann-Whitney* test. On the contrary, for the *Lohmann* eggs a difference of about 0.02 units for the yolk index, 0.01 mJ and 3.1 mN for the membrane-yolk system rupture energy and maximum force was observed. One day after laying and even for the *Lohmann* eggs, a significant difference of about 0.02 mJ and 8 mN emerged respect to the *Hy-Line* ones.

Table 1 Relations obtained from the multiple linear regression analysis.

Parameter	Function	R^2
Albumen height (mm)	A=5.902-1.003(Tb)-0.656(GT)-0.00348(D)-0.132(Ta)	0,364
Haugh index	H=76.431-9.349(Tb)-7.605(GT)-0.0234(D)-1.817(Ta)	0,383
Yolk index	Y=0.420-0.0566(Tb)-0.0264(Ta)+0.0177(GT)	0,425
Rupture energy (mJ)	$E=0.109-8.874*10^{-5}(D)+6.624*10^{-3}(Ta)+9.143*10^{-3}(GT)-5.891*10^{-3}(Tb)$	0,055
Maximum force (mN)	F=34.272-5.190(Tb)+3.095(GT)-0.0182(D)-1.527(Ta)	0,233

D, day of storage at 0°C;
Ta and Tb, post-refrigeration treatment (Ta=0 and Tb=0: analysis at 0°C; Ta=1 and Tb=0: analysis at 18°C; Ta=0 and Tb=1: analysis at a further week at 18°C);
GT, genetic type of hen (0: *Hy-Line white*; 1: *Lohmann brown*).

Table 2 *P-level* of the independent variables used in the models.

Parameter	GT	D	Ta	Tb
Albumen height (mm)	0,000	0,000	0,005	0,000
Haugh index	0,000	0,000	0,000	0,000
Yolk index	0,000	*	0,000	0,000
Rupture energy (mJ)	0,000	0,000	0,004	0,011
Maximum force (mN)	0,000	0,000	0,000	0,000

D, Ta and Tb, GT: see Table 1;
*Non-significant variable (p-level>0.05).

The results of the present work give some indications useful to improve the shelling process of the eggs, above all about the influence of the post-refrigeration treatments. In fact, the permanence of the eggs outside the refrigerated cell (18°C) for seven days before processing involves a higher decrease (14-17%) in the maximum force absorbed by the membrane-yolk systems than the decrease caused by about seven months of storage at 0°C (10-12%). The loss in force for the eggs after 5-6 h outside the cell is 4-5% respect to the eggs at 0°C. The rupture energy decrease of 14 - 17% in about seven months of refrigerated storage; seven days at 18°C after refrigeration involves a decrease of 5-7%. A long storage at 0°C does not involve a high decrease in the Haugh index (6–8 %).

The differences in force and energy of the membrane-yolk system observed after laying for the two genetic types of hen tends to minimize during storage.

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